



# Mapping Global Research Trends on Ethnoscience-Based Chemistry Learning Integrated with Project-Based Learning and Flipped Classroom to Support Sustainable Development Goals: A Bibliometric Review

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**Abstract:** This study maps global research trends on ethnoscience-based chemistry learning integrated with Project-Based Learning (PjBL) and the Flipped Classroom (FC) using a bibliometric approach. A total of 118 journal articles published between 2016 and 2025 were analyzed with VOSviewer to examine publication trends, keyword co-occurrence, and thematic clusters. Results show a significant increase in publications after 2020, highlighting five main clusters: (1) ethnoscience and local wisdom, (2) PjBL and active pedagogy, (3) FC and digital learning, (4) scientific literacy and 21st-century skills, and (5) bibliometric analysis and research trends. Overlay and density visualizations indicate a recent focus on PjBL-FC integration to enhance scientific literacy, while ethnoscience provides a contextual foundation. This study identifies gaps in fully integrated empirical research and offers directions for future studies and practical implications for curriculum design, teacher training, and sustainable learning. These findings provide actionable insights for educators and policymakers aiming to enhance culturally responsive, technology-supported chemistry education that promotes sustainable development aligned with the United Nations Sustainable Development Goals.

**Keywords:** Bibliometric analysis; Chemistry education; Ethnoscience; Flipped classroom; Project-based learning; Sustainable education

## Introduction

Scientific literacy is a fundamental competence in chemistry education for addressing 21st-century challenges that require critical thinking, problem-solving, and evidence-based decision-making. Chemical scientific literacy extends beyond conceptual understanding to include the ability to interpret chemical phenomena in real-life, environmental, and socio-cultural contexts, enabling learners to make informed decisions related to sustainability and societal well-being (OECD, 2019). International assessments such as the Programme for International Student Assessment consistently report that students' scientific

literacy, particularly in developing countries, remains at a moderate to low level, indicating the need for innovative and contextualized instructional approaches (OECD, 2023).

Ethnoscience integrated learning tools, such as those developed by Putri et al. (2023), have shown promise in fostering active engagement and cultural relevance in science classrooms. Similarly, project-based learning combined with flipped classroom strategies enhances students' critical thinking, collaboration, and practical problem-solving abilities (Sari et al., 2025).

Ethnoscience has emerged as a pedagogical approach that integrates indigenous knowledge, local wisdom, and cultural practices into science learning,

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making chemistry concepts more meaningful and relevant to students' everyday experiences (Aikenhead & Michell, 2011; Rahayu et al., 2023). Previous studies have shown that ethnoscience-based learning can enhance students' conceptual understanding, scientific literacy, and environmental awareness by bridging formal scientific knowledge with local cultural contexts (Amini et al., 2021; Nugraheni et al., 2022).

Project-Based Learning (PjBL) promotes higher-order thinking skills, collaboration, and problem-solving through authentic, inquiry-oriented learning tasks (Kokotsaki et al., 2016). The Flipped Classroom (FC) supports this approach by reallocating instructional time, allowing students to engage with learning materials independently while maximizing classroom interactions for active learning and discussion (Bergmann & Sams, 2012; Lo et al., 2017).

Although ethnoscience, Project-Based Learning, and the Flipped Classroom have been widely studied as separate instructional approaches, research that explicitly integrates all three within chemistry education remains fragmented. Most existing studies emphasize single-variable implementations, such as ethnoscience-based learning without technology integration or Project-Based Learning without culturally responsive elements. This fragmentation does not necessarily indicate limited effectiveness, but rather reflects the relative novelty of combining culturally responsive pedagogy with technology-enhanced and project-oriented instructional designs in chemistry education. Consequently, the rapid growth of publications in this field has not yet been systematically analyzed to reveal dominant themes, emerging trends, and research gaps.

From a broader perspective, integrating ethnoscience with Project-Based Learning and the Flipped Classroom aligns closely with the Sustainable Development Goals, particularly SDG 4, which emphasizes inclusive and equitable quality education, and SDG 12, which promotes responsible consumption and production through scientific awareness and environmental responsibility (United Nations, 2015). Despite this strong conceptual and policy alignment, existing studies remain fragmented and predominantly focus on partial instructional implementations. To date, no comprehensive study has systematically mapped global research trends, thematic structures, and research gaps related to the integration of ethnoscience, Project-Based Learning, and the Flipped Classroom in chemistry education.

In this context, bibliometric analysis provides a systematic and objective approach to examining large volumes of scientific literature by identifying publication trends, keyword co-occurrence patterns, and thematic structures within a research field. This method has been widely applied in educational research to map

intellectual landscapes, reveal research gaps, and inform future research directions (Donthu et al., 2021; Aria & Cuccurullo, 2017).

Accordingly, this study aims to map global research trends on ethnoscience-based chemistry learning integrated with PjBL and FC through a bibliometric review. Bibliographic data were retrieved from Google Scholar using Publish or Perish software to ensure broad coverage. Specifically, this study analyzes publication growth, keyword co-occurrence, and thematic clustering to identify dominant research themes, emerging trends, and underexplored areas related to scientific literacy and sustainability-oriented chemistry education.

## Method

This study employed a bibliometric review method to map research trends on ethnoscience-based chemistry learning integrated with Project-Based Learning and the Flipped Classroom. The bibliometric approach was selected because it enables the systematic analysis of publication patterns, keyword relationships, and thematic structures based on bibliographic metadata rather than full-text content analysis. This method is appropriate for identifying research growth, dominant themes, and potential research gaps within a specific scientific field.

### *Data Collection*

The data source for this study was the Google Scholar database, accessed through the Publish or Perish application due to its capability to retrieve comprehensive bibliographic metadata and citation information. The search was conducted on 17 December 2025, with publication years limited to the 2016–2025 period. The search strategy applied combinations of the following keywords: ethnoscience, chemistry education or chemistry learning, project-based learning or PjBL, flipped classroom, and scientific literacy. The initial search retrieved a total of 199 documents that matched the defined search scope. All retrieved records were exported in RIS format and organized using reference management software to facilitate screening and data cleaning.

### *Inclusion and Exclusion Criteria*

To ensure the relevance and quality of the bibliometric dataset, inclusion and exclusion criteria were applied based on document type and research focus. The inclusion criteria comprised peer-reviewed journal articles that explicitly addressed ethnoscience, chemistry education, project-based learning, flipped classroom strategies, or scientific literacy. Documents categorized as conference proceedings, theses, dissertations, book chapters, reports, preview

documents, non-journal publications, and duplicate records were excluded. After applying these criteria through title and abstract screening, 118 journal articles were retained and included in the bibliometric analysis. The document selection procedure is summarized in Figure 1.

*Data Analysis*

Bibliometric analysis was conducted using VOSviewer version 1.6.20 to visualize and interpret relationships among research keywords and thematic structures. Bibliographic metadata from the selected articles were analyzed through keyword co-occurrence mapping to identify dominant research themes and conceptual linkages. Three types of visualization were generated, including network visualization to examine the strength of keyword relationships and cluster structures, overlay visualization to analyze temporal trends in research development, and density visualization to identify well-established and emerging

research areas. Descriptive citation metrics were obtained using Publish or Perish to support publication trend analysis without influencing article inclusion.

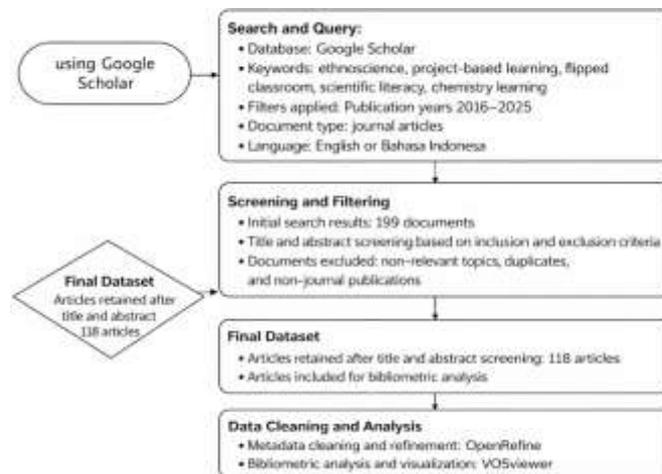


Figure 1. Research procedure of bibliometric analysis

Table 1. Citation Metrics

Criteria	Results
Object	Conducting a systematic literature review on Project-based Ethnoscience Integrated with Flipped Classroom to Improve Learners' Science Literacy
Data source	Google scholar
Keywords.	ethnoscience, project-based learning, flipped classroom, scientific literacy, chemistry learning
Year of publication	2016-2025
Quote year	9 (2016-2025)
Last time to search the database	December 17, 2025
Selected documents	199.00
Document filtered	118.00
Excerpt	1235.00
Citation/year	137.22
Citation/paper	10.47
Author/paper	2.79
H-Index	17.00
g-index	33.00
hI,nom	10
hI-annual	1.11
I-hA-index	11
Paper with ACC	>=1,2,5,10,20:77,52,32,14,7
Documents analyzed	The database information obtained was then analyzed with the help of Microsoft Excel, VOSviewer and Harzing's Publish or Perish.

This article search uses the Google Scholar database by utilizing the Publish or Perish application. The following is a display of article data obtained from the Publish or Perish application.

In conducting the literature search, publication years were limited to 2016–2025, resulting in a total of 199 journal articles retrieved from the Google Scholar database using the Publish or Perish application after document type filtering. All retrieved articles were considered relevant to the research scope and were therefore included in the bibliometric dataset. Of these, 118 articles met the minimum citation threshold and

were subsequently analyzed using VOSviewer for keyword co-occurrence and research trend mapping.

The selected bibliographic data were saved in RIS format and imported into VOSviewer software (version 1.6.20) for bibliometric analysis. VOSviewer was used to visualize and analyze keyword co-occurrence through three types of visualization: network, overlay, and density. Network visualization illustrates the relationships and strength of co-occurrence among research keywords, overlay visualization depicts the temporal development of research themes based on publication years, and density visualization indicates

the concentration and prominence of specific research topics (Eck & Waltman, 2010; Zakiyyah et al., 2022).

In this study, VOSviewer analysis focused on mapping research trends related to ethnoscience in chemistry learning integrated with Project-Based Learning and the Flipped Classroom, particularly in

relation to scientific literacy. The visualization results were used to interpret dominant themes, emerging topics, and research patterns within the selected publication dataset indexed by Google Scholar (Triwahyuningtyas et al., 2021; Huda et al., 2023).

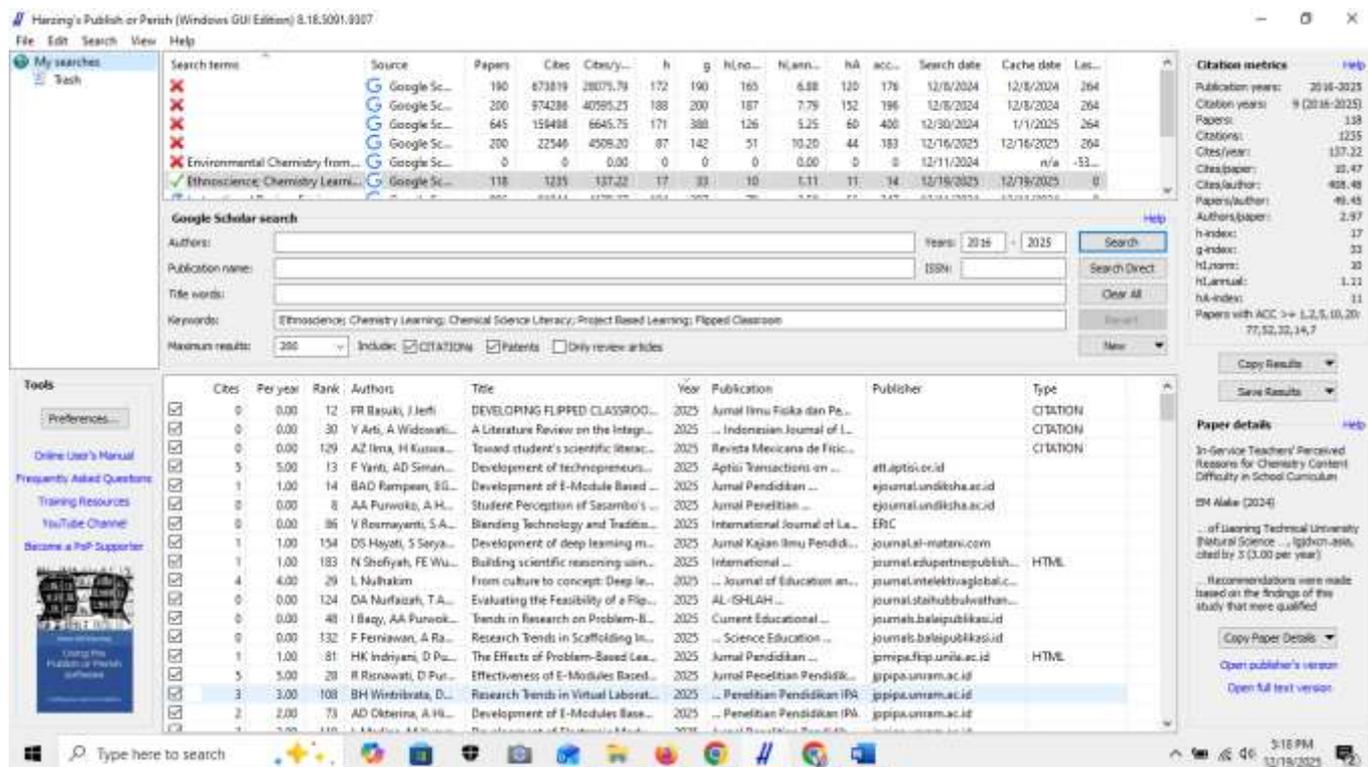


Figure 2. Search method through publish or perish

## Result and Discussion

Bibliometric analysis has been widely recognized as a robust approach for identifying research trends, mapping intellectual structures, and revealing thematic developments within a scientific field. Previous bibliometric studies have demonstrated the effectiveness of VOSviewer in visualizing keyword networks, thematic clusters, and citation relationships to support systematic interpretation of research landscapes (Donthu et al., 2021; Aria & Cucurullo, 2017). In science education research, bibliometric approaches have been increasingly used to explore the integration of pedagogy, culture, and technology to support meaningful and contextual learning. Moreover, bibliometric mapping not only identifies thematic structures but also informs strategic research planning and highlights areas of innovation that are emerging in the global scientific community.

Building on these methodological advances, the present study investigates global research trends related to the integration of ethnoscience-based chemistry learning with Project-Based Learning (PjBL) and the

Flipped Classroom (FC) model to support scientific literacy. A systematic bibliometric procedure was applied using VOSviewer to analyze keyword co-occurrence, citation performance, and thematic clustering. The results provide insights into publication growth, dominant research themes, and emerging directions, offering an empirical foundation for future pedagogical and empirical studies in chemistry education. This integrative approach is particularly relevant in the context of 21st-century learning, where cultural relevance, active learning, and digital fluency converge to enhance student outcomes.

### Publication Trends

Analysis of the 118 selected articles indicates a noticeable increase in publication output after 2020, with the highest number of publications recorded in 2023. Recent bibliometric analyses reveal a global trend in integrating ethnoscience with Project-Based Learning and computational thinking to support the achievement of the Sustainable Development Goals, particularly SDG-6 (Damayanti et al., 2024; Samodra et al., 2025),

reflecting growing scholarly attention to context-based and sustainability-oriented chemistry education.

The increasing prominence of ethnoscience-based learning within this dataset highlights a sustained effort to contextualize chemistry concepts through local wisdom and indigenous knowledge. Prior empirical studies have shown that ethnoscience integration enhances conceptual understanding, learning relevance, and student engagement by bridging scientific concepts with students' cultural backgrounds (Sudarmin & Asyhar, 2012; Handayani et al., 2018; Widodo et al., 2021). This trend confirms that ethnoscience has evolved from a complementary approach into a central pedagogical strategy within contemporary chemistry education research. Additionally, the international attention to ethnoscience-based learning indicates its potential applicability in multicultural classrooms globally.

#### *Keyword Co-occurrence Analysis*

Keyword co-occurrence analysis using VOSviewer identified five major clusters, representing the conceptual structure of research on ethnoscience-based chemistry learning integrated with Project-Based Learning and the Flipped Classroom (Van Eck & Waltman, 2010). To maintain analytical consistency, the clusters are described below using a unified thematic framework aligned with the network visualization.

#### *Cluster 1 – Ethnoscience and Local Wisdom*

This cluster centers on keywords such as ethnoscience, local wisdom, local culture, and context-based learning. The dominance of these terms indicates that cultural knowledge and indigenous practices form the foundational context for chemistry learning innovation. Studies within this cluster emphasize the role of ethnoscience in enhancing conceptual relevance and fostering meaningful learning by connecting abstract chemical concepts with students' lived experiences (Sudarmin & Asyhar, 2012; Widodo et al., 2021). Additionally, ethnoscience-based approaches contribute to environmental awareness and sustainability literacy by integrating traditional ecological knowledge with contemporary scientific principles.

#### *Cluster 2 – Project-Based Learning and Active Pedagogy*

Cluster 2 highlights keywords related to project-based learning, problem solving, student engagement, and learning activities. Empirical evidence from Dewi et al. (2025) showed that project-based chemistry labs with natural materials significantly enhance critical thinking and scientific literacy, reinforcing the pedagogical value of culturally contextualized projects (Kokotsaki et al., 2016; Parmin et al., 2019). Furthermore, PjBL enhances

metacognitive skills, enabling students to plan, monitor, and evaluate their own learning processes in culturally responsive contexts.

#### *Cluster 3 – Flipped Classroom and Digital Learning*

Keywords such as flipped classroom, blended learning, online learning, and digital tools dominate Cluster 3. This cluster represents the technological dimension of contemporary chemistry education, highlighting the role of digital platforms in facilitating pre-class content delivery and in-class active learning. The integration of flipped classroom strategies with PjBL allows instructional time to be optimized for discussion, experimentation, and project development (Akçayır & Akçayır, 2018; Strelan et al., 2020). The use of digital tools supports differentiated instruction, personalized learning, and flexibility, particularly relevant in post-pandemic learning environments.

#### *Cluster 4 – Scientific Literacy and 21st-Century Skills*

Cluster 4 focuses on learning outcomes, including scientific literacy, critical thinking, creative thinking, and competence. The close linkage between this cluster and PjBL-FC approaches indicates that the primary objective of integrating ethnoscience with innovative pedagogies is the development of higher-order thinking skills and transferable competencies required in 21st-century education (OECD, 2019; Lestari & Rahmawati, 2020).

#### *Cluster 5 – Bibliometric Analysis and Research Trends*

The final cluster includes keywords such as bibliometric analysis, research trend, and literature review. This cluster reflects the growing scholarly interest in evaluating the development and maturity of ethnoscience and chemistry education research. The presence of this cluster indicates that the field has reached a stage where systematic mapping and critical synthesis are necessary to identify research gaps and future directions (Donthu et al., 2021; Zakiyyah et al., 2022). Bibliometric approaches enable meta-analytical insights into methodological rigor, publication patterns, and interdisciplinary linkages.

#### *Interpretation of Network, Overlay, and Density Visualizations*

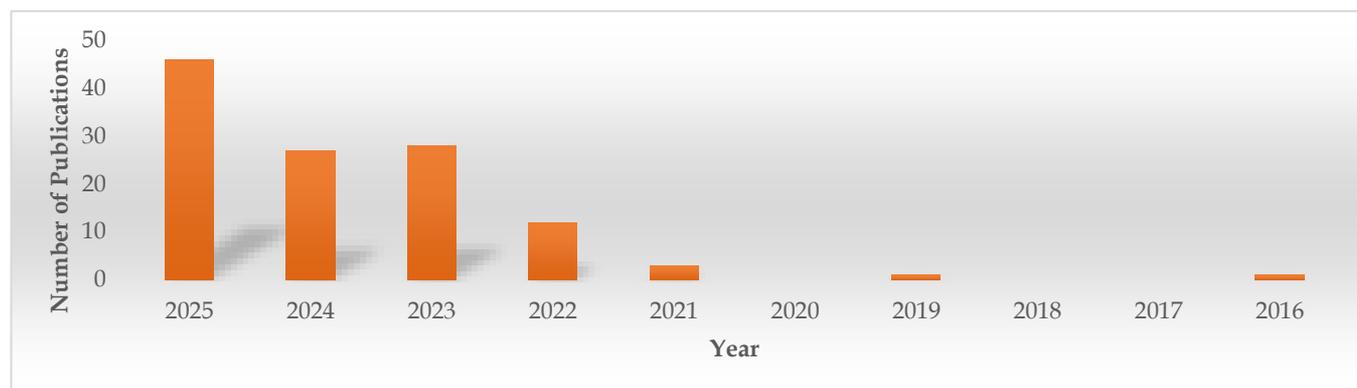
Overlay visualization indicates that earlier studies emphasized ethnoscience and contextual learning, whereas more recent research increasingly focuses on PjBL, FC strategies, scientific literacy, and digital learning resources. Density visualization shows that FC, PjBL, and scientific literacy constitute high-density areas, forming the core of current research, while ethnoscience acts as a contextual foundation linking pedagogy and learning outcomes. Low-density regions

highlight underexplored areas for empirical studies integrating ethnoscience, PjBL, and FC.

**Table 2.** Citation Metrics Summary

Metric	Value
Total Articles Analyzed	118
Total Citations	1235
Average Citations per Year	137.22
Average Citations per Article	49.45
h-index	17
g-index	33

The dataset generated 1,235 citations, with an average of 137.22 citations per year and 49.45 citations per article, indicating a solid scholarly interest. The h-index of 17 suggests that at least 17 articles have received 17 or more citations, and the g-index of 33 confirms the influence of highly cited studies. This trend highlights growing recognition of ethnoscience integration in chemistry education and its alignment with culturally responsive pedagogy, digital literacy, and 21st-century skill development.



**Figure 3.** Annual distribution of publications (2016-2025)

*Highly Cited Articles and Key Contributions*

Table 3 summarizes the most cited articles published between 2016 and 2025, which have significantly influenced the development of ethnoscience-based learning research. These highly cited studies address diverse themes, including local wisdom integration, active learning models, digital learning environments, and bibliometric analysis.

The most cited study by Ramdani et al. (2021) demonstrates that integrating the 5E learning cycle with local wisdom significantly improves students' critical thinking skills, emphasizing the pedagogical value of culturally contextualized instruction. Similarly,

Suprpto et al. (2021) mapped ethnoscience research trends using bibliometric analysis and highlighted Indonesia's substantial contribution to this field.

Other influential studies, such as Puspita et al. (2023) and Jannah et al. (2022), reinforce the importance of student-centered and problem-based learning approaches in developing scientific literacy. More recent publications (2024-2025) reflect emerging research directions emphasizing sustainability, interdisciplinary approaches, and advanced analytical methods, indicating a shift toward more integrative and technology-supported educational research.

**Table 3.** Most cited articles (2016-2025)

Author(s)	Title	Year	Citations
Ramdani et al.	Analysis of students' critical thinking skills in terms of gender using science teaching materials based on the 5e learning cycle integrated with local wisdom	2021	84
Suprpto et al	Research trend on ethnoscience through bibliometric analysis (2011-2020) and the contribution of indonesia	2021	59
Puspita et al.	Problem-based science learning in elementary schools: a bibliometric analysis	2023	26
Jannah et al.	Ethnoscience in learning science: a systematic literature review	2022	23
Prayogi et al.	Physics learning technology for sustainable development goals (sdgs): literature study	2024	23
Yang et al.	Spatial visualization ability assessment for analyzing differences and exploring influencing factors: literature Review with bibliometrics and experiment	2024	20
Chamdani et al.	The project based learning integrated ethnoscience: a model of learning to enhance scientific literacy among pre-service elementary teacher	2025	5

*Keyword Analysis and Research Clusters*

Keyword mapping using VOSviewer identified five major research clusters that represent the conceptual

structure of ethnoscience-based chemistry learning integrated with Project-Based Learning (PjBL) and the Flipped Classroom. Figure 3 presents the network

visualization of frequently co-occurring keywords, illustrating the strength of relationships among research themes (Eck & Waltman, 2010).

Cluster 1 (Red): Ethnoscience and Local Wisdom focuses on keywords such as ethnoscience, local culture, and context-based learning. This cluster highlights the central role of cultural knowledge and indigenous practices in contextualizing chemistry concepts, supporting findings that ethnoscience-based instruction enhances relevance and conceptual understanding (Sudarmin & Asyhar, 2012; Widodo et al., 2021).

Cluster 2 (Green): Project-Based Learning (PjBL) emphasizes active learning, problem-solving, and creativity. The strong linkage between this cluster and scientific literacy indicates that PjBL serves as a pedagogical bridge between cultural context and higher-order thinking skills, consistent with prior studies demonstrating PjBL's effectiveness in fostering inquiry, collaboration, and real-world problem solving (Kokotsaki et al., 2016; Parmin et al., 2019).

Cluster 3 (Blue): Flipped Classroom highlights terms such as blended learning, digital tools, and online instruction. This cluster reflects the growing integration of technology in chemistry education, particularly in

supporting student-centered and flexible learning environments. Previous research confirms that flipped classroom models enhance learning engagement and cognitive outcomes when combined with project-based approaches (Akçayır & Akçayır, 2018; Strelan et al., 2020).

Cluster 4 (Yellow): Scientific Literacy and Competence includes keywords such as critical thinking, competence, and attitudes. This cluster represents the primary learning outcomes targeted by the integration of ethnoscience, PjBL, and flipped classroom strategies, emphasizing the development of scientific reasoning and transferable skills required in 21st-century education (OECD, 2019; Lestari & Rahmawati, 2020).

Cluster 5 (Purple): Research Trends and Analysis Focuses on bibliometric mapping, citation metrics, and systematic reviews, indicating increasing scholarly interest in evaluating research development and identifying gaps within ethnoscience and chemistry education research. The presence of this cluster confirms the maturity and growing complexity of the research field (Donthu et al., 2021; Zakiyyah et al., 2022).

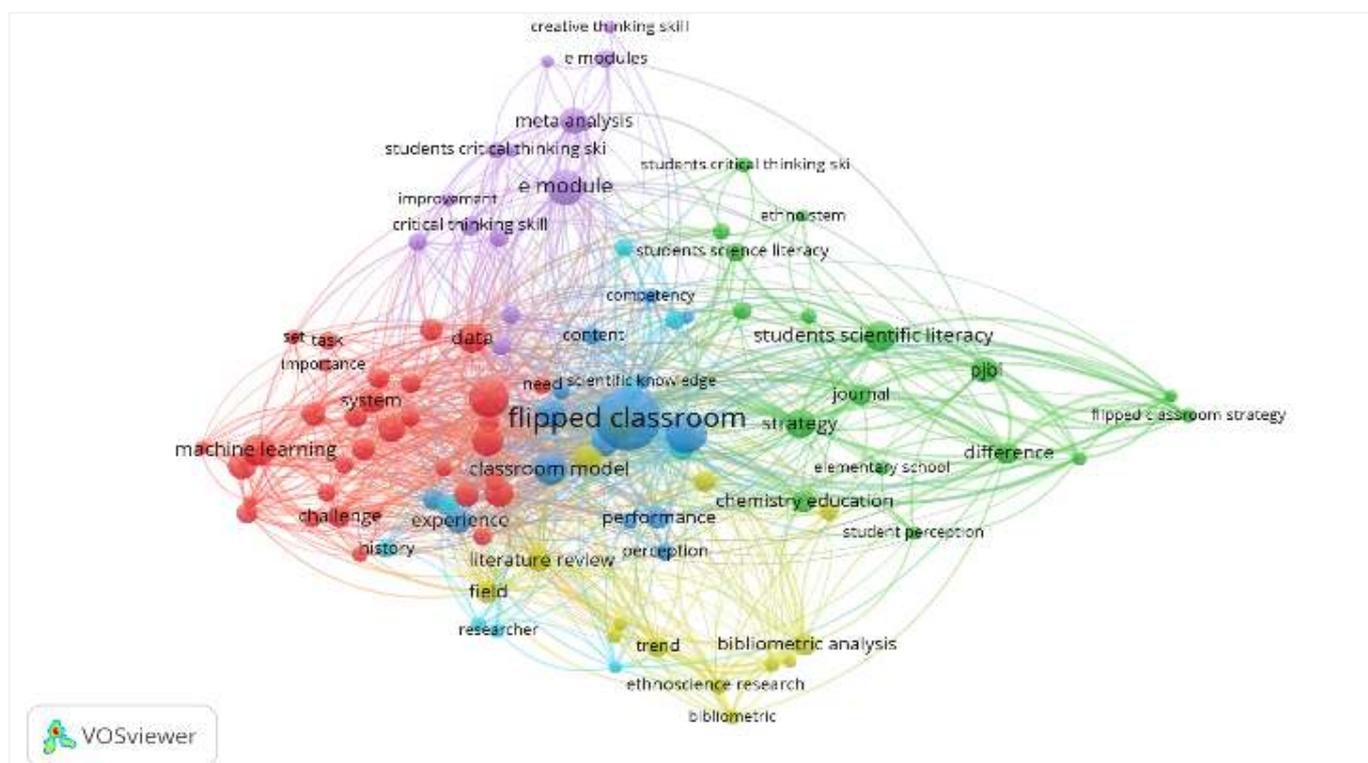


Figure 4. Network visualization of keywords

*Overlay and Density Visualizations*

Overlay visualization (Figure 5) reveals a temporal shift from earlier studies emphasizing ethnoscience and contextual learning toward more recent research focusing on PjBL, flipped classroom strategies, scientific literacy, and digital learning resources. This trend

reflects broader transformations in education toward culturally responsive and technology-integrated pedagogy (OECD, 2023).

Density visualization (Figure 6) further confirms that flipped classroom, scientific literacy, project-based

learning, and chemistry education represent the most dominant and interconnected research themes. The high-density areas indicate that these topics form the

core of current research, while ethnoscience acts as a contextual foundation linking pedagogy and learning outcomes.

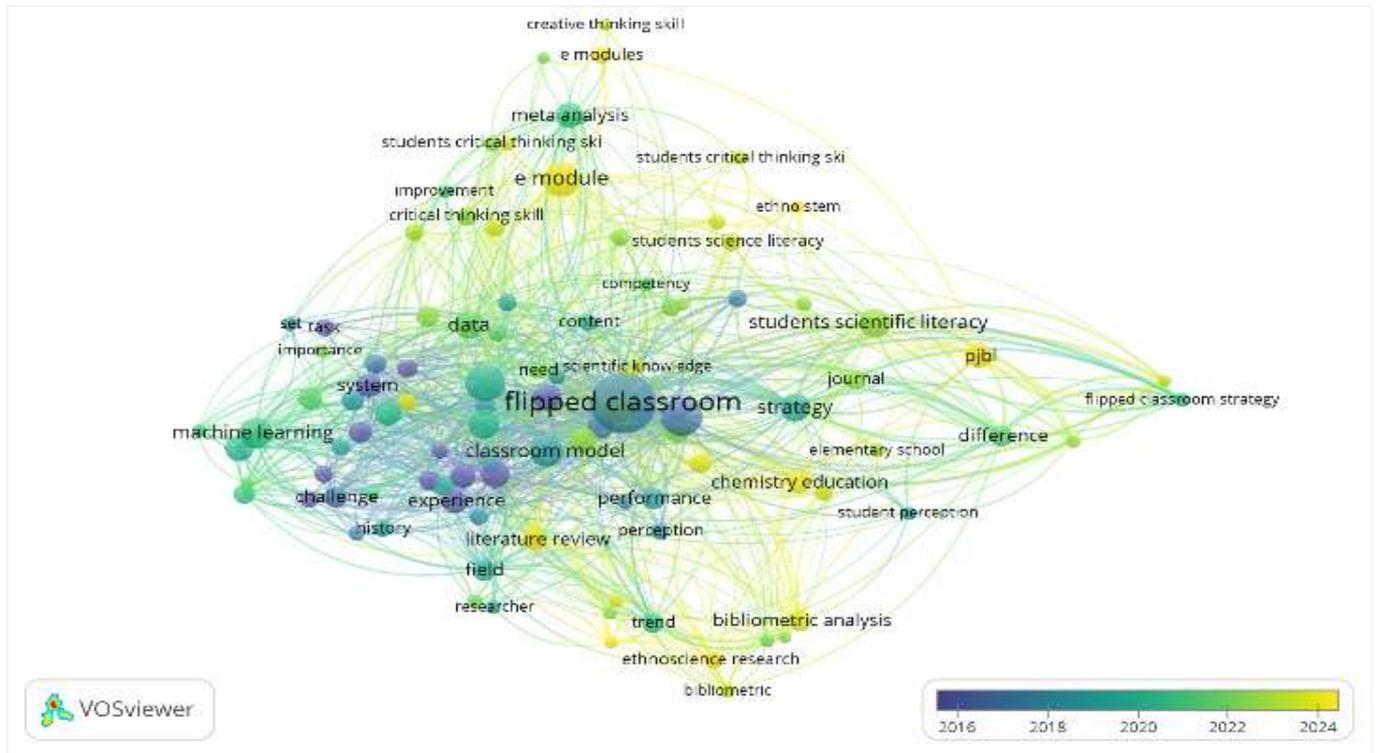


Figure 5. Overlay visualization of research trends

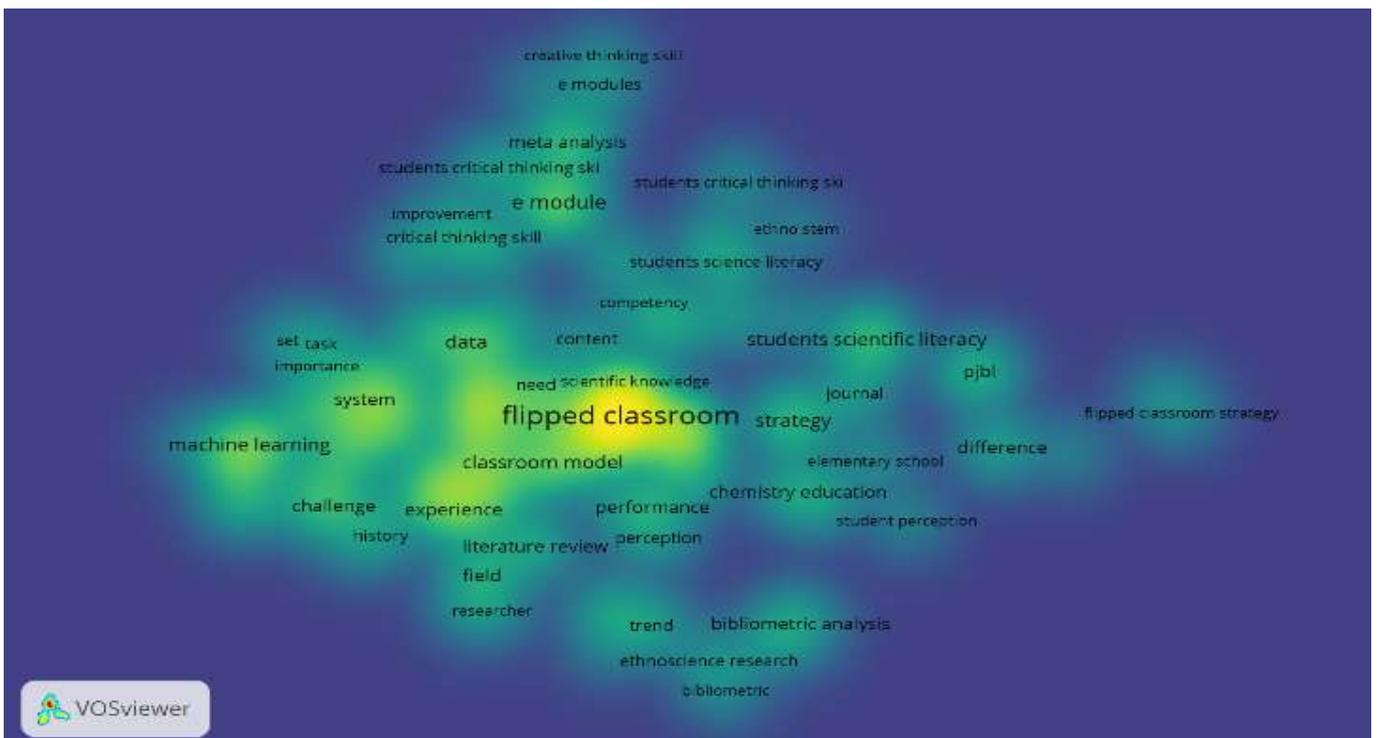


Figure 6. Density visualization of keywords

*Empirical Evidence Supporting Ethnoscience-Based PjBL*

Recent studies indicate that project-based chemistry laboratories using natural materials can

significantly enhance students’ scientific literacy and critical thinking skills (Dewi et al., 2025). The integration of ethnoscience into PjBL learning modules also

supports collaboration, creativity, and critical reasoning abilities (Rosita et al., 2024; Imron et al., 2025).

*Research Gaps and Implications*

Despite the growing number of publications, empirical studies that simultaneously integrate

ethnoscience, PjBL, and the Flipped Classroom remain limited. Most studies focus on partial integration or conceptual discussions. This gap highlights the need for empirical, experimental, and longitudinal investigations examining the effectiveness, scalability, and learning outcomes of fully integrated instructional models.

**Table 4.** Challenges and Recommendations in Implementing Ethnoscience-Based PjBL-Flipped Classroom

Challenge	Recommendation
Limited access to digital technology	Strengthen digital infrastructure and provide equitable access, especially in rural or under-resourced settings.
Limited teacher competence in PjBL-FC	Develop continuous professional development on instructional design, digital pedagogy, and ethnoscience integration.
Time constraints in PjBL-FC activities	Design flexible lesson plans supported by blended learning and modular digital resources.
Limited empirical evidence on scalability	Conduct large-scale and longitudinal studies to evaluate effectiveness across contexts.

The challenges identified in Table 3 are consistent with the bibliometric findings, which indicate that most existing studies focus on partial or small-scale implementations of ethnoscience-based learning. Issues related to technological access, teacher readiness, and instructional time frequently emerge in studies integrating PjBL and flipped classroom approaches. Addressing these challenges is essential to support scalable and sustainable implementation of culturally responsive chemistry education.

*Future Research Directions*

- a) **Integrated Experimental Studies:** Conduct controlled studies examining learning outcomes of ethnoscience-PjBL-FC models in chemistry education.
- b) **Longitudinal Studies:** Evaluate sustainability of learning gains, cultural value internalization, and 21st-century skill development over time.
- c) **Technology-Enhanced Pedagogy:** Investigate the role of emerging digital tools, virtual labs, and gamification in ethnoscience-based instruction.
- d) **Cross-Cultural Comparative Research:** Explore applicability and adaptation of ethnoscience-based PjBL-FC models in diverse cultural and geographical contexts.
- e) **Policy-Oriented Research:** Analyze how national curricula and teacher professional standards influence implementation and outcomes of integrated pedagogy.

*Practical Implications*

- a) **Curriculum Design:** Incorporate local wisdom and culturally responsive content into chemistry curricula aligned with PjBL and FC models.
- b) **Teacher Training:** Focus professional development on integrating cultural knowledge with active and digital pedagogies.

- c) **Learning Environment:** Provide equitable access to digital resources, collaborative spaces, and flexible scheduling to optimize project-based and flipped classroom activities.
- d) **Assessment:** Design assessment strategies that measure both scientific literacy and application of local knowledge, fostering holistic learning outcomes.
- e) **Community Engagement:** Collaborate with local communities to ensure authenticity and sustainability of ethnoscience-based learning projects.

**Conclusion**

This bibliometric review reveals a growing global research interest in ethnoscience-based chemistry learning, particularly after 2020, reflecting increasing attention to contextual, student-centered, and sustainability-oriented pedagogy. The keyword co-occurrence analysis identifies five major thematic clusters, namely ethnoscience and local wisdom, project-based learning, flipped classroom, scientific literacy, and bibliometric research trends, indicating a strong conceptual linkage between cultural context, active learning strategies, and learning outcomes. Overlay and density visualizations further demonstrate a recent shift toward integrating Project-Based Learning and Flipped Classroom approaches to support scientific literacy and 21st-century skills, while ethnoscience functions as a contextual foundation rather than a dominant research focus. Despite this positive trend, the findings highlight a significant research gap in empirical studies that comprehensively integrate ethnoscience, PjBL, and flipped classroom models within chemistry education. Therefore, future research is strongly encouraged to move beyond conceptual and partial integration studies toward empirical and longitudinal investigations that

examine the effectiveness of fully integrated instructional models in enhancing scientific literacy and supporting Sustainable Development Goals. This study provides a conceptual map and research agenda for scholars and educators seeking to design culturally responsive and innovative chemistry learning frameworks.

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#### Author Contributions

Minarni, Rayandra Asyhar, Haryanto, and Bambang Hariyadi contributed to the conception and design of the study. Minarni prepared the original draft. Rayandra Asyhar and Haryanto contributed to reviewing and editing the manuscript. Bambang Hariyadi supervised the study and provided guidance on methodology and visualization. All authors read and approved the final version of the manuscript.

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#### Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this article.

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