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A Trend Analysis of Project-based Learning in Chemistry Experiment: A Bibliometric Analysis

Ika Hasanah[1], Sjaeful Anwar[1*], Iqbal Musthapa[2]

[1] Chemistry Education Department, Universitas Pendidikan Indonesia, Bandung, Indonesia.
[2] Chemistry Department, Universitas Pendidikan Indonesia, Bandung, Indonesia.

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Corresponding Author:
Sjaeful Anwar
saefulanwar@upi.edu

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Abstract: Project-based learning is a global trend, widely adopted across countries. Project-based learning has developed diversely by emphasizing interdisciplinary, cross-domain, and regional collaboration. To provide in-depth resources for researchers and educators on project-based learning in chemistry experiments, this study aims to make a bibliometric analysis on the topic of project-based learning globally using publication characteristics analysis. The database used in this study used Scopus and obtained 5900 articles from 2018-2023. Bibliometric analysis was analyzed using VOSviewer and Microsoft Excel. The results of the bibliometric analysis show that Boone, C.D. is the author with the highest number of citations on the research topic, Project-based learning in a chemistry experiment. The United States is the most productive country in researching this topic, with 1351 articles. The most influential journal with the highest number of articles is the Journal of Physics Conference Series, with 243 articles. The major contextualized learning literatures in this study tend to fall into broad groups such as Project-based Learning, Education, and STEM Education. These findings suggest the need for multidisciplinary and cross-disciplinary studies on project-based learning research on chemistry learning and advocate for the inclusion of project-based learning research in education from a broader geographical context.

Keywords: Bibliometric analysis; Chemistry experiment; Project-based learning; VOSviewer

Introduction

Project-based learning (PjBL) has become a powerful instructional approach to enhance student learning and engagement, especially in chemistry laboratory courses. This method engages students in a continuous process of inquiry according to their interests, encouraging the application of complex concepts and skills (Chu et al., 2023). In contrast to conventional teaching methods, PjBL empowers learners to combine theoretical knowledge with real-world experiences, resulting in deeper understanding and better learning outcomes.

The multifaceted nature of Project-Based Learning includes driving questions, phenomenon exploration, artifact development, collaboration, and model building (Domenici, 2022; He et al., 2023). The structured syntax of PjBL, including initiating learning with an essential question, designing a project plan, and evaluating results, has been described in depth (Suradika et al., 2023). In addition, PjBL fosters student autonomy, allowing them to generate meaningful learning messages through the creation of practical projects (Sudarmin et al., 2023). So the innovative application of PjBL in science education and organic chemistry, using natural materials, holds promise in fostering critical, creative, and innovative thinking skills among students

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(McLaughlin et al., 2024). Research on Project-Based Learning (PjBL) remains important because this approach continues to grow and become a major concern in the field of education, especially in chemistry practicum. By continuing to conduct PjBL research, education can continue to be improved to provide more meaningful and relevant learning experiences for students around the world.

Bibliometric research in chemical sciences is gaining popularity along with the advancement of information technology and scientific research. The notion of bibliometrics is gaining prominence due to its utilization of mathematical and statistical approaches in scrutinizing research subjects derived from bibliographic origins. Essentially, bibliometric analysis is a methodological framework that furnishes a profound insight into the intellectual framework and evolutionary trajectories of a research subject or field by amassing, arranging, and analyzing bibliometric data extensively. By applying these techniques, researchers can identify patterns underlying the development of chemical science, explore the interconnections between studies, and understand the impact and direction of future developments in this field. Bibliometric analysis involves two techniques, namely performance evaluation and scientific mapping. Performance evaluation aims to examine the research and publication performance of individuals, institutions, and countries (Yalcinkaya & Yucel, 2024). This research uses bibliometric analysis because it can be a valuable instrument for recognizing patterns and directions of development in the literature, highlighting significant studies and researchers, and uncovering possible topics and research directions for the future.

Systematic bibliometric analysis in the field of science education is very important and has been conducted extensively (Donthu et al., 2021). Ahmad et al. (2023) carried out a bibliometric analysis on the use of PjBL to enhance problem-solving skills, critical thinking abilities, and collaboration and teamwork capabilities. This study reviewed articles published in the Scopus database from 2010 to 2022, with a focus on Project-based Learning in Vocational Education. Solihah et al. (2024) performed a bibliometric analysis on the application of PjBL to boost problem-solving skills, analyzing articles from the Scopus database spanning 2013 to 2023, and centered on Project-based Learning in relation to Science, Technology, Engineering, and Mathematics (STEM) Education for Sustainable Development (ESD). Rivadeneira et al. (2023) examined the use of PjBL to foster innovation in teaching and learning processes through a bibliometric analysis, utilizing data from the Web of Science (WoS) and Scopus databases between 2018 and 2022. Sagita et al. (2023) conducted a bibliometric study on the implementation of PjBL to improve mathematical and financial literacy, focusing on articles in the Scopus database from 1994 to 2022.

All these studies provide valuable insights into their respective subjects and the years they cover. However, a more comprehensive, detailed, and in-depth study encompassing all years is needed. Additionally, there has yet to be a bibliometric analysis specifically on the application of project-based learning in chemistry experiment. Specifically, this article explores the bibliometric analysis of project-based learning in chemistry experiment research published between 2018 and 2023. VOSviewer is the bibliometric visualization tool used to analyze the data in this study. Based on this need, the study decided to examine all studies related to project-based learning in experimental chemistry research published between 2018 and 2023. Therefore, the study aims to review papers on project-based learning in chemistry laboratories from an international perspective and to uncover trends in project-based learning in chemistry laboratories by considering various variables using bibliometric mapping methods.

The primary objective of this study is to assess significant contributions to project-based learning by analyzing the development of publication numbers over the years, author productivity, citation counts, and journals publishing articles on project-based learning. Furthermore, the authors plan to simplify the study of project-based learning through keyword analysis to identify trends and developments in the field. This research is expected to provide a statistical evaluation of the progress in publications on the topic of project-based learning, which will be useful for shaping future research directions that are relevant, in demand, and central to current interests.

Method

This study used bibliometric analysis to explore and visualize the literature on project-based learning in chemistry practicum, considering various variables. Bibliometric analysis is an effective method to evaluate the progress of a field by observing indicators such as the most influential journals, publications, authors, institutions, and countries (Alfaro-Ponce et al., 2024; Eck et al., 2010; Jiang et al., 2024; Mhando et al., 2023). This approach converts qualitative data into quantitative data, allowing inferences to be drawn about the amount of research that has been done in a field or topic. It provides a comprehensive overview of the attention paid to a particular topic, paradigms adopted, and trends in thinking (Baraibar-Diez et al., 2020). An important step in this process is bibliometric mapping, which reveals the themes of research related to "Project-Based Learning in Chemistry Practicum", as well as how

those research trends are evolving and the identification of influential authors and affiliations. Other objectives are to evaluate the quality of studies, analyze key areas of research, visualize intellectual, conceptual, and social structures, and forecast future research directions (Yalcinkaya & Yucel, 2024). The bibliometric method consists of three main stages: data collection, data mapping, and data refinement of publications on project-based learning in chemistry practicum, as described in Figure 1.

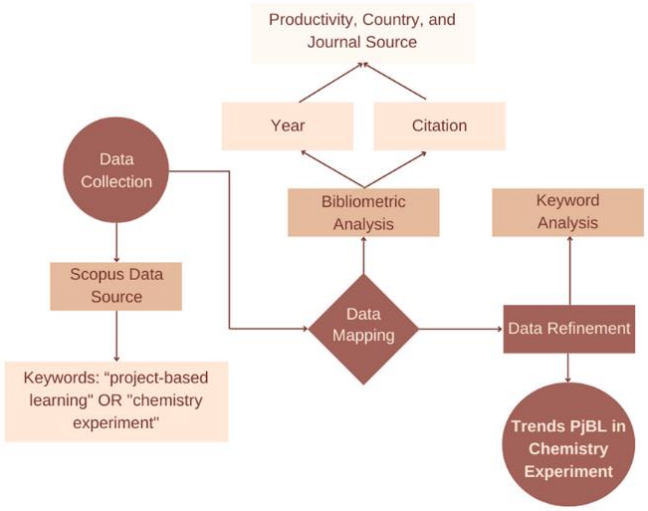

Figure 1. The Structure of the research stages

Table 1. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Published in the period 2018 to 2023	Articles or proceedings not indexed by Scopus
	Content not related to project-based learning in chemistry experiment

Only sources from reputable international journals formed the basis for this study. No other documents such as notes, reviews, or book chapters were considered. Relevant document metadata were downloaded in CSV format for bibliometric analysis using VOSviewer. Aspects analyzed included citation trends, author productivity, country productivity, and journals that published articles on project-based learning in chemistry practicum. The next stage included keyword identification from the database and refinement of the analysis of research on project-based learning in chemistry practicum. This refinement involves examining the frequency of use of keywords and the relationship between them to understand thematic evolution and recent research trends. The aim is to provide insights to empirical researchers to discover new research and innovation opportunities.

Result and Discussion

Publication Characteristics of Project-based Learning in Chemistry Experiment

This study reviews research topics related to project-based learning in chemistry practicum at the global level using publication characteristics analysis. Based on bibliometric analysis, it was found that 5900 articles obtained from the Scopus database and spread from 2018 to 2023 were used as data sources in this study. Overall, Table 2 presents important information related to the database used.

Table 2. Key information of the database

Criteria	Explanation
Time range	2018-2023
Source	1.716
Documents	5.900
Authors	5.616
Author keywords	560

The information listed in Table 2 shows that during the period 2018-2023, there were 5,647 scientific papers published in 111 international journals indexed in Scopus. The author collaboration reached 5,616 people, producing a total of 560 keywords. The publication development map can be seen in Figure 2.

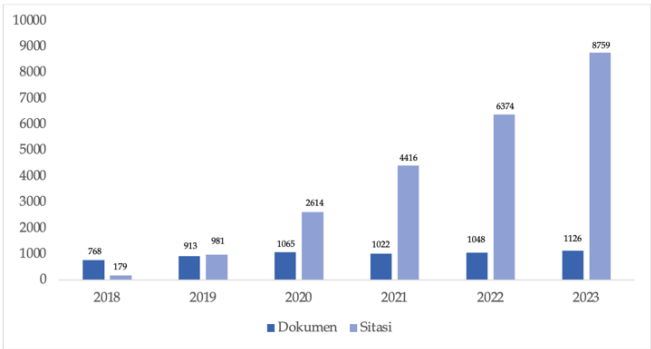

Figure 2. Distribution of publication and citation trends

Figure 2 illustrates that research on project-based learning in chemistry experiments has shown a significant upward trend from 2018 to 2023. Over the past five years, there has been a consistent increase in the number of publications. The most notable surge occurred between 2019 and 2020, with the number of publications rising from 913 to 1065. Although the increase is not always dramatic each year, the data shows a sustained positive trend in this research area, with publications growing from 768 in 2018 to 1126 in 2023.

The growing interest in this field indicates that researchers are increasingly recognizing the value of project-based learning, particularly in the context of chemistry experiments, as a method that supports more

meaningful learning. Additionally, the number of citations for publications on project-based learning in chemistry experiments has also seen rapid growth. In 2018, the citation count was relatively low at 179. However, this figure has increased dramatically in subsequent years to 981, 2614, 4416, 6374, and peaked at 8759 citations in 2022.

The most frequently cited article is the one by Hsu et al. (2018), which has received 383 citations. This article discusses computational thinking learning methods based on a literature review, highlighting its significant contribution to the field. The substantial increase in citations in 2022 underscores the growing interest in research on project-based learning in chemistry experiments, driven by technological advancements, the accessibility of information through digital technology, and collaboration among researchers. This underscores the importance of this topic in the development of chemistry education and highlights the need for further research in this area.

Publication Characteristics of Project-based Learning in Chemistry Experiment Based on Author Productivity

Based on the results of the analysis, Figure 3 shows the 10 authors who published the most articles on the research topic of project-based learning in chemistry experiments.

Figure 3 shows that Boone, C.D. is the author with the highest number of publications on the topic of project-based learning in chemistry experiments, namely 29 documents. In addition, Lima, R.M. is the author with the second highest number of publications after Boone, C.D. who was able to produce 25 documents. Alves, A.C. and Bernath, P.F. both produced 22 documents. In fifth place, there is Du, X. who produced 19 documents. Furthermore, Mesquita, D. was recorded as the author who produced 18 documents followed by Fernandes S. who produced 17 documents. In the order of nine and ten, there are Guedes, P. and Malheiro, B. who both produce 15 documents. Next, we conducted a selection process aimed at prioritizing the articles that were most relevant to the intersection of project-based learning and chemistry experiments. The focus was on articles that specifically investigated the application of project-based learning in chemistry practicum and had the highest number of citations. The top ten articles, distinguished by their number of citations, are organized in Table 3.

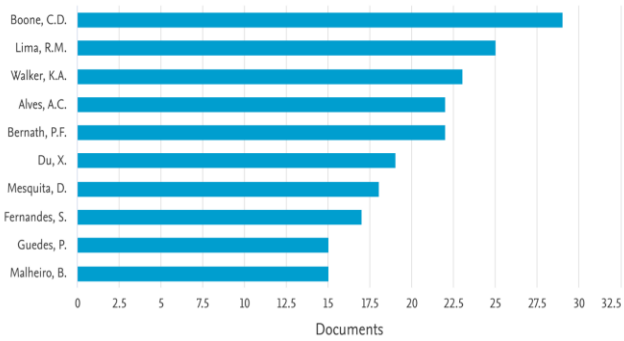

Figure 3. Top 10 authors with the highest number of articles

Table 3. Top 10 Articles with the Highest Number of Citations

Title	Authors	Sources	Year	Cit.	Ref.
How to learn and how to teach computational thinking: Suggestions based on a review of the literature	Hsu, T.-C., Chang, S.-C., Hung, Y.-T.	Computers and Education	2018	383	(Hsu et al., 2018)
A review of project-based learning in higher education: Student outcomes and measures	Guo, P., Saab, N., Post, L. S., Admiraal, W.	International Journal of Educational Research	2019	240	(Guo et al., 2020)
Revisiting the effects of project-based learning on students' academic achievement: A meta-analysis investigating moderators	Chen, C.-H., Yang, Y.-C.	Educational Research Review	2019	240	(C.-H. Chen & Yang, 2019)
Trends and research issues of mobile learning studies in nursing education: A review of academic publications from 1971 to 2016	Chang, C.-Y., Lai, C.-L., Hwang, G.-J.	Computers and Education	2018	161	(Chang et al., 2018)
Forms of implementation and challenges of PBL in engineering education: a review of literature	Chen, J., Kolmos A., Du, X.	European Journal of Engineering Education	2021	160	(J. Chen et al., 2021)
PdAg Nanoparticles Supported on Functionalized Mesoporous Carbon: Promotional Effect of Surface Amine Groups in Reversible Hydrogen Delivery/Storage Mediated by Formic Acid/CO_2	Masuda, S., Mori, k., Futamura, Y., Yamashita, H.	ACS Catalysis	2018	143	(Masuda et al., 2018)
The effect of authentic project-based learning on attitudes and career aspirations in STEM	Beier, M.E., Kim, M.H., Saterbak, A.,	Journal of Research in Science Teaching	2019	126	(Beier et al., 2019)

Title	Authors	Sources	Year	Cit.	Ref.
	…Bishnoi, S., Gilberto, J.M.				
Emerging learning environments in engineering education	Hadgraft, R.G., Kolmos, A.	Australasian Journal of Engineering Education	2020	122	(Hadgraft & Kolmos, 2020)
The hard work of soft skills: augmenting the project-based learning experience with interdisciplinary teamwork	Vogler, J.S., Thompson, P., Davis, D.W., …Finley, P.M., Yasseri, D.	Instructional Science	2018	117	(Vogler et al., 2018)
Supervised machine learning in multimodal learning analytics for estimating success in project-based learning	Spikol, D., Ruffaldi, E., Dabisias, G., Cukurova, M.	Journal of Computer Assisted Learning	2018	115	(Spikol et al., 2018)

Based on Table 3, the 10 most cited articles published in reputable journals are presented so that they can be used as credible main references for the advancement of science, especially on the topic of project-based learning in chemistry experiments. "How to learn and how to teach computational thinking: Suggestions based on a review of the literature" is the most cited article, with 383 citations. Using a database of research publications on the topic of project-based learning in chemistry experiments from 2018 to 2023, the 10 articles with the highest number of citations were published between 2018 and 2021, totaling 1,807 citations. The year for the highest number of citations on published articles occurred in 2018 with a total of 919 citations from 5 articles.

Publication Characteristics of Project-based Learning in Chemistry Experiment by Country

The project-based analysis of experimental chemistry publications aims to identify the largest contribution of countries in publishing articles on the topic. By visualizing countries based on author affiliations, we can recognize the central role of countries in research as well as show important academic collaborations among different countries (Wang et al., 2024). Figure 4 displays the contributions of countries in this study.

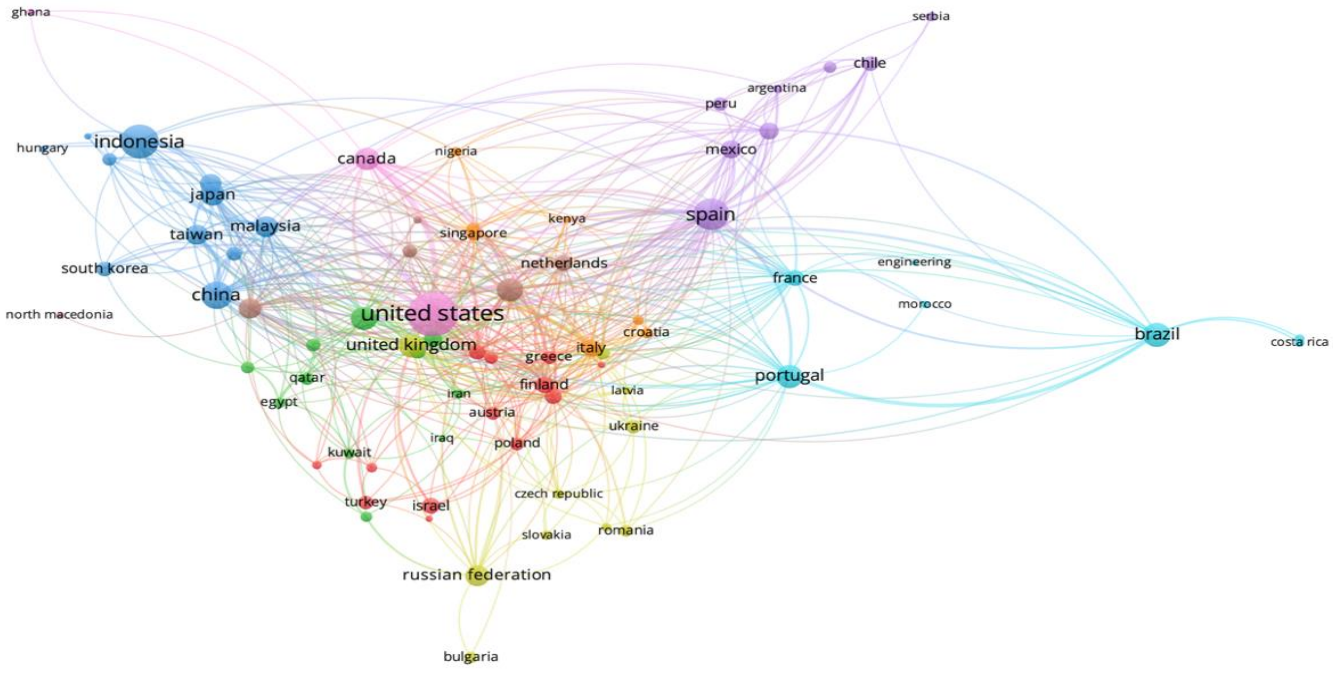

Figure 4. Collaborative publication of project-based learning in chemistry experiment

Based on Figure 6, only 77 countries out of a total of 202 countries (approximately 38.12%) met the minimum requirements by producing at least 5 publications and creating 9 distinct clusters marked with different

colours. The United States appears to be a highly influential centre of publication collaboration, indicated by the size of the largest sphere representing the country. Each sphere in the figure represents one country, and the larger it is, the more citations originate from that country. The lines connecting the spheres represent collaborations between countries. The collaboration map shows active collaboration between authors on the topic of project-based learning in chemistry experiments around the world, regardless of continent or geographical location. This reflects a strong level of cooperation in related research around the world, suggesting that project-based learning in chemistry experiments as a relevant topic is receiving widespread attention from the international education community.

Publication Characteristics of Project-based Learning in Chemistry Experiment by Source

Citation per publication and h-index are two metrics that combine information from two key aspects of academic research. Citation per publication measures how often a paper is cited in the academic literature, while the h-index attempts to measure the productivity and impact of a researcher by considering the number of citations and the number of publications cited. As such, both give an idea of how significant and influential a study is within a group (Donthu et al., 2021). The 10 most productive journal sources are presented in Table 4.

Table 4. Top 10 most published source articles

Sources	Number of Articles	h-index	Quartile
Journal of Physics Conference Series	243	91	-
ACM International Conference Proceeding Series	128	137	-
Proceedings Frontiers in Education Conference Fie	121	45	-
AIP Conference Proceedings	113	80	-
Journal of Chemical Education	111	95	Q2
International Journal of Engineering Education	87	56	Q2
Advances in Intelligent Systems and Computing	85	58	Q4
Journal of Engineering Education Transformations	84	9	Q4
Sustainability	80	135	Q1
Lecture Notes in Networks and Systems	60	27	Q4

According to the data listed in Table 4, "Journal of Physics Conference Series" is recognized as the main journal in the publication of project-based learning in chemistry experiments, judging from the number of articles, which is 243 articles. On the other hand, the "ACM International Conference Proceeding Series" is also listed as the main journal in the publication of project-based learning in chemistry experiments, judging from the h-index and the number of articles (being the second most after the Journal of Physics Conference Series). high h-index indicates that in terms of quality, these journals have an advantage over other journals. There are four journals belonging to Conference Proceedings, 1 journal belongs to Quartile 1 (Q1), 2 journals belong to Quartile 2 (Q2), and three journals are in Quartile 4 (Q4).

Distribution Map of Project-Based Learning Research in Chemical Experiments Based on Co-occurrence Analysis

Computational mapping was performed on the article data. VOSviewer was used in computational mapping. Analyzing the keywords used by authors is a key element in exploring existing or emerging relationships among topics in a research field, with a focus on publication content (Donthu et al., 2021). This section will evaluate the research process associated with publications on project-based learning in chemistry experiments. We will analyze the authors' use of keywords, the evolution of themes, and emerging topic trends.

From the results of the computational mapping conducted, 560 items were found. Each item was found to be related to project-based learning in chemistry experiments in data mapping and divided into 20 groups, including: (1). Cluster 1 consists of 54 items characterized by the main keyword "project based learning" with 292 links, total link strength 771, and occurences 481; (2) Cluster 2 consists of 47 items and characterized by the main keyword "curriculum" with 73 links, total link strength 121, and occurences 46; (3) Cluster 3 consists of 45 items and characterized by the main keyword "cooperative learning" with 57 links, total link strength 85, and occurences 35; (4) Cluster 4 consists of 44 items and is characterized by the main keyword "project management" with link 66, total link strength 142, and occurences 60; (5) Cluster 5 consists of 39 items and is characterized by the main keyword "active learning" with link 171, total link strength 500, and occurences 231; (6) Cluster 6 consists of 38 items and is characterized by the main keyword "motivation" with link 92, total link strength 177, and occurences 67; (7) Cluster 7 consists of 37 items and is characterized by the main keyword "problem-based learning" with 132 links, total link strength 309, and occurences 135; (8) Cluster 8

consists of 36 items and is characterized by the main keyword "project-based learning (pbl)" with 40 links, total link strength 53, and occurences 34; (9) Cluster 9 consists of 35 items and is characterized by the main keyword "project-based learning" with 487 links, total link strength 3539, and occurences 2135; (10) Cluster 10 consists of 29 items and is characterized by the main keyword "collaboration" with 66 links, total link strength 121, and occurences 44; (11) Cluster 11 consists of 28 items and is characterized by the main keyword "pbl" with link 185, total link strength 385, and occurences 186; (12) Cluster 12 consists of 26 items and is characterized by the main keyword "assessment" with link 97, total link strength 197, and occurences 70; (13) Cluster 13 consists of 22 items and is characterized by the main keyword "sustainability" with link 91, total link strength 162, and occurences 62; (14) Cluster 14 consists of 21 items and is characterized by the main keyword "primary education" with link 23, total link strength 45, and occurences 22; (15) Cluster 15 consists of 20 items and is characterized by the main keyword "project-based learning (pbl)" with link 116, total link strength 184, and occurences 119; (16) Cluster 16 consists of 15 items and is characterized by the main keyword "course design" with link 27, total link strength 44, and occurences 24; (17) Cluster 17 consists of 10 items and is characterized by the main keyword "creativity" with link 88, total link strength 210, and occurences 72; (18) Cluster 18 consists of 7 items and is characterized by the main keyword "prpblem-solving skills" with link 18, total link strength 26, and occurences 13; (19) Cluster 19 consists of 4 items and is characterized by the main keyword "pjbl" with link 33, total link strength 49, and occurences 23; (20) Cluster 20 consists of 3 items and is characterized by the main keyword "engineering education" with link 188, total link strength 654, and occurences 296.

Evaluating author keywords means examining how a particular term appears in various research documents, intending to understand the relationships between these terms and provide an overview of the knowledge structure and developmental trends in a specific academic discipline or field (Tao et al., 2024). The relationships between different terms are visually displayed in individual clusters. Each term is labeled using colored circles, where the size of the circle reflects how often the term appears. Larger circles indicate a higher frequency of occurrence. The mapping visualization in this study includes three key components: network visualization (see Figure 5), overlay visualization (see Figure 6), and density visualization (see Figure 7).

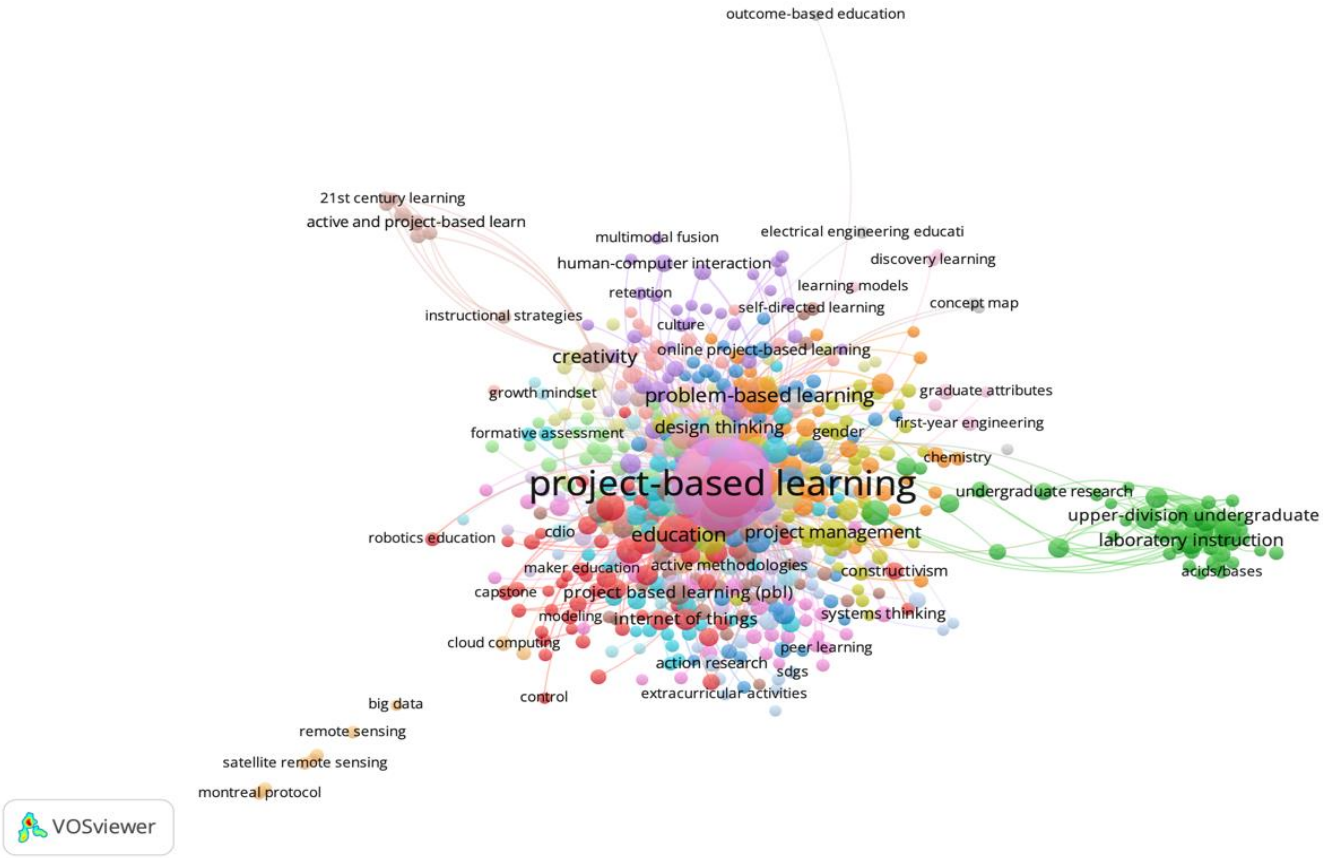

Figure 5. Network visualization of project-based learning in chemistry experiment keyword

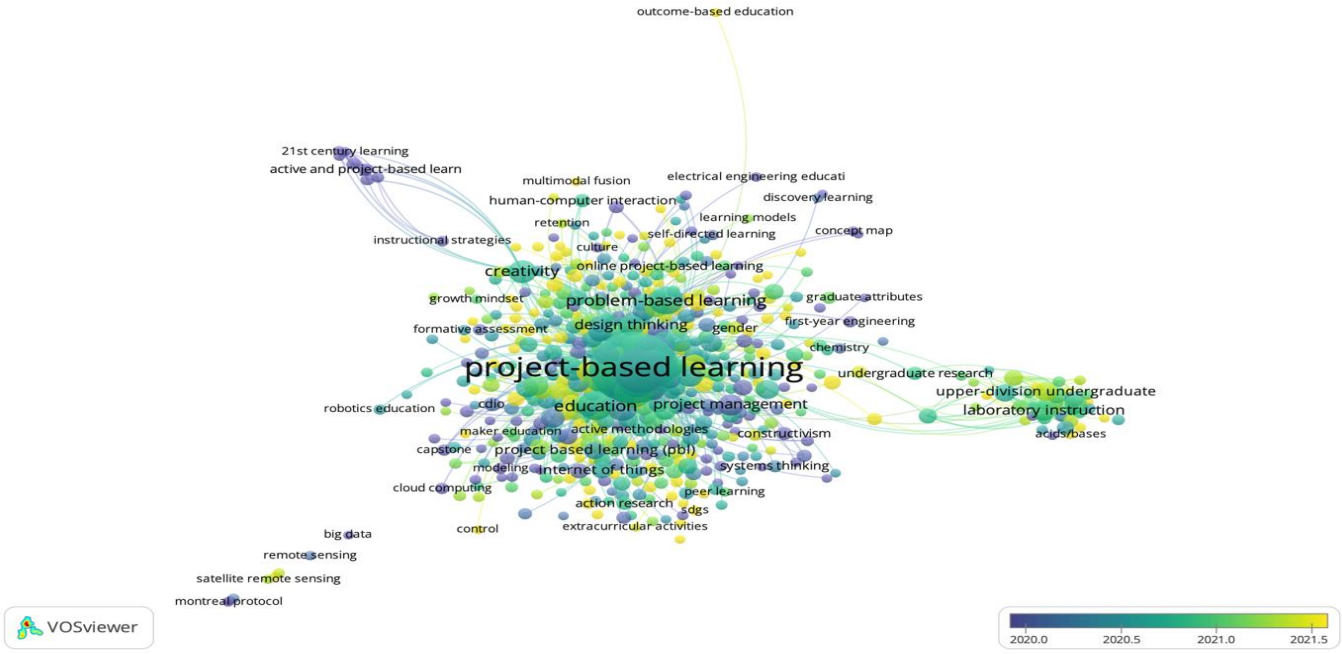

Figure 6. Overlay visualization of project-based learning in chemistry experiment keyword

Figure 5 illustrates the interconnection among terms in the network. These clusters represent commonly explored terms concerning the research topic of project-based learning in chemistry experiments. The network visualization exhibits clear clusters, delineating project-based learning and chemistry laboratory investigations as distinct domains. Specifically, "project-based learning" is situated within cluster 9, featuring 487 connections, a cumulative link strength of 3539, and 2135 instances (refer to Figure 8).

Similarly, the "chemistry experiment" resides in cluster 8, with 10 connections, a total link strength of 10, and 6 instances (refer to Figure 9). It's noteworthy that the term "project-based learning" extends beyond solely chemistry practicum; Figure 6 presents an overlay visualization of project-based learning research in chemistry experiments, indicating the innovation in related terms.

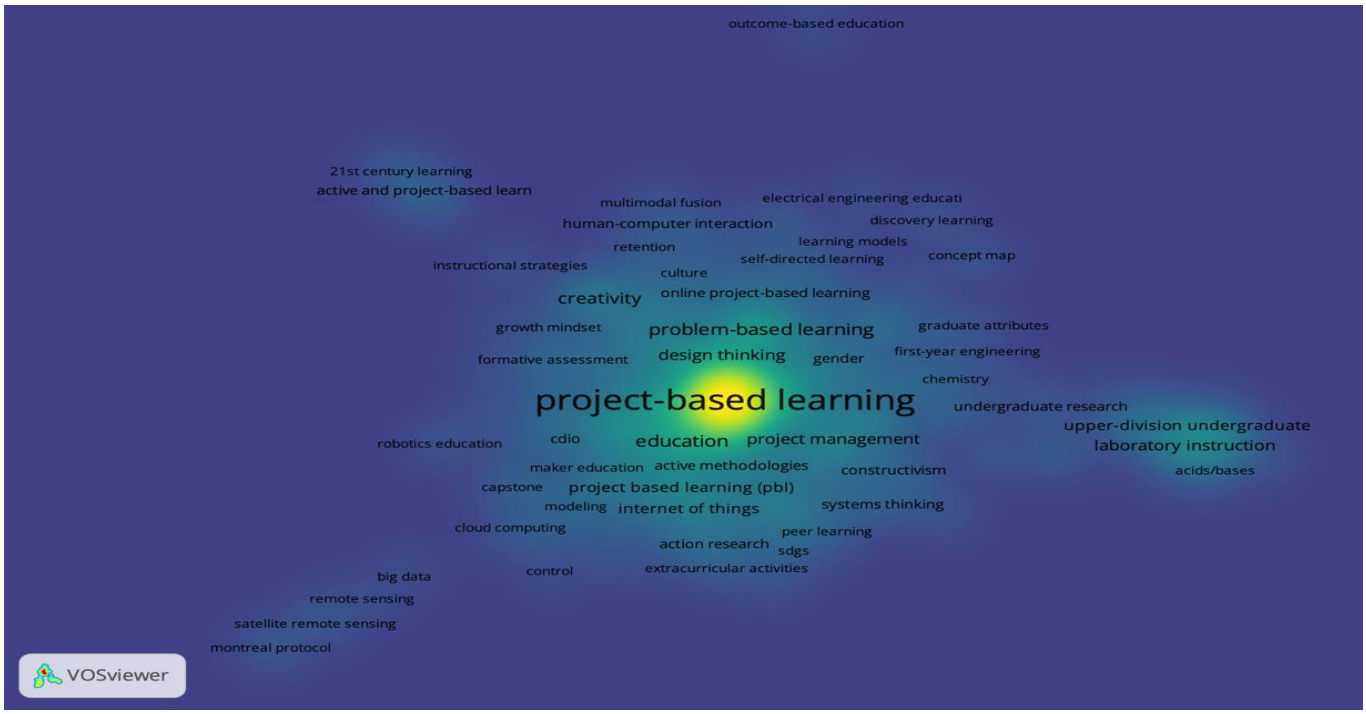

Figure 7. Density visualization of project-based learning in chemistry experiment keyword

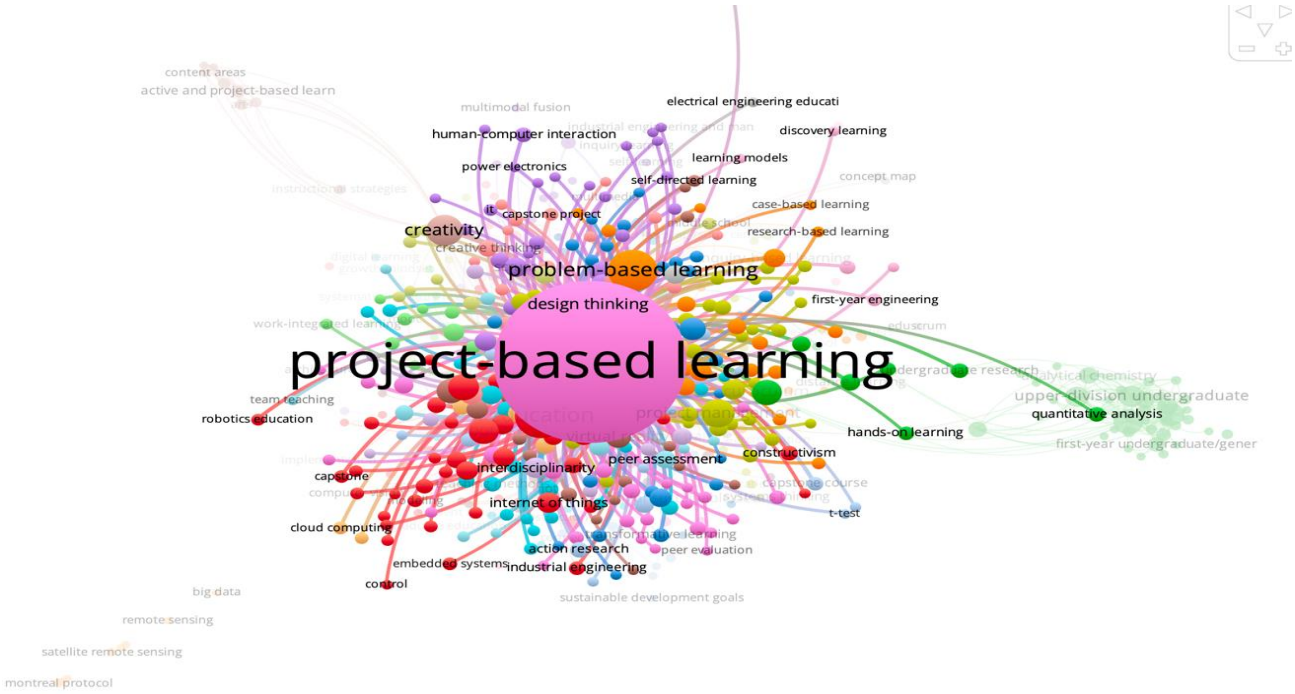

Figure 8. Networking of project-based learning

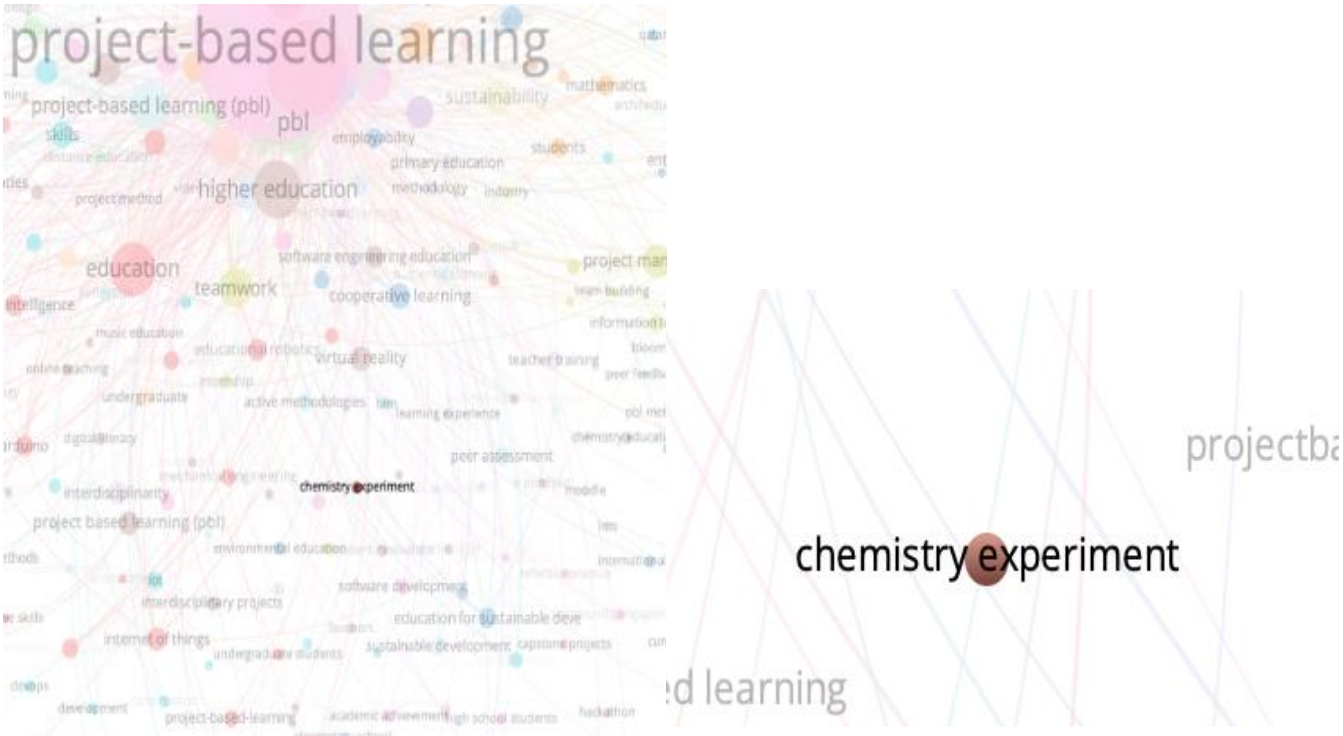

Figure 9. The "chemistry experiment" resides in cluster 8, with 10 connections, a total link strength of 10, and 6 instances

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presents an overlay visualization of project-based learning research in chemistry experiments, indicating the innovation in related terms. Additionally, Figure 7 showcases a density visualization, where brighter yellow hues and larger label diameters signify higher term frequency, reflecting extensive research in related areas. Conversely, fading colours indicate limited research on certain terms. Based on Diagram 5, it can be seen that research related to the concept of project-based learning shows labels with a very large diameter and a bright yellow colour, indicating the high intensity of research on project-based learning. Meanwhile, in the research on chemistry practicum, the diameter of the label circle is very small, and the colour is almost the same as the background (there are so few related studies, that the writing is not visible on the surface), indicating that there is little research on chemistry practicum. Meanwhile, the term project-based learning in chemistry experiments has not appeared, indicating that research on project-based learning in chemistry experiments is still rare. The popularity of project-based learning research in chemistry experiments is very high these days. Therefore, it shows that there is a great opportunity to conduct further research on project-based learning in chemistry experiments by researching related keyword trends.

Conclusion

From 2018 to 2023, there was an increase in the number of articles on project-based learning in chemistry experiments published in international journals each year. In addition, the total and average number of citations of these articles also increased significantly each year. Boone, C.D. is the author with the highest number of citations on the research topic of project-based learning in chemistry experiments. The most cited article is "How to Learn and How to Teach Computational Thinking: Suggestions based on a Review of the Literature" with 383 citations. Based on the collaboration map between countries, the United States is the most productive country in researching this topic, with 1351 articles. The most influential journal with the highest number of articles is the Journal of Physics Conference Series, with 243 articles. The primary literature in this study tends to fall into more general groups such as Project-based Learning, Education, and STEM Education. The findings identified 560 subtopics with at least five linkages that are trending and can provide an overview of topics for empirical researchers, including Project-based Learning, Education, STEM, Curriculum, Project Management, Chemistry Experiments, and Laboratory Instruction. This study suggests the need for multidisciplinary and interdisciplinary studies on project-based learning research in chemistry learning and advocates for the inclusion of project-based learning research in education from a wider geographical context. The main conclusions of the study may be presented in a short Conclusions section, which may stand alone or form a subsection of a Discussion or Results and Discussion section

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Author Contributions
Writing original draft preparation, I.H.; result, I.H.; discussion, I.H.; methodology, S.A. and I.M.; analysis, I.H.; supervision, S.A. and I.M.; conclusion, I.H., S.A., and I.M.; review, S.A. and I.M.

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Conflicts of Interest
The authors declare that there is no conflict of interest regarding the publication of this paper.

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