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Research Trends and Gaps on Project-Based Learning, Green Chemistry, and Local Wisdom in Chemistry Learning: A Sceptical Review

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A B S T R A C T

The transformation of 21st-century chemistry learning demands a contextual, sustainable, and culturally based approach. This study aims to analyze publication trends and potential links between Project-Based Learning (PjBL) and Project-Based Learning (PjBL). PjBL), Green Chemistry (GC), and Local Wisdom (LW) in chemistry education. A search was conducted through the Scopus database (2014–2025) using three main keyword combinations, each linked to "Chemistry Education." 793 articles were obtained, and after selection, 269 articles were analyzed using VOSviewer. Visualization shows that the three topics developed separately without explicit connections. Meanwhile, a combined search of the three keywords did not produce a single publication. This finding indicates a research gap and integration opportunities for the development of contextual and sustainable chemistry learning.

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INTRODUCTION

21st-century science learning demands the development of competencies not only in the cognitive domain, but also in the affective and psychomotor domains in an integrated manner. Contemporary educational transformation is no longer sufficient if it only emphasizes the delivery of scientific facts and theories; it also requires instilling critical thinking skills, problem-solving skills, and social and environmental awareness.(Krajcik & Delen, 2016)In this context, project-based science learning (PjBL) has become a pedagogical approach that has received much attention because it is able to encourage students to be actively involved in scientific and contextual processes.

Several studies show that PjBL in science learning is effective in increasing scientific literacy, collaborative skills, and learning motivation (Hasni et al., 2016).This model positions students as active participants in solving real-world, project-based problems relevant to everyday life. However, PjBL implementation practices are often limited to methodological aspects, without meaningful integration with local environmental and cultural values. This leaves a gap in contextual learning, which ideally could bridge modern science with local community life.

On the other hand, Green Chemistry (GC) has become an important concept in modern chemistry education, promoting awareness of sustainability and environmentally friendly chemical practices. GC principles encompass energy efficiency, the use of environmentally friendly materials, and the reduction of waste and chemical toxicity.(Anastas & Warner, nd). In the educational context, GC integration is highly relevant to building scientific understanding that is not only theoretical, but also ethical and applicable, especially in responding to global environmental issues.

The integration of GC in science education has been shown to increase students' awareness of sustainability issues and improve conceptual understanding of chemical principles that are more relevant to the challenges of the times (Hughes, n.d.). However, this integration is often top-down and content-based, without being pedagogically linked to learning models like PjBL, which enable active student engagement. This gap highlights the opportunity to integrate GC content with the PjBL approach to make it more applicable and contextually meaningful.

On the other hand, local wisdom is an important component in contextual science learning, especially in a multicultural country like Indonesia. Local wisdom encompasses traditional values, practices, and knowledge that have been passed down from generation to generation and are closely linked to scientific practices within society.(Pujiati & Kristiyanto, nd). Integrating local values into chemistry learning not only strengthens students' cultural identity, but also increases the relevance of learning to their own environment.

Unfortunately, although numerous studies have highlighted the importance of local wisdom-based education, its application in chemistry learning remains sporadic and has not been systematically integrated with the PjBL approach or GC principles. Yet, the collaborative potential of these three is

enormous in forming a holistic learning approach that combines active pedagogy, environmental awareness, and cultural identity.

In practice, it is rare to find chemistry learning designs that explicitly combine the PjBL approach, GC principles, and the Local Wisdom context simultaneously. The available literature tends to address one or two components only partially. This indicates a significant gap in the development of an integrative approach to chemistry learning that is not only scientific but also rooted in local culture and oriented toward sustainability.

This lack of integration can result in students' weak engagement in meaningful science learning, due to the lack of a bridge between the scientific knowledge taught in school and their everyday life experiences. However, strong scientific literacy is measured not only by conceptual mastery but also by students' ability to critically and reflectively connect science to environmental, social, and cultural issues (OECD, 2019).

Based on initial literature mapping in the Scopus database, no articles have been found that comprehensively examine the relationship between these three themes in the context of chemistry education. This situation indicates that an integrative approach between Project-Based Learning, Green Chemistry, and Local Wisdom remains an underexplored area in the academic literature, particularly in the context of chemistry learning at the secondary school level.

Thus, this study aims to map research trends and identify gaps in the integration of these three concepts through a Systematic Literature Review (SLR) approach. This study is expected to provide theoretical contributions to the development of a conceptual framework for contextual, sustainable, and culturally based chemistry learning, as well as serve as a foundation for further research and the development of more transformative science education innovations.

However, despite the importance of each concept Project-Based Learning, Green Chemistry, and Local Wisdom. Existing research tends to treat them in isolation. Bibliometric mapping of Scopus-indexed articles (2014–2025) shows no single study that explicitly integrates all three in the context of chemistry education. This fragmentation highlights a significant research gap and reveals a missed opportunity to develop holistic, culturally grounded, and sustainability-oriented chemistry instruction. Hence, this study seeks to address this gap by systematically mapping existing literature and identifying integration opportunities among these three critical elements.

THEORETICAL REVIEW

Project-Based Learning in Science Education

Project-Based Learning (Project-Based Learning (PjBL) is a learning approach oriented toward active student involvement in solving authentic problems through structured projects. In the context of science education, PjBL is highly relevant for building conceptual understanding while developing 21st-century skills such as critical thinking, collaboration, and creativity. According to(A et al., 2025), implementation PjBL in science classes allows students to build

experience-based scientific understanding, increase material retention, and strengthen connections between theory and experimental practice.

The study conducted by(Hindun et al., 2024) (Kurt & Akoglu, 2023)shows that the implementation PjBL in science curriculum can significantly improve scientific literacy,increasing student engagement and academic achievement in science and other subjects, including outperforming ELL (English Language Learners) students(Deutscher et al., 2021)This approach places students in complex yet purposeful learning situations, where they learn not only to master scientific concepts, but also to integrate social and technological skills. Therefore, PjBL is considered as one of the most effective pedagogical strategies in bridging academic learning and character development.

Green Chemistry as Sustainable Education Content

Green Chemistry (GC) is an approach that focuses on the design of chemical products and processes that reduce or eliminate the use and production of hazardous materials.(Mammino, 2024)In the world of education, the concept of GC is not only seen as scientific content, but also as a paradigm for sustainable education that encourages environmental awareness in chemistry learning. The integration of GC in science education encourages students to understand the ethical and ecological dimensions of chemistry.(Mitarlis et al., 2023).

Research byKrystyniak et al., nd (2022) revealed that integrating GC principles into learning not only enriches chemistry content but also increases students' awareness of environmentally friendly laboratory practices. This makes GC a vehicle for contextualizing chemistry within global challenges such as climate change, pollution, and waste management.

Local Wisdom as a Context for Chemistry Learning

Local wisdom is traditional knowledge and values that develop within a community and are passed down from generation to generation. In science education, local wisdom can be used as a learning context that strengthens the social and cultural relevance of scientific concepts. According to(Koten & Rohaeti, 2024)(Silfianah et al., 2024), the integration of local values in chemistry learning can increase student participation, strengthen cultural identity, and encourage mastery of concepts through authentic experiences.

Study by(Silfianah et al., 2024)In the context of ethnoscience, it has been shown that integrating local cultural elements into science learning can develop conceptual understanding while building contextual ecological awareness. This demonstrates the potential synergy between local wisdom and science education to create a more inclusive and transformative learning approach.

The Urgency of Integration PjBL, GC, and Local Wisdom in Chemistry Education

These three concepts—PjBL, GC, and Local Wisdom—represent distinct yet complementary dimensions of contextual science learning. PjBL offers a pedagogical structure, GC presents content relevant to global environmental issues, and local wisdom provides a bridge between science and culture.

However, so far, there have been few learning frameworks that systematically integrate all three within the context of chemistry education.

The results of literature exploration by Nurhasanah & Suyanto, nd (2023) suggested that integrating scientific content and local values has the potential to strengthen scientific literacy and encourage active student participation. Therefore, integrating these three approaches is not simply a demand for learning innovation, but also a response to the need for more meaningful, relevant, and sustainable science learning.

METHODOLOGY

This study uses a Systematic Literature Review (SLR) approach to map trends, thematic relationships, and identify research gaps in scientific publications related to the integration of Project-Based Learning, Green Chemistry, and Local Wisdom in chemistry learning. This approach was chosen to systematically synthesize selected publications, not to develop a product or conduct direct field interventions.

The SLR in this study was compiled following the 2020 PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, which emphasize transparency, systematicity, and reproducibility of the literature search and analysis process. Article searches were conducted systematically using the databaseScopus, given its high reputation as an internationally renowned provider of scientific literature, was used. The search was conducted in August 2025, covering publications between 2014 and 2025.

The keywords used were Boolean combinations as follows: "Project-Based Learning" AND "Chemistry Education"; "Green Chemistry" AND "Chemistry Education"; "Local Wisdom" AND "Chemistry Education" and "Project-Based Learning" AND "Green Chemistry" AND "Local Wisdom". Each combination resulted in a different set of articles, which were then further filtered based on inclusion and exclusion criteria.

The inclusion criteria used are: Scopus indexed articles, in English, focused on chemistry/science learning, social science, chemistry, chemical engineering, using one or more of the main keywords (PjBL, GC, LW), peer-reviewed articles (journals or scientific proceedings), available in full text. While the exclusion criteria are: Articles in the form of editorials, opinions, or non-peer-reviewed, not available in full text, not relevant to the context of chemistry education, languages other than English.

The found article data was imported from Scopus in .RIS format, with checked information including: Citation information, Bibliographical information, Abstract & keywords and Other information. After that, the articles were filtered based on exclusion criteria which included: duplication, non-peer-reviewed articles, articles irrelevant to the context of chemistry/science learning, and articles that were not available in full-text. After initial screening, 524 articles were excluded from the analysis. The results of the eligibility assessment, where 269 articles were used in the analysis process.

RESULTS

Initial Search Results

A search of the Scopus database for the period 2014–2025 did not find a single scientific article that simultaneously linked the concepts of Project-Based Learning, Green Chemistry, and Local Wisdom in the context of Chemistry Education. Therefore, a bibliometric analysis was conducted separately on three main topics, namely: Project-Based Learning (PjBL), Green Chemistry (GC), and Local Wisdom (LW). The results of the data search in the Scopus database can be seen in Table 1 below.

Table 1. Summary of the Number of Articles Based on Keywords in the Scopus Database (2014–2025)

Search Keywords	Total number of articles	Articles that meet the criteria	Search year
Project-Based Learning AND Green Chemistry AND Local Wisdom	0	0	2014-2025
Project-Based Learning AND Chemistry Education	173	66	2014-2025
Green Chemistry AND Chemistry Education	609	198	2014-2025
Local Wisdom AND Chemistry Education	11	5	2014-2025

Source: Author's search results using the Scopus database (2025)

Visualization Results Per Topic

a. Project-Based Learning (PjBL) + Chemistry Education

Bibliometric visualization for the keyword combination "Project-Based Learning" AND "Chemistry Education" was conducted on 66 selected articles from the search results in the Scopus database in the period 2014 to 2025. This analysis uses VOSviewer software to produce visual mapping based on keyword co-occurrence, as well as the temporal distribution of keyword occurrences (overlay visualization) can be seen in Figure 1 and its interpretation in Table 2.

The displayed image reflects the relationships between keywords that frequently appear together in scientific publications, the number of times the words appear, and the topical clusters they form. Larger nodes indicate higher frequencies, while the colors in the overlay indicate the temporal trends of topic emergence in the literature map. This visualization aims to identify research trends in the application of Project-Based Learning to chemistry learning and to demonstrate whether there are explicit links to sustainability topics or local values.

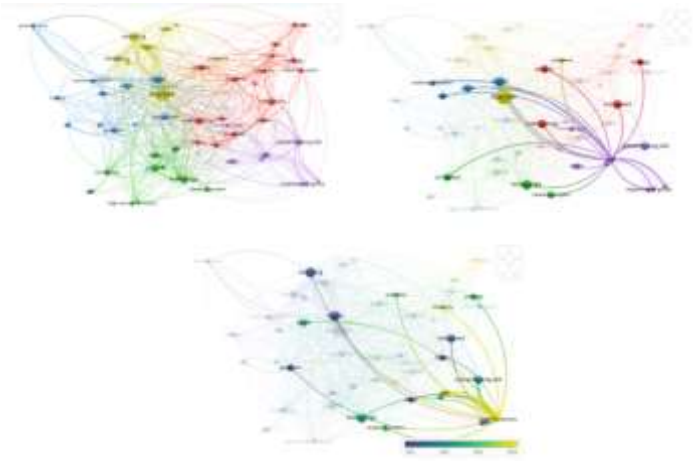

Figure 1. Network Visualization and Overlay PjBL-chemistry education from Vosviewr

Table 2. Bibliometric Visualization Results of Project-Based Learning and Chemistry Education Topics

Topics	Number of Articles	Dominant Keywords	Key Trends of the Year	Relationship with GC / LW	Gap Found
PjBL + Chemistry Education	173 (66 analyzed)	teacher, learning model, scientific literacy, critical thinking, student-centered	2018–2024	Not connected	There is no explicit integration with Green Chemistry or Local Wisdom

Source: VOSviewer visualization results of 66 selected articles based on the keywords "Project-Based Learning" AND "Chemistry Education" (Scopus, 2014–2025)

b. Green Chemistry + Chemistry Education

Bibliometric analysis for the keyword combination "Green Chemistry" AND "Chemistry Education" was conducted on 198 selected articles from the search results in the Scopus database for the period 2014–2025. The visualization results using VOSviewer show keywords that frequently appear together in the literature on sustainability-based chemistry education.

Keywords such as sustainability, environmental education, curriculum, and green lab emerged as important nodes forming dominant clusters. However, this visualization also reveals no explicit link between green chemistry and project-based pedagogical approaches such as Project-Based Learning, or approaches based on cultural values.local wisdom. As seen in Figure 2 and Table 3.

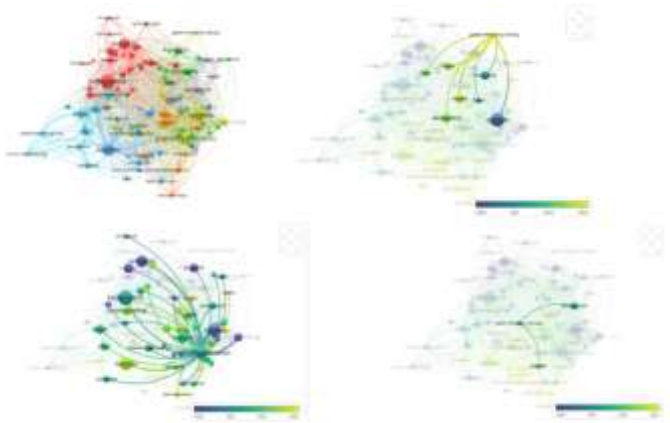

Figure 2. Network Visualization and Overlay Green Chemistry-chemistry education from Vosviewr

Table 3. Bibliometric Visualization Results for Green Chemistry and Chemistry Education Topics

Topics	Number of Articles	Dominant Keywords	Key Trends of the Year	Relation to PjBL / LW	Gap Found
Green Chemistry + Chemistry Education	609 (198 analyzed)	sustainability, environment, green chemistry, curriculum, green lab, education policy	2019–2025	Not connected	Not yet connected to Project-Based Learning or Local Wisdom

Source: VOSviewer visualization results of 198 selected articles based on the keywords "Green Chemistry" AND "Chemistry Education" (Scopus, 2014–2025).

c. Local Wisdom + Chemistry Education

A bibliometric analysis of the keyword combination "Local Wisdom" AND "Chemistry Education" was conducted on five selected articles from the Scopus database spanning 2014–2025. Although the number of articles is relatively small compared to previous topics, visualization using VOSviewer still provides an overview of keyword trends and emerging research directions. As can be seenin Fig. 3 and Table. 4

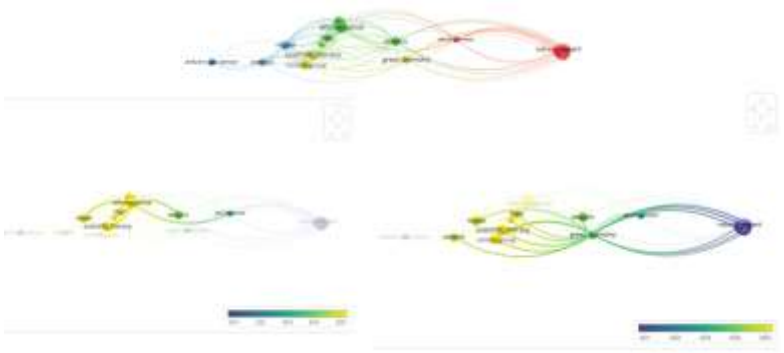

Figure 3. Network Visualization and Overlay Local Wisdom-chemistry education from Vosviewr

Table 4. Bibliometric Visualization Results of Local Wisdom and Chemistry Education Topics

Topics	Number of Articles	Dominant Keywords	Key Trends of the Year	Relation to PjBL / GC	Gap Found
Local Wisdom + Chemistry Education	11 (5 analyzed)	local wisdom, ethnoscience, culture, contextual learning, indigenous knowledge	2016–2024	Not connected	There is no integration with Green Chemistry and Project-Based Learning yet

Source: VOSviewer visualization results of 5 selected articles based on the keywords "Local Wisdom" AND "Chemistry Education" (Scopus, 2014–2025).

The visualization results show that keywords such as ethnoscience, culture, contextual learning, and local knowledge form the main nodes. This topic emphasizes a local context-based learning approach rooted in cultural values. However, no direct link has been found with the concept of Green Chemistry or the Project-Based Learning approach. This indicates that research related to Local Wisdom in chemistry learning remains fragmented and tends to focus on aspects of cultural values or local context, without integrating more innovative pedagogical approaches or global sustainability issues.

DISCUSSION

Context of Initial Findings

The absence of any scientific publication that integrates PJBL, GC, and LW underscores a critical blind spot in the evolution of chemistry education research. While each concept individually aligns with 21st-century educational goals—active learning, sustainability, and contextual relevance—their compartmentalized development reveals a lack of theoretical and pedagogical dialogue between domains. This segmentation may be influenced by the dominant trends in science education research that prioritize global frameworks (such as Green Chemistry)

over localized cultural pedagogies, or focus on methodology (like PJBL) without integrating ethical or sociocultural dimensions. Furthermore, the lack of co-occurrence in bibliometric mapping suggests that scholars have not yet conceptualized a multi-dimensional instructional model that leverages the synergistic potential of these approaches. This disconnect is not merely academic—it reflects classroom realities where innovative methods are often implemented without sustainability content, or where local cultural elements are treated as anecdotal rather than embedded in curriculum design.

A systematic search through the Scopus database between 2014 and 2025 revealed no articles discussing these three topics simultaneously. This finding indicates that the integration of project-based learning strategies, the sustainability values of green chemistry, and cultural approaches based on local wisdom has not yet become a primary focus in the globally indexed academic literature on chemistry education.

Individual topics have developed with their own trends and scopes. This disconnect between clusters is evident not only in the visual representation but also in their temporal distribution. Overlay visualizations show that each topic has a distinct temporal trend of emergence and lacks strong semantic relationships. Thus, visually and bibliometrically, research in chemistry learning still tends to be segmented into three main streams that are not yet epistemologically integrated.

The bibliometric clusters of PJBL, GC, and LW each reflect distinct priorities in chemistry education. PjBL clusters emphasize pedagogical strategies such as collaboration and inquiry-based learning. GC clusters center around environmental policies, curriculum development, and sustainability content. LW clusters emphasize ethnoscience, culture, and indigenous knowledge. While each cluster shows internal consistency, the lack of interconnection suggests a conceptual fragmentation. For example, PjBL lacks cultural contextualization; GC remains content-heavy but lacks pedagogical innovation; and LW focuses more on values and context but is rarely supported by structured methods like PjBL.

This separation may reflect deeper issues in education systems—such as rigid curricula, fragmented teacher training, or the tendency of researchers to work within disciplinary silos. These findings call for an integrated learning model where pedagogical innovation (PjBL), environmental responsibility (GC), and cultural grounding (LW) work together to shape future chemistry education.
This finding also aligns with the results of previous bibliometric studies that reinforce the research gap. For example,(Hasanah et al., nd 2024)In their bibliometrics of PjBL in experimental chemistry learning, they stated that although there is a trend of increasing research, there is no explicit connection to sustainability or local context. Similarly,(Chakraborty & Galatro, nd)(2025) showed that the development of PjBL in the context of Education 4.0 towards Society 5.0 still does not touch on local values or green chemistry issues in science education practices. The study byFatmawati & Irwanto, nd(2024) even emphasized that sustainability and local culture are often positioned as separate aspects of project-based pedagogy in science education. Thus, the integrative gap between PjBL, Green Chemistry, and Local Wisdom in chemistry learning is not

only theoretical, but also supported by empirical evidence and bibliometric visualization.

Topical Analysis of Bibliometric Results

The results of a bibliometric analysis of three main topic combinations yield an interesting picture regarding concept mapping and research directions in chemistry education. Each combination was analyzed using VOSviewer to identify dominant keywords, the clusters formed, and the temporal direction of research trends.

The combination of PjBL and Chemistry Education keywords shows that this topic has grown significantly from 2018 to 2024, dominated by topics such as critical thinking, scientific literacy, and student-centered learning. Bibliometric visualizations show that PjBL plays a strong role in strengthening 21st-century competencies and improving the quality of learning based on active engagement. However, no direct link was found between the PjBL approach and Green Chemistry or Local Wisdom in the analyzed keyword clusters or networks.

Bibliometric results on the topics of Green Chemistry (GC) and Chemistry Education show a strong tendency towards sustainability, curriculum, and environmentally friendly laboratories. Dominant keywords such as sustainability, environmental education, and green lab occupy a central position in the network. However, GC in the context of chemistry education appears to be still oriented towards curriculum content and policies, with minimal links to pedagogical innovations such as PjBL, or local contexts based on culture or community values. The number of publications on the topic of Local Wisdom (LW) and Chemistry Education is still relatively limited. Only five articles were analyzed, but they still provide insight into the research focus on ethnoscience, contextual learning, and indigenous knowledge. This local wisdom-based chemistry learning is typically oriented toward preserving cultural values and strengthening local identity, but has not yet been connected to the Green Chemistry framework or methodological integration through PjBL.

These findings indicate that the three topics develop in separate domains: PjBL as a pedagogical approach, GC as sustainability-based content, and LW as a cultural context. The lack of intersections or connecting nodes in the visualization is also reinforced by the fact that literature that explicitly integrates the three is very rare. One publication that comes relatively close to integrating the three is research by(Pujiati & Kristiyanto, nd)(2025), which developed a local wisdom-based project learning approach for environmental chemistry. However, despite its similarities in the realm of environmental education, this study did not formally use the Green Chemistry framework and is not indexed in global databases.

Thus, it can be emphasized that the disconnect between these three concepts is not only theoretical but also manifests itself in the landscape of scientific publications. They have not yet been brought together in an integrative and systemic research framework. This situation presents a significant opportunity to design a learning model that can integrate a project-based pedagogical approach, the environmental sustainability values of Green Chemistry, and

cultural relevance through local wisdom within a single, transformative, contextual chemistry learning environment.

Theoretical Implications and Novelty

The findings demonstrating the absence of explicit connections between Project-Based Learning, Green Chemistry, and Local Wisdom in the chemistry education literature have significant implications for the development of science, particularly in the theoretical and practical dimensions of contextual education. In general, the three themes have different conceptual depths, yet they complement each other in forming a holistic learning approach.

Theoretically, the Project-Based Learning approach has long been associated with improving 21st-century skills such as critical thinking, collaboration, and scientific literacy.(Al-Qoyyim & Kurniawan, nd)(2025) and(Restiani et al., nd)(2025) demonstrated that the integration of PjBL significantly and sustainably promotes students' scientific literacy, creativity, and collaborative work. However, in practice, PjBL is often developed without considering educational content that reflects global issues such as sustainability or local contexts relevant to students' lives. Green Chemistry, on the other hand, embodies the values of sustainability and environmental ethics, but is more often integrated into the curriculum through content rather than as an applicable pedagogical approach. Local Wisdom, on the other hand, plays a role in grounding chemistry education in local cultural realities and values, but is often separated from project-based approaches and sustainability principles.

This situation opens up conceptual space for the integration of the three within a unified learning framework. Ontologically, PjBL can be positioned as an implementation strategy, Green Chemistry as the content of scientific values and principles, and Local Wisdom as the cultural and social context. This approach allows for the formation of a transformative pedagogy that emphasizes not only cognitive competence but also fosters ecological awareness and strengthens students' cultural identities. This aligns with the principles of contextual learning emphasized in the Indonesian national curriculum (Kurikulum Merdeka), where learning is directed toward personal, social, and environmental meaning.

The implications of this novelty can also be seen in the potential for further research in developing a chemistry learning model that combines these three aspects. This model will not only contribute to relevant and applicable chemistry learning but also present an alternative curriculum design that integrates global sustainability values with local wisdom. In the literature, this represents a contribution to enriching the theory of contextual chemistry learning based on multiple aspects (pedagogy, content, and culture), which to date has not been explored systematically or empirically.

Furthermore, this learning model has the potential to be a strategic tool for realizing the goal of sustainable chemistry education, namely equipping students with scientific knowledge, ecological awareness, and local cultural values in a balanced manner. Therefore, this research serves not only as a gap-mapping tool but also as a conceptual foundation for promoting multifaceted integration in chemistry learning that is more humanistic, ecological, and contextual.

Limitations of SLR Research

a. Limited Database Coverage

Literature searches were only conducted through the Scopus database, so publications from other platforms (e.g. Google Scholar, Web of Science, ERIC, or the national journal SINTA) were not covered.

b. Keyword Terminology Bias

Variations of terms such as "ethnoscience" (for local wisdom) or "sustainable chemistry" (for green chemistry) may result in a number of relevant articles not being detected by search systems.

c. Bibliometric Visual Focus, Not Content Synthesis

This study did not conduct an in-depth content review, so the conceptual relationships in the articles were only analyzed through the frequency and relationship of keywords, not the narrative content.

d. Limitations of VOSviewer Representation

The resulting visualizations tend to highlight popular keywords and do not necessarily represent new conceptual innovations that have a low frequency.

e. Uneven Number of Articles

The Local Wisdom + Chemistry Education theme yielded only a few articles (n = 5), so the conclusions for this theme are still limited and exploratory. Conduct an in-depth content analysis of all articles.

Further Research Directions

This research opens up several strategic opportunities for further research exploration, particularly in integrating pedagogical approaches (Project-Based Learning), sustainability principles (Green Chemistry), and local cultural values (Local Wisdom) within the context of chemistry education. Based on the visualization results, the identified conceptual gaps can serve as a starting point for designing more integrative and innovative research directions. Some key directions that can be developed include:

a. Development of an Integrative Learning Model

Future research could focus on developing and validating chemistry learning models that explicitly integrate PjBL, GC, and LW. These models could be designed to develop scientific literacy as well as awareness of sustainability and local wisdom in students.

b. Exploration of Local Cultural and Environmental Context

Field studies are needed to explore the potential of local wisdom relevant to green chemistry principles, such as community practices in natural waste management, the use of traditional chemicals, or local rituals with ecological value. The results of this exploration can be used as contextual content in learning.

c. Curriculum Analysis and Teacher Practice

Further studies can be directed at analyzing the implementation of the national curriculum (e.g., the Independent Curriculum) to assess the extent to which aspects of sustainability and local wisdom are accommodated in project-based science learning in schools.

d. Development of a Contextual Science Literacy Assessment Instrument

In addition to model development, research also needs to develop and test the validity of assessment instruments that are capable of measuring scientific literacy by considering cultural and environmental dimensions.

e. Combination of SLR Method and Qualitative Study

To complement bibliometric analysis, subsequent systematic studies should involve a combination of literature reviews and qualitative approaches such as case studies, school ethnographies, or analyses of teachers' instructional practices.

f. Database Expansion and Terminology Diversification

Further research is recommended to use more than one database (e.g. WoS, Google Scholar, ERIC) and to expand keywords to capture relevant literature with alternative terms such as sustainable chemistry, ethnoscience, or place-based education.

CONCLUSIONS AND RECOMMENDATIONS

This study concludes that although Project-Based Learning, Green Chemistry, and Local Wisdom have each been extensively researched in the context of chemistry education separately, no scientific publication has been found that explicitly integrates all three within a coherent learning framework. Bibliometric analysis using VOSviewer indicates that the three themes have different conceptual depths and development trends, but theoretically complement each other to support contextual, sustainable, and culturally based chemistry learning. The lack of direct connection between the three themes in a single publication indicates a significant research gap as well as an opportunity to develop new learning models. Therefore, further research is highly recommended to develop an integrative PjBL-based model that incorporates Green Chemistry principles and local wisdom values to strengthen students' scientific literacy and sustainability awareness.

FURTHER STUDY

AThe main materials that can be developed include:

1. Development of an Integrative Learning Model
2. Exploration of Local Cultural and Environmental Context
3. Curriculum Analysis and Teacher Practice
4. Development of a Contextual Science Literacy Assessment Instrument
5. Combination of SLR Method and Qualitative Study
6. Database Expansion and Terminology Diversification

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