Research Trends in Technology-Assisted Project-Based Learning: A Scoping Review Using Bibliometric Analysis

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***Abstract* – This study aims to deliver a thorough bibliometric analysis of technology-assisted Project-Based Learning in educational contexts, focusing on research trends from 2015 to 2024. This research addresses the gap in literature regarding the systematic review of publications, citation trends, influence of technological integration Project-Based Learning (PjBL). Using the Scopus database, this study employs bibliometric techniques, including citation analysis, co-word analysis and co-authorship analysis to investigate document productivity, author influence, geographic contributions, institutional support, and keyword distribution. Data were collected from 2,966 documents identified with the keyword "technology" AND "Project-Based Learning," and filtered based on specific inclusion criteria. The results reveal stable publication rates and fluctuating citation trends, with notable contributions from authors, countries, and institutions leading in technology integration within PjBL. Findings highlight the significant role of emerging digital tools, such as e-learning and web technologies, in enhancing PjBL.**

This study underscores the need for further exploration into advanced digital tools and innovative pedagogical strategies within PjBL, recommending future research to integrate digital resources and assess their impact on students' critical thinking, collaboration, and creativity. The findings offer significant insights for educators, policymakers, and curriculum writers to effectively integrate technology in Project-Based Learning, in alignment with 21st-century educational goals.

***Keywords* – Bibliometric, Project-Based Learning, technology, Scopus.**

DOI: 10.18421/TEM144-81
https://doi.org/10.18421/TEM144-81

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Received: 02 January 2025.
Revised: 13 June 2025.
Accepted: 03 October 2025.
Published: 27 November 2025.

1. Introduction

Project-Based Learning (PjBL) in education is an approach that focuses on active student engagement through the completion of real-life projects, allowing students to develop problem-solving, collaboration, and critical thinking skills [1], [2]. With technological advancements, technology-assisted project-based learning has emerged, incorporating digital technology into project-based learning to create a more immersive and interactive learning experience [3], [4]. The integration of technology in Project-Based Learning is expected to enrich the teaching and learning process, enabling students to engage in projects that support both theoretical understanding and the application of practical knowledge, which is essential in the digital era [5], [4], [6].

Technology-enhanced Project-Based Learning, especially within the framework of STEM education (Science, Technology, Engineering, and Mathematics) offers a new approach that enables students not just to get knowledge concepts but also to implement them through digital tools and e-learning platforms. By using technology, students can learn flexibly and independently, enhancing their engagement in the learning process [7], [8].

However, while technology offers significant benefits, its application in Project-Based Learning is not without challenges, especially regarding resource readiness, teacher training, and adaptation to constantly evolving technologies [9], [10]. Additionally, differences in cultural contexts and educational systems across countries also influence the effectiveness of technology-based Project-Based Learning implementation, highlighting the importance of cross-national research to understand best practices in applying technology in diverse learning environments [11], [12].

Technology-assisted Project-Based Learning possesses considerable potential to improve educational quality, existing literature indicates that comprehensive studies on trends in technology-based Project-Based Learning implementation are still limited. Previous studies have largely focused on pedagogical aspects or specific methodologies without providing an in-depth analysis of publication trends and citation patterns over time [11], [13]. A bibliometric analysis approach can offer a clearer picture of these research trends by evaluating the volume, citation patterns, and impact of publications over time [14], [15]. This analysis not only identifies the most influential studies and researchers but also reveals emerging topics and gaps that warrant further exploration.

This study attempts to provide a comprehensive bibliometric analysis of technology-assisted Project-Based Learning from 2015 to 2024. This study will utilize a bibliometric method to ascertain the most prolific and impactful papers, authors, countries, organizations, and sources in this domain of research. Additionally, Co-word analysis will be utilized to ascertain the most prevalent keywords, while co-authorship analysis will reveal social interaction patterns among authors and countries involved in this research. The study also targets an analysis of the distribution of key keywords over time to illustrate how research trends in technology-assisted Project-Based Learning have evolved [15].

Recent years have witnessed substantial increase in research on technology-assisted Project-Based Learning, especially with the implementation of digital technologies and innovative pedagogical approaches such as flipped classrooms, collaborative learning, and experiential learning [16], [17].

Technologies like Artificial Intelligence and machine learning have been integrated into Project-Based Learning to facilitate tailored instruction and deliver automated feedback [18], [19]. However, implementing technology in Project-Based Learning also requires adjustments in teaching strategies and educational resources, which presents unique challenges for educational institutions in various countries [20], [21].

This research attempts to provide a comprehensive analysis of the development, contributions, and obstacles associated with technology-assisted Project-Based Learning, while also identifying opportunities for further research. This study will function as a valuable resource for educators, curriculum creators, academics aiming comprehend contemporary trends in the incorporation of technology into Project-Based Learning and its effects on improving students' abilities and competences in the 21st century. Using the Scopus database, this study attempts to provide a bibliometric and bibliographic analysis of various research on technology-based Project-Based Learning. This bibliometric analysis is directed by the following research questions:

1. What are the trends in publications and citations for technology-assisted Project-Based Learning in mathematics from 2015 to 2024?
2. Which publications, authors, countries, institutions, and sources exhibit the highest productivity and influence concerning Project-Based Learning?
3. What are the most commonly recurring keywords associated with Project-Based Learning? What is the distribution of the most prevalent terms from 2015 to 2024?
4. What are the social relationships among writers and nations about Project-Based Learning?

2. Methodology

A systematic study utilizing a bibliometric analysis was conducted to provide an overview of the bibliometric and bibliographic elements in research on technology-assisted Project-Based Learning [22], [23].

According to [24] dan [25], this bibliometric analysis comprises five steps (Figure 1).

The subsequent subsections provide a detailed description of each stage of the bibliometric analysis conducted in this study.

Figure 1. The phases of executing bibliometric analysis

2.1. Defining Search Keyword

The Scopus database was chosen to search for and identify papers pertaining to research on technology-assisted Project-Based Learning. According to [26], Scopus is a premier scientific database, providing an extensive collection of high-quality documents, making it suitable for obtaining relevant and credible documents on this topic. The inquiry was executed utilizing the keywords "technology" and " Project-Based Learning " to find the relevant documents. This search process was carried out on November 7, 2024, at exactly 12:27 PM.

2.2. Initial Search Results

The preliminary search using the keywords "technology" AND "Project-Based Learning" produced 2,966 documents published from 2015 to 2024. Of these, 36 documents are still in press, while 2,930 documents have been published in final form. The document sources include journals, book series, conference proceedings, books, and trade journals.

The document types include articles, conference proceedings, book chapters, conference critiques, monographs, evaluations, notes, errata, editorials, and reports.

These documents are available in various languages, including English, Spanish Russian, Portuguese, Japanese, French, Turkish, Chinese, Ukrainian, Thai, Serbian, Lithuanian, Korean, and Italian.

2.3. Refinement of Search Results

To find documents pertinent to the study of technology, a number of inclusion criteria were developed supported project-based education. First, documents had to include the keywords “technology” AND “Project-Based Learning” in the title. Second, documents had to be in their final published form. Third, the sources of documents were limited to journals or conference proceedings. Fourth, documents needed to be written in English. Fifth, only articles and conference papers were selected. Lastly, only documents published in the past 10 years, specifically from 2015 to 2024, were included. The document selection followed four systematic stages: First, identification; second, screening; third, eligibility; and fourth, inclusion [27], [28]. Figure 2 illustrates the document selection procedure used in this bibliometric analysis study.

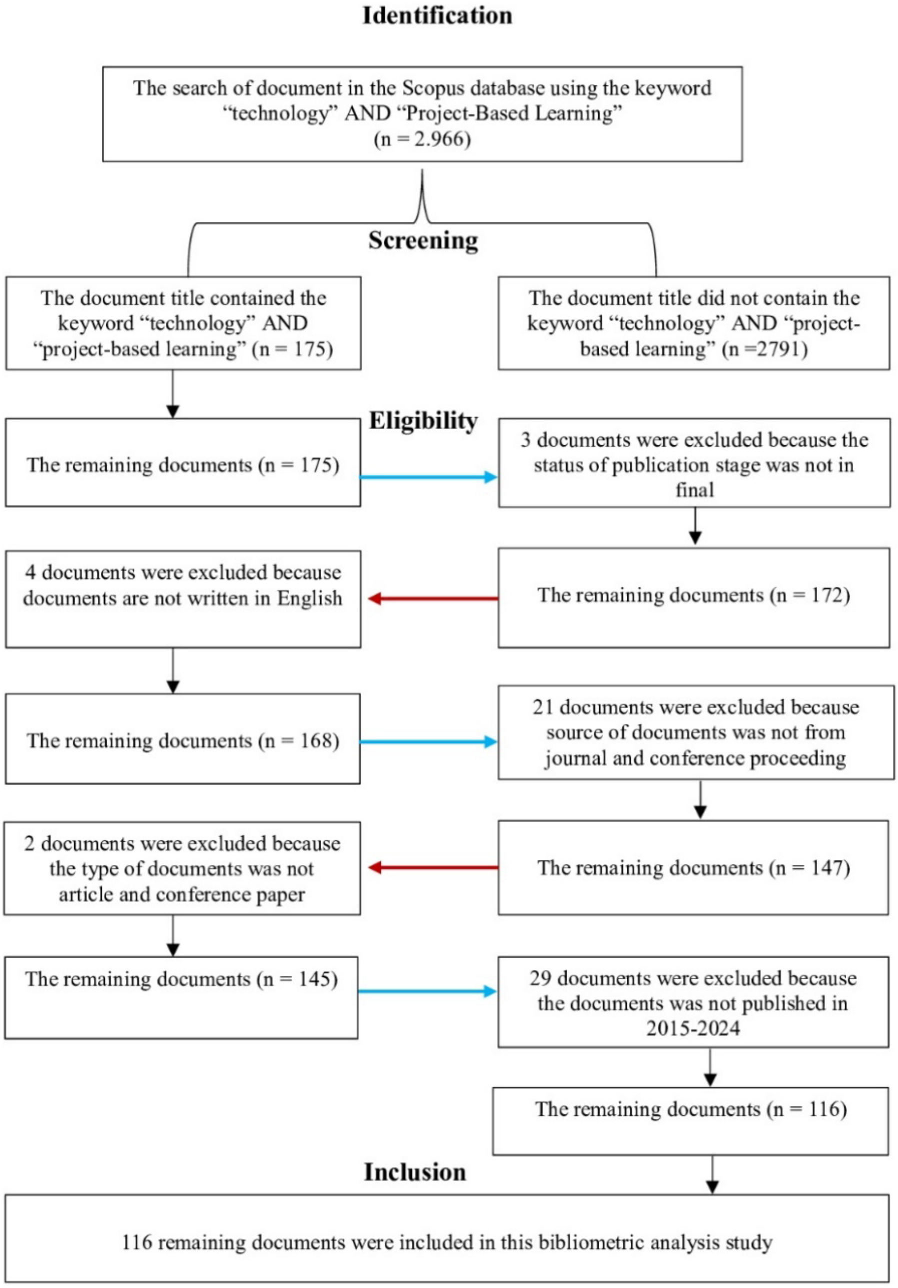

Figure 2. Document selection steps

2.4. Compiling Initial Data

Comma-separated values and research information systems are two formats for document retrieval from the Scopus database. These formats consist of abstracts, keywords, bibliographic information, and bibliometric data [29]. Initial data, including document titles, document kinds, citation counts, author names, publishing years, publishers, and sources, can be analyzed using the publish or perish software. Additionally, this software provides a summary of descriptive analysis elements, total citations, total publications, number authors publication, number citations publication, number citations year, g-index, m-index, and h-index [27].

2.5. Data Analysis

Performance analysis reveals publication and citation trends within technology-assisted project-based learning studies. The PoP software was used to facilitate this analysis. Additionally, several science mapping techniques were used to investigate the connections between research components, including analysis citation, co-word analysis, and co-authorship analysis [24]. Specifically, citation analysis was used to determine which papers, authors, nations, associations, and sources in the subject of technology-assisted Project-Based Learning were the most productive and significant.

Meanwhile, co-word analysis was applied to display frequently occurring keywords in technology-assisted Project-Based Learning studies and to illustrate the distribution of prominent keywords from 2015 to 2024.

Alternatively, co-authorship analysis revealed social relationships between the countries and writers of these studies. Furthermore, to enrich science mapping, network and overlay visualizations as well as hierarchical clustering were conducted [30], [31], [24]. The scientific mapping and network analysis were performed with VOSviewer software [32].

3. Results

This section summarizes the main findings from the bibliometric analysis that was conducted, including the publication and site analysis, as well as the scholarly research and network analysis that identified the most influential contribution based on technological projects.

3.1. Performance Analysis

The development of research on technology-assisted Project-Based Learning from 2015-2024, according to the quantity of citations and publications is presented in Figure 3.

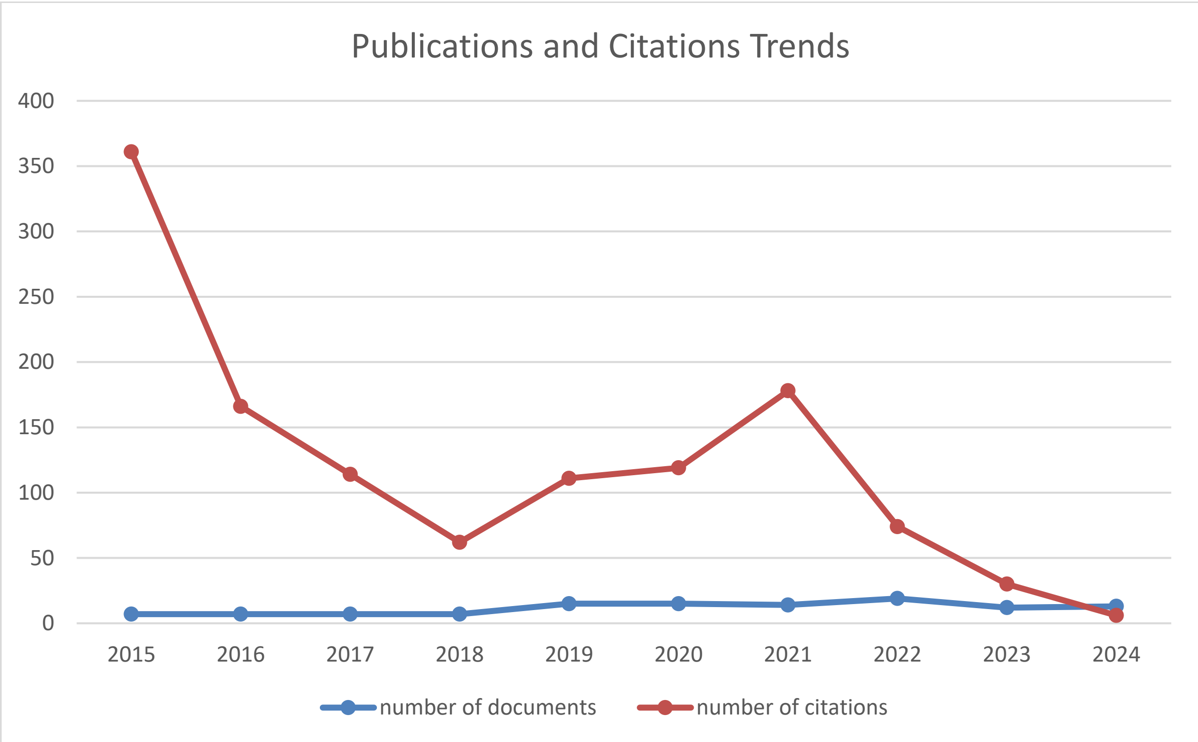

Figure 3. Publication and citation trends for project-based learning with technology assisted

The trends in the quantity of publications and citations from 2015 to 2024 are depicted in the "Publications and Citations Trends" chart. There are two lines in the chart: publications are represented by the blue line, and citations are represented by the orange line. There is an intriguing pattern seen while looking at the chart. In 2015, citations reached their highest peak, around 350, indicating significant attention to earlier publications. However, citations sharply declined after that, dropping drastically below 100 by 2018. From 2019 to 2021, there were slight fluctuations, but the citation count remained relatively stable. In 2021, there was a brief increase, surpassing 150 citations, before sharply dropping to nearly zero by 2024. This may be due to decreasing relevance or interest in this research area among scholars.

On the other hand, the annual number of publications show a different pattern. From 2015 to 2024, the publication count remained very stable and low, never exceeding 20 publications per year. Although there was a slight increase in 2020 and 2021, this change was insignificant, and the numbers stabilized again through 2024. This suggests that this research field has limited publication capacity or that there may not be many researchers focusing on this area. The stability in publication numbers could indicate resource limitations or a lack of interest in this research topic.

All things considered, the chart shows a disparity between the quantity of publications and citations. Although the quantity of articles is still small and steady, citations show a notable decline after 2015, followed by a brief uptick in 2021.

This suggests that although there are few publications, the quality or relevance of this research was initially high but has gradually declined over time.

3.2. Science Mapping and Network Analysis

The most fruitful and significant papers, writers, nations, organizations, and sources pertaining to technology-assisted Project-Based Learning are displayed through citation analysis.

To determine which authors, nations, organizations, and sources are the most productive, total publications (TP) are employed. On the other hand, total citations (TC) are used to identify the most significant papers, writers, nations, organizations, and sources [33], [34]. Each component is analyzed in detail in this section. First, the five most-cited documents related to technology-assisted Project-Based Learning are presented in Table 1.

Table 1. The ten most cited documents

Cites	Authors	Title	Year	Source
301	[35]	How Science, Technology, Engineering, and Mathematics (Stem) Project-Based Learning (Pbl) Affects High, Middle, and Low Achievers Differently: The Impact of Student Factors on Achievement	2015	International Journal of Science and Mathematics Education
83	[36]	Effects Of Infusing the Engineering Design Process into STEM Project-Based Learning to Develop Preservice Technology Teachers' Engineering Design Thinking	2021	International Journal of STEM Education
82	[37]	Project-Based Learning (PBL) Through the Incorporation of Digital Technologies: An Evaluation Based on The Experience of Serving Teachers	2017	Computers in Human Behavior
50	[38]	How Science, Technology, Engineering, and Mathematics Project Based Learning Affects High-Need Students in The U.S.	2016	Learning and Individual Differences
47	[39]	The Effect of Science, Technology, Engineering and Mathematics (STEM) Project Based Learning (PBL) on Students' Achievement in Four Mathematics Topics	2016	Journal of Turkish Science Education
37	[40]	Post Secondary Project-Based Learning in Science, Technology, Engineering and Mathematics	2016	Journal of Technology and Science Education
35	[41]	Towards A Successful Integration of Project-Based Learning in Higher Education: Challenges, Technologies and Methods of Implementation	2019	Universal Journal of Educational Research
34	[42]	Project-Based Learning Approach for Teaching Mobile Application Development Using Visualization Technology	2020	International Journal of Emerging Technologies in Learning
27	[43]	Interdisciplinary Project-Based Learning: Technology for Improving Student Cognition	2015	Research in Learning Technology
25	[44]	The Effectiveness of Using 3D Printing Technology in STEM Project-Based Learning Activities	2018	Eurasia Journal of Mathematics, Science and Technology Education

Table 1 presents various studies on project-based learning in the context of STEM, examining a number of factors that academics have looked at. Han S., Capraro R., and Capraro M.M. (2015) wrote the most-cited paper, which examines how Project-Based Learning in STEM affects students with high, middle, and low ability levels. This article has been cited 301 times, indicating its significance and influence in educational research, particularly in understanding how Project-Based Learning can affect learning outcomes for students from diverse academic backgrounds.

Additionally, a recent study, published in 2021 by Lin K.Y., Wu Y.T., Hsu Y.T., and Williams P.J., with 83 citations, investigates the improvement of engineering design thinking in pre-service technology educators through the incorporation of the engineering design process into project-based instruction. The relatively high citation count for this newly published study highlights significant interest in how engineering design methods can be incorporated into curricula to strengthen the skills of future teachers.

Several other studies also demonstrate how new technologies are utilized in Project-Based Learning approaches. A 2017 study by Basilotta Gomez-Pablos V., Martin del Pozo M., and Garcia-Valcarcel Munoz-Repiso A., for instance, received 82 citations for integrating digital technology into project-based learning and evaluating its efficacy among active teachers. This suggests that there is increasing interest in using digital technology in the classroom to produce more engaging lessons. Additionally, Lin, Hsiao, Chang, Chien, and Wu conducted a study in 2018 to investigate the efficacy of Utilization of 3D printing technology in Project-Based Learning initiatives, with 25 citations reflecting an interest in innovative technology within STEM teaching methods.

This table also emphasizes the focus implementation Project-Based Learning throughout diverse educational tiers and within certain courses. Han S., Rosli R., Capraro M.M., and Capraro R.M. (2016) investigated how Project-Based Learning affected students' performance in four different areas of mathematics, indicating a deeper focus on specific sub-disciplines within STEM.

Meanwhile, the difficulties and strategies for implementing project-based learning in higher education were examined in a 2019 study by Shpeizer R, revealing distinct challenges in applying this approach at advanced educational levels.

Overall, in Table 1 show that Project-Based Learning is gaining prominence in STEM education, particularly through the integration of digital technology and innovative methodologies like 3D printing, with an emphasis on improving learning outcomes tailored to the different needs of learners. The increase in citations for studies involving new technologies also indicates that innovation in project-based learning approaches within STEM is a primary focus in current educational research.

The distribution of publications and citations for the top five authors within the pertinent discipline is displayed in the table below. This table lists each author's total publications (TP) along with their affiliated institutions, in addition to the authors with the greatest citation counts (TC) and their respective institutional connections.

Table 2. Five authors with the highest citations and publications

The Top 5 Author with the Highest Publication			**The Top 5 Author with the Highest Citation**		
Author	**Institution**	**TP**	**Author**	**Institution**	**TC**
Han, Sunyoung	Texas Tech University, Lubbock, Texas	3	Han, Sunyoung	Texas Tech University, Lubbock, Texas	398
Isa, Muhammad Umar	Niger State, Nigeria, Department of Technical and Engineering Education	3	Capraro, Mary Margaret	Texas A&M University, College Station, Texas	301
Kamin, Yusri bin	Niger State, Nigeria, Department of Technical and Engineering Education	3	Capraro, Robert	Texas A&M University, College Station, Texas	301
Lin, Kuen-Yi	Department of Technology Application and Human Resource	2	Lin, Kuen-Yi	Department of Technology Application and Human Resource	108
Wu, Ying-Tien	Department of Technology Application and Human Resource	2	Wu, Ying-Tien	Department of Technology Application and Human Resource	108

Table 2 shows that, with 3 publications and 398 citations, Han, Sunyoung of Texas Tech University in Lubbock, Texas, is the author with the most numbers of publications and citations. Regarding publications, Han, Sunyoung from Texas Tech University, along with Isa, Muhammad Umar, and Kamin, Yusri bin from Niger State, Nigeria; The first three spots are occupied by the Department of Technical and Engineering Education, each of which has three publications. With two papers and 108 citations apiece, Lin, Kuen-Yi, and Wu, Ying-Tien from the Department of Technology Application and Human Resources are rated fourth and fifth, respectively.

Furthermore, in terms of citations, with 301 citations apiece, Mary Margaret and Robert Capraro Texas A&M University located in College Station, Texas, are ranked second and third, respectively. This indicates that although some authors may have fewer publications, they still make a significant impact in the domain of technology-enhanced project-based learning, as indicated by the citation count.

Thirdly, the distribution of publications and citations for the top five nations in the relevant field of study is shown in Table III. This table lists the total publications (TP) for each country along with the highest citation count (TC) received by publications from these countries.

Table 3. The top five nations with the most citations and publications

The Top Five Nations with the Most Publications		The Top Five Citation-Rated Nation	
Nation	**TP**	**Nation**	**TC**
United States	22	United States	502
Indonesia	19	Taiwan	144
Malaysia	12	Spain	119
Taiwan	8	Malaysia	108
Spain	8	South Korea	98

According to Table 3, The United States excels globally in both publications and citations pertaining to research on technology-assisted Project-Based Learning, with 22 publications and 502 citations.

Indonesia ranks second with 19 publications, despite the fact that it is not one of the top five nations with the most citations. Malaysia ranks fourth in terms of citations with 108 overall, and third with 12 publications. Taiwan and Spain have the same number of publications, eight each, but Taiwan surpasses Spain in citation count. South Korea ranks fifth in total citations with 98 citations, despite not being in the top five nations for the number of publications.

Fourth, the top five universities with the most publications and citations in technology-assisted Project-Based Learning are listed in Table 4. Based on total publications (TP) and total citations (TC), this table gives a summary of each institution's role in the growth of this field.

Table 4. The five leading institutions by citations and publications

The Top Five Institution with the Highest Publication			The Top Five Institutions with the Highest Citation		
Institution	**Country**	**TP**	**Institution**	**Country**	**TC**
National Central University	Taiwan	2	Graduate Institute of Network Learning Technology, National Central University	Taiwan	301
Texas A&M University, College Station, Texas	United State of America	1	Texas A&M University, College Station, Texas	United State of America	301
Texas Teach University, Lubbock, Texas	United State of America	1	National Central University	Taiwan	108
Kaye Academic College of Education	Israel	1	Chien-Kuo Junior High School	Taiwan	83
Padang State University	Indonesia	1	National Taiwan Normal University	Taiwan	83

Table 4 shows the distribution of publications and citations from various institutions contributing to research in technology-assisted Project-Based Learning. In terms of publication count, National Central University in Taiwan leads with the highest number, totaling two publications. Although this is not a large number, it is sufficient to make it the leader in publication count compared to other institutions. Other institutions, include Israel's Kaye Academic College of Education and the United States' Texas A&M University and Texas Tech University, and Padang State University from Indonesia, each have only one publication. This suggests that the field represented in this table may have very specific characteristics or stringent publication criteria, keeping the publication count low for any institution.

On the other hand, a different pattern emerges when considering citation counts. With 301 citations apiece, Texas A&M University in the US and National Central University in Taiwan's Graduate Institute of Network Learning Technology have the most citations.

This high citation count indicates that the research produced by these institutions is highly influential and frequently referenced by other researchers, signifying high quality or relevance within the academic community. The Graduate Institute of Network Learning Technology's association with National Central University underscores the institution's significant impact in the domain, both in terms of the volume of publications it produces and their generally acknowledged caliber.

Fifth, derived from the volume of articles and citations acquired, Table 5 lists the top five sources that have significantly advanced the field of technology-assisted Project-Based Learning research. This table summarizes the journals and conferences that have disseminated the most relevant articles and garnered the greatest number of citations.

Table 5. The five sources with the highest publications and citations

The Five of the Best Sources for Publication			The Top Five Citation-Rated Sources		
Source	**Publisher**	**TP**	**Source**	**Publisher**	**TC**
Journal of Physics: Conference Series	IOP Publishing Ltd	10	International Journal of Science and Mathematics Education	Kluwer Academic Publishers	301
ASEE Annual Conference and Exposition, Conference Proceeding	American Society for Engineering Education	6	International Journal of Emerging Technologies in Learning	Kassel University Press GmbH	87
International Journal of Emerging Technologies in Learning	Kassel University Press GmbH	5	International Journal of STEM Educational	Springer Science and Business Media Deutschland GmbH	83
Universal Journal of Educational Research	Horizon Research Publishing	4	Computer in Human Behavior	Elsevier Ltd	82
ACM International Conference Proceeding Series	Association for Computing Machinery	3	Learning and Individual Differences	Elsevier Ltd	50

The distinction between the most influential and the most productive sources is shown in this table. Sources that are quite fruitful, such as the Journal of Physics: Conference Series tend to have a high volume of publications but are not among the most highly cited, which may suggest that while this journal is frequently utilized, its influence in terms of citations may not be as significant as some other journals. Journals with strong citation counts, however, incorporate the International Journal of Science and Mathematics Education and the International Journal of STEM Education, indicating a greater impact in the field, even if their publication volume is not as high as other sources. This suggests that the number of publications does not always correlate directly with a journal's influence or quality.

3.2.1. Coauthor Analysis

Two major units of analysis were taken into consideration when doing the co-author analysis: author units and country units. The first step, author unit analysis, was carried out to identify collaboration patterns or social relationships among authors, as well as their contributions to publications related to technology-assisted project-based learning. This analysis used a minimum threshold of two documents and citations per author. Thirteen interconnected authors were identified, forming a single cluster (Figure 4).

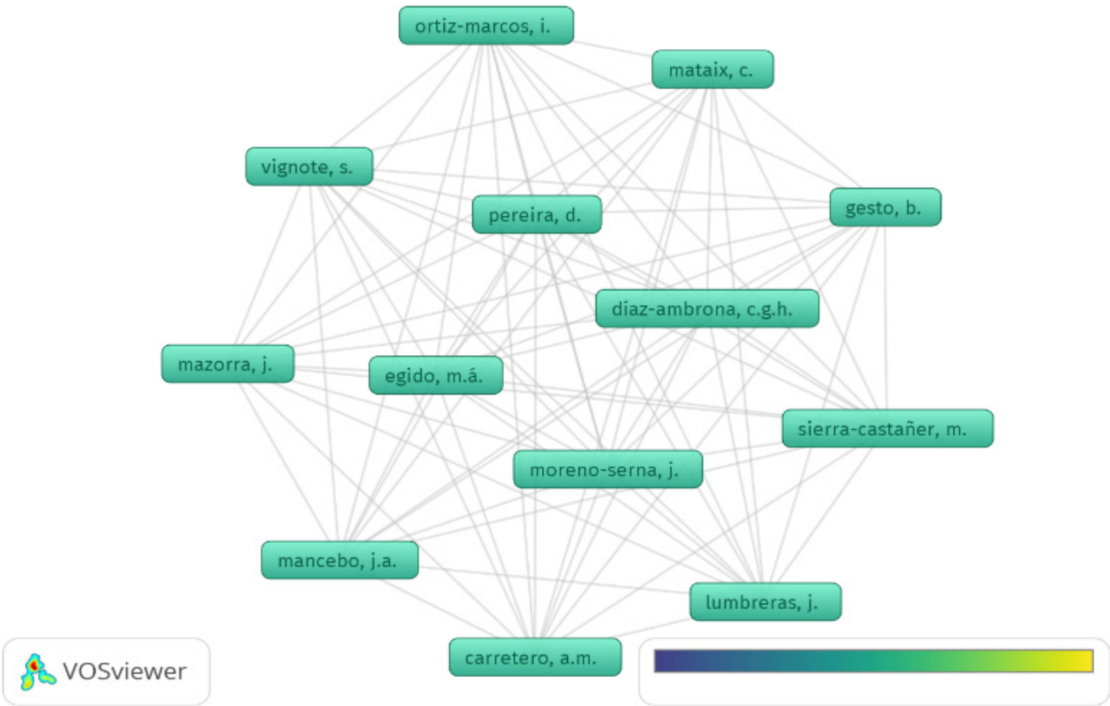

Figure 4. Social relationship trends regarding technology- assisted project-based learning

Figure 4 illustrates the visualization of the author collaboration network produced with VOSviewer. Each green box represents a specific author, and the lines connecting these boxes indicate collaborative relationships or research partnerships among authors. The thickness and density of the lines connecting writers signify the intensity and frequency of their interactions.

From this visualization, it can be observed that authors such as Ortiz-Marcos, I., Pereira, D., and Díaz-Ambrona, C.G.H. occupy a more central position in the network, suggesting that they serve as key connectors within this research collaboration. They have more connections with other authors compared to those located on the network's periphery, such as Mazaorra, J., or Gesto, B.

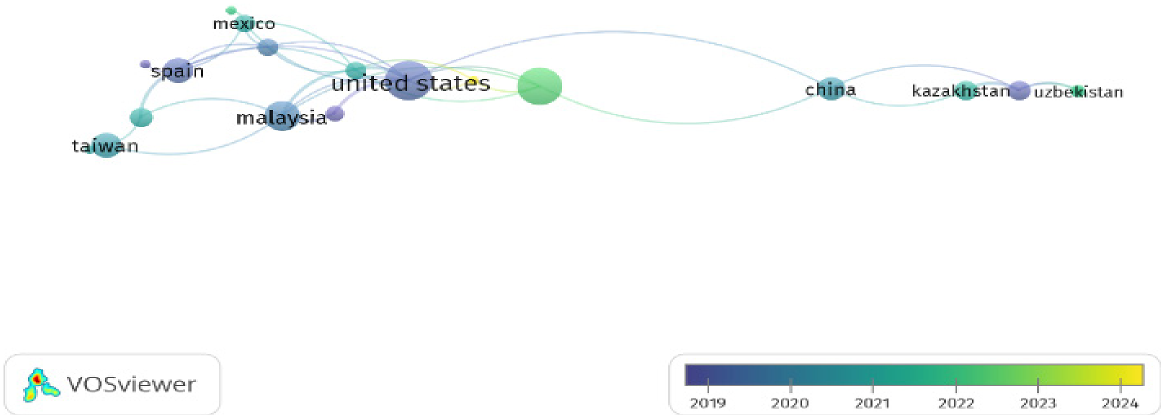

Figure 5. The interrelations among nations concerning technology-assisted project-based learning

The international research partnership network is visualized using VOSviewer in Figure 5, spanning the years 2019–2024. Each circle represents a specific country, and the lines connecting these circles indicate research collaborations between countries. The size of each circle represents the intensity or level of contribution of that country in the collaboration, while the gradient color from blue to green to yellow shows the progression of collaboration over the years.

From this visualization, the United States occupies a dominant position in the collaboration network, marked by a larger circle size, indicating its high level of involvement in international research collaborations. Other countries connected with the United States, such as Malaysia, Taiwan, Spain, and China, show strong collaboration, particularly in the early period of this research, represented by the blue and green colors.

As time progresses toward 2024, there is an observed increase in involvement from Central Asian countries such as Kazakhstan and Uzbekistan.

This may indicate new developments in research collaborations involving these countries, indicating their increasing interest in the subject matter being analyzed.

3.2.2. Co-Word Analysis

Co-word analysis focuses on “words,” examining the content of publications based on the premise that frequently occurring words have thematic relationships.

However, its use must be strategic to address its limitations and can enrich the understanding of thematic clusters and predict future research directions [24]. The terms in the co-word analysis are sourced from the "index keywords" shown in the network visualization results (Figure 6) and overlay visualization (Figure 7). The initial analysis is presented as a network visualization combined with cluster analysis to display keywords related to technology-assisted project-based learning. Keywords with a minimum occurrence of two were selected, connecting with 28 other keywords.

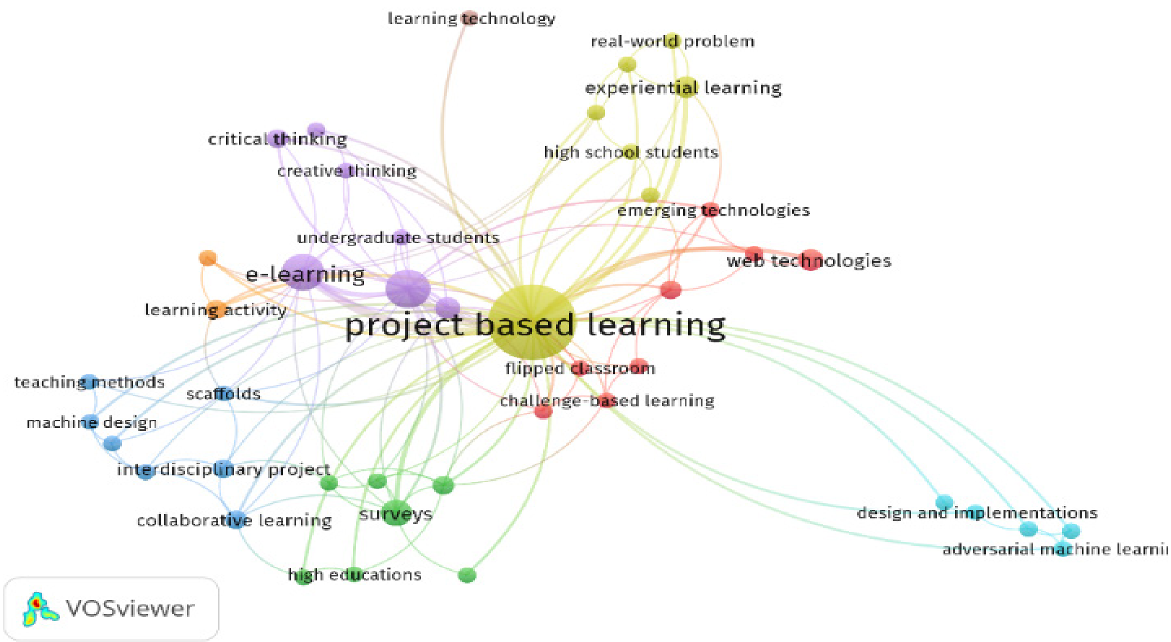

Figure 6. List of keywords related to technology-based project learning

Figure 6 represents a visualization image showing the network of keywords related to Project-Based Learning, divided into several color-coded clusters to indicate inter-topic connections. At the center of the network, Project-Based Learning serves as the focal point, linking various learning concepts. Keywords like "e-learning," "learning activity," and "critical thinking" are highlighted in the purple cluster, highlighting the importance of digital technology and the growth of critical thinking abilities in project-based learning.

The orange cluster includes keywords such as “teaching methods,” “scaffolds,” and “interdisciplinary project,” indicating a cross-disciplinary Project-Based Learning approach supported by structured teaching methods.

Keywords like "surveys," "higher education," and "collaborative learning" are found in the light green cluster, highlighting the significance of assessment and teamwork in higher education. Light blue cluster is connected to topics like “machine design,” “design and implementations,” and “adversarial machine learning,” reflecting the combination of design and technological applications in Project-Based Learning.

The red cluster involves “emerging technologies,” “web technologies,” and “flipped classroom,” indicating the use of new technologies and flipped classroom methods to enhance learning experiences. Detailed information for each cluster is presented in Table 6.

Table 6. The emerging keywords' hierarchical clustering analysis results

Theme	Keywords	Occurrence
ICT	Learning Technology	2
	E-Learning	12
	Education Computing	13
	Information Technology	2
	Science Technology	2
	Technology Entrepreneur	3
Strategy	Experiential Learning	4
	Federate Learning	2
	Adversarial Machine Learning	2
	Instructional Strategy	2
	STEM Education	4
	Scaffolds	2
	Challenge-Based Learning	2
	Flipped Classroom	2
	Student-Centered Learning	2
	Activity Learning	3
	Collaborative Learning	2
Product	Interdisciplinary Project	2
	Machine Design	2
	Application Program	2
	Software Design	2
	Web Technology	4
Skill	Technical Skill	2
	Motivation	2
	Critical Thinking	3
	Creative Thinking	2
	Softskill	2
	Communication Skill	2

Subsequently, the results from the overlay visualization obtained from index keywords with a minimum occurrence of twice generated 116 interconnected keywords, along with the distribution of keyword occurrences during the 2018-2024 period related to technology-assisted Project-Based Learning.

Additionally, there are also cluster analysis results that demonstrate the interconnections between each emerging keyword.

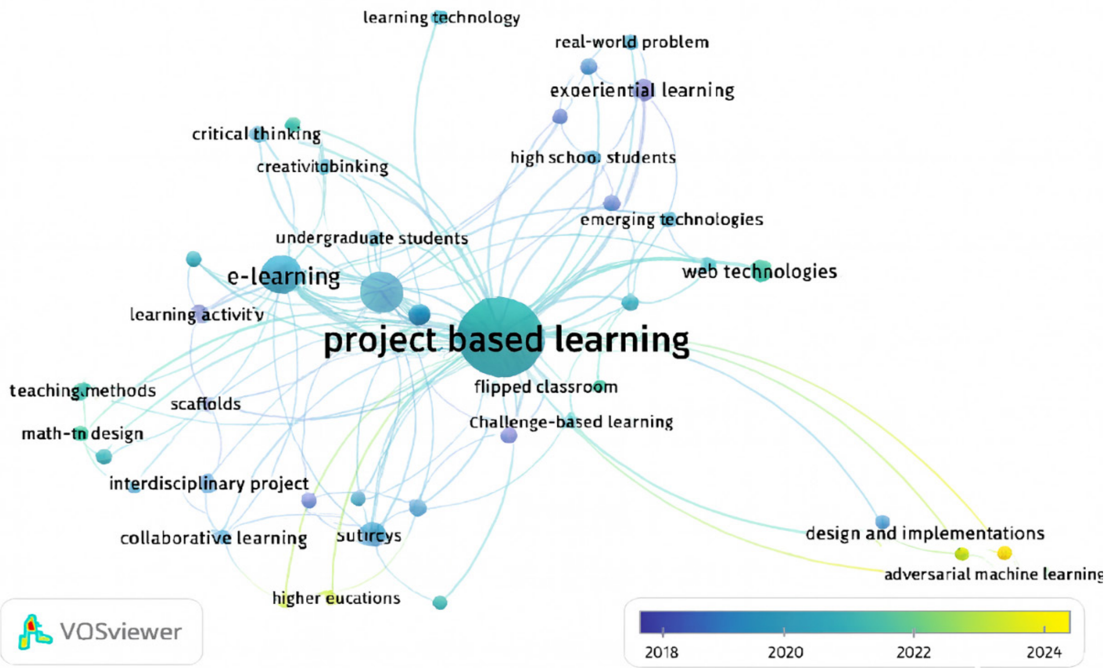

Figure 7. The distribution of emerging keywords regarding technology-assisted project-based learning in the recent period

The research trends in technology-assisted project-based learning from 2015 to 2024 are depicted in Figure 7, with the appearance of relevant keywords. It is clear that Project-Based Learning has greatly advanced in its use of technology, marked by keywords such as "e-learning," "web technologies," "emerging technologies," and "adversarial machine learning." Over time, technology has become increasingly integrated into project-based learning methods, providing students with opportunities for interactive and collaborative learning. Starting in 2018, foundational technologies like e-learning began to appear, progressing to more advanced technologies such as web technologies and emerging technologies in subsequent years. This trend continues through 2024, where topics like design and implementations and adversarial machine learning indicate that machine learning and system design technologies are playing an increasingly important role in supporting learning experiences that are project-based.

4. Discussion

This section repeats the results presented previously, discusses the impact of publication and citation patterns, and reviews the role of the most influential documents, authors, countries, institutions, and sources in shaping the development of research on technology-assisted Project-Based Learning.

4.1. Trend in Publication and Citation on Technology Assisted Project-Based Learning

Recent years have witnessed notable trends in publications and citations regarding technology-assisted Project-Based Learning, in line with the growing role of technology in education. Based on network visualization and keyword clustering, there has been a trend of increased use of digital technology and innovative teaching methods in project-based learning from 2018 to 2024. Although publications on this topic show annual variations, an overall stable trend is evident, with a growing focus on technology integration, such as e-learning, web technologies, and emerging technologies. As noted by several researchers [45], [3], the role of technology in education is significant, but its practical implementation remains challenging. Obstacles such as the need for sufficient resources, continuously evolving learning tools, and adapting to technological changes affect the publication rate on this topic.

The citation trends in research on technology-assisted project-based learning also vary, with certain years showing significant citation spikes, especially for publications introducing new approaches or innovative technologies in project-based learning. In particular years, groundbreaking works have played a crucial role in influencing subsequent studies, similar to findings by [46] regarding the impact of significant publications in different fields.

Publications leveraging new technologies, such as flipped classroom, collaborative learning, and challenge-based learning, have become key references for other researchers interested in developing modern teaching methods. These citation fluctuations may also be associated with international collaborations and the widespread adoption of innovative teaching methods that attract broad interest.

For instance, concepts like experiential learning and STEM education frequently appear in this research, becoming major trends that garner significant citations. Academic discussions on this subject are greatly advanced by studies that emphasize multidisciplinary collaboration and challenge-based learning, especially those that concentrate development of critical and creative thinking skills. In this regard, project-based learning technology-assisted not only enhances students' learning experiences through direct interaction and project-based activities but also drives research focused on technological innovations that support learning relevant to the real world.

Thus, the trends in publications and citations on technology-assisted Project-Based Learning reflect a growing need for learning approaches relevant to the digital era and highlight the importance of technology in supporting collaborative, critical, and experiential learning. This perspective indicates that while the role of technology in Project-Based Learning is recognized, its implementation still faces challenges, yet it remains a significant focus in modern educational research.

4.2. The Documents, Authors, Nations, Organizations, and Sources That Influence Technology-Assisted Project-Based Learning the Most

In research related to technology-assisted Project-Based Learning, several documents, authors, countries, institutions, and publication sources have demonstrated significant contributions and become key references on this topic. Based on the available data, the five most-cited publications cover various critical aspects of applying technology in Project-Based Learning, such as e-learning integration, cross-disciplinary collaboration, integrating new technologies into the classroom and encouraging students to think critically and creatively. For example, works that address e-learning and web technologies are often referenced as they provide practical guidelines for implementing technology to support project-based learning. These contributions reflect the relevance of technology in contemporary education, especially in enhancing interactive and skill-based learning experiences.

Some well-known writers—possibly those with a large number of citations—help to clarify the methods for putting technology-assisted Project-Based Learning into practice and how it affects student participation.

Authors addressing topics like experiential learning and STEM education play a crucial role in enriching the academic discussion on applying Project-Based Learning within the context of technology and science. Their works often draw on social learning theories, such as Vygotsky's constructivism theory, highlighting student participation as a component of deep cognitive processes and stressing the value of social connection in the learning process.

Geographically, the nation that has contributed the most to this research is the United States, both in terms of publications and citations, likely due to strong institutional support for educational technology research. Other countries, such as Taiwan and Malaysia, participate in the worldwide network of collaborations, especially in studies centered on educational technology advancements. Institutional support from U.S. universities, such as Michigan State University and the University of Texas, positions them at the forefront of technology-assisted project-based learning development, with highly influential publications.

In terms of publication sources, journals like the International Journal of STEM Education and Computers in Human Behavior serve as primary outlets for publishing research on technology-assisted Project-Based Learning. These journals are not only prolific in publishing work related to this topic but also have high citation rates, making them key references for researchers interested in the application of technology in education. Articles published in these journals typically provide in-depth analyses of new learning technologies, such as flipped classrooms and adversarial machine learning, which are increasingly relevant in the context of project-based learning.

4.3. Social Interactions among Authors and Countries Regarding Technology Assisted Project-Based Learning

A significant and organized network of collaboration is revealed by the social connections between writers and nations pertaining to technology-assisted Project-Based Learning, with several clusters of authors and countries sharing similar research focuses and objectives. In one of the main clusters, several authors work closely together to develop innovative technology-based learning methods and practices. Authors in this cluster are often involved in research on learning strategies such as e-learning, flipped classrooms, and collaborative learning. This collaboration reflects a shared goal of enhancing Project-Based Learning methods through technology, particularly to improve students' critical and collaborative thinking skills.

Additionally, in another cluster, there are authors focused on topics such as emerging technologies and adversarial machine learning, aiming to explore the potential of new technologies in education. The authors connected within this cluster have strong research backgrounds in technology and STEM education, and their collaboration aims to generate innovations in technology-assisted Project-Based Learning. The interaction between these clusters indicates an exchange of ideas centered on applying the latest technologies to support Project-Based Learning.

Geographically, in the global network of collaboration pertaining to technology-assisted project-based learning, the United States appears as a key hub. Researchers in the United States often collaborate with counterparts in countries such as Malaysia, Taiwan, and Spain. This collaboration indicates that the United States has an extensive research network and frequently serves as a bridge in cross-country studies exploring the integration of technology in Project-Based Learning. On the other hand, countries like China, Kazakhstan, and Uzbekistan are also involved in newer collaborative networks, particularly in the application of web-based technologies and machine learning for education.

4.4. The Construction of Novelty in Technology Assisted Project-Based Learning Studies

This section comprehensively describes the novelties in Project-Based Learning research using technology, by grouping emerging keywords based on several key themes, such as ICT, learning strategies, resulting products, and skill enhancement.

4.4.1. ICT in Technology-Assisted Project-Based Learning Studies

The ICT cluster in technology-assisted Project-Based Learning research encompasses a variety of educational technologies that support Project-Based Learning processes. Keywords such as education Computing, with the highest frequency of occurrence (13 times), and E-Learning (12 times) indicate the prominence of digital technology in implementing Project-Based Learning. Terms like Learning Technology, Information Technology, Science Technology, and Technology Entrepreneurship also appear within this cluster, each highlighting innovations that provide access to diverse digital learning resources. The advent of the phrase Technology Entrepreneurship signifies a novel trend in education, wherein students are urged to cultivate technology entrepreneurship abilities via Project-Based Learning. This cluster aims to utilize diverse technologies to enhance an interactive and adaptable learning experience.

4.4.2. Strategies in Technology-Assisted Project-Based Learning

The strategy cluster encompasses various approaches used in technology-assisted Project-Based Learning, with keywords such as Experiential Learning and STEM Education, each appearing four times. These approaches indicate that Project-Based Learning is often applied in experiential and STEM-based education to provide students with real-world experiences in knowledge application. Other keywords, such as Federated Learning, Adversarial Machine Learning, and Flipped Classroom, each appearing twice, reflect innovative strategies supported by advanced technology. Challenge-Based Learning and Student-Centered Learning also appear in this cluster, emphasizing the importance of student-centered and challenge-based learning, which encourages students to actively engage in problem-solving. Additionally, Activity Learning, mentioned thrice, and Collaborative Learning, mentioned twice, underscore the significance of cooperation and student engagement in educational activities that foster the enhancement of social and cognitive skills.

4.4.3. Strategies in Technology-Assisted Project-Based Learning

The product cluster focuses on the outcomes or products generated from implementing technology-assisted Project-Based Learning. Web Technology appears most frequently (four times) in this cluster, indicating that web technology serves as a primary platform for supporting Project-Based Learning. Other keywords, such as Interdisciplinary Project, Machine Design, Application Program, and Software Design, suggest that interdisciplinary projects and software design are integral components of Project-Based Learning. These items not only facilitate the learning process but also motivate students to develop practical skills, real-world applications. This product-oriented approach enables students to apply learned skills to technology design and development, enriching the Project-Based Learning experience with tangible outcomes.

4.4.4. Skill Development in Technology-Assisted Project-Based Learning

The skills cluster in technology-assisted Project-Based Learning highlights various competencies developed through this approach. Keywords such as Critical Thinking (appearing three times) are emphasized as a primary skill, indicating that Project-Based Learning focuses on cultivating critical thinking abilities essential for problem-solving.

Additionally, Creative Thinking, Technical Skill, Motivation, Soft Skill, and Communication Skill each appear twice, demonstrating a variety of abilities cultivated through Project-Based Learning. These skills encompass technical abilities, communication proficiency, as well as motivation and creativity, all of which are crucial for the success of project-based learning. Developing these skills enables students to adapt to dynamic learning environments and prepares them to face the increasingly complex challenges of the workforce.

4.4.5. Limitation and Suggestions

This study on technology-assisted Project-Based Learning has several limitations. First, it relies solely on the Scopus database to search for relevant documents, which may result in an incomplete picture of research trends in technology-assisted Project-Based Learning. Employing alternative databases, including Web of Science, IEEE Xplore, or Google Scholar, may enhance the findings and offer a more comprehensive perspective on trends and current research in this domain.

Second, in analyzing frequently occurring keywords, this study relies only on co-word analysis. While this method is useful for examining keyword relationships, additional approaches, including bibliographic coupling and co-citation analysis, may provide profound insights into the keywords and themes arising inside technology-assisted Project-Based Learning. These methods can help identify more profound connections between documents and related topics.

Third, this study uses VOSviewer as a visualization tool for networks of keywords, authors, and countries. While VOSviewer is effective in presenting bibliometric data, its visual limitations can sometimes make the results less clear for users. Considering other tools, such as Gephi or Bibliometrix R, may provide more detailed and user-friendly visualizations, especially for identifying complex networks involving keywords, countries, affiliations, sources, and related documents.

Fourth, the use of specific search terms like "technology-assisted Project-Based Learning " may limit the number of documents found, as other related terms such as "technology-integrated Project-Based Learning " or "digital Project-Based Learning " may also be relevant. Expanding the range of terms could broaden the research scope and allow for the identification of documents that might offer additional insights on this topic.

For future research, it is recommended to utilize multiple scientific databases and a broader range of analytical methods to achieve more comprehensive and accurate results.

Additionally, expanding search terms and employing more sophisticated visualization tools can help in better understanding trends, interactions, and influences in the field of technology-assisted Project-Based Learning.

5. Conclusion

This bibliometric analysis explains the development of research on technology-assisted Project-Based Learning from 2015 to 2024. The annual volume of articles concerning technology-based Project-Based Learning has been consistently steady, although citation trends show fluctuations that reflect increased attention to certain publications. During this period, a number of highly prolific and influential documents, authors, countries and institutions have made significant contributions to the advancement of technology-enabled Project-Based Learning studies. From 2015 to 2024, a total of 116 documents related to technology-assisted project-based learning were published, with a total of 1,221 citations, although citation levels varied significantly among these documents.

Future research trends could focus on exploring the application of new technologies in Project-Based Learning. Integration technologies such as e-modules, web technologies, interactive media, and other digital innovations can enhance Project-Based Learning, developing a more engaging and pertinent educational experience for learners in the digital era. Future research will concentrate on the utilization of digital tools and software in Project-Based Learning to enhance creative pedagogical approaches. Education today must adapt to the latest technological developments and learning strategies that support technology-based Project-Based Learning to be more effective in enhancing students' collaboration skills, critical thinking, and creativity.

Furthermore, future research is expected to identify and develop new learning models that deeply integrate technology into the Project-Based Learning process. Follow-up studies should also evaluate the impact of technology on student skills, particularly within the framework of project-based learning that prioritizes developing of 21st-century skills. This research thus provides guidance for stakeholders in the education sector to continue developing and adopting technology in project-based learning, ensuring its implementation supports effective and adaptive learning that meets students' needs for the future.

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