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Ethnochemistry In Chemistry Learning: Insights from Indonesian Local Wisdom

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Abstract: This study aims to analyze the role of ethnochemistry as an innovative approach in chemistry education by examining its impact and development strategies based on local wisdom. Ethnochemistry combines cultural practices with chemical concepts to create meaningful and inclusive learning. This study focuses on the impact of ethnochemistry on chemistry learning and its development strategies to support inclusive and multicultural chemistry education. These findings are expected to enrich culturally relevant chemistry education and support the preservation of cultural heritage. This study employed the Systematic Literature Review (SLR) method, adhering to the PRISMA protocol to ensure transparency and repeatability. The initial search was conducted in Scopus, Google Scholar, Semantic Scholar, and Crossref, using the keyword "ethnochemistry." From a total of 225 articles, 27 articles were selected that met the inclusion criteria in the form of publications from 2020-2025. Articles must contain the keyword ethnochemistry or "ethnochemistry" in the title, must not be articles published in proceedings or repositories, must not duplicate articles with the same title, and must be indexed by Scopus or articles accredited by Sinta 1 and 2. The results showed that ethnochemistry significantly improved students' conceptual understanding, 21st-century skills (such as critical and creative thinking), and motivation. This approach also strengthens cultural preservation by connecting chemical concepts and local cultural practices. The main strategies for its development include: (1) Technology-based teaching materials (e.g., AR/VR, Adobe Flash), (2) Contextual learning approaches (e.g., PBL and CRT), (3) Collaboration with local communities, and (4) Expansion of research on underrepresented cultures. It can thus be concluded that ethnochemistry not only enhances the appeal and relevance of chemistry learning but also plays an important role in preserving cultural heritage. To optimize its potential, comprehensive strategies are necessary, including integrating ethnochemistry into the national curriculum, increasing teacher capacity through training, and utilizing digital technologies. Further research is also needed to evaluate the long-term impact and expand its application to various cultural contexts. This approach ensures inclusive, sustainable, and globally relevant chemistry education.

Keywords: ethnochemistry, local wisdom, education, inclusive, systematic review.

▪ INTRODUCTION

What if chemistry lessons, often considered boring, could actually be a powerful tool for preserving cultural traditions? This research offers a solution through an approach: conceptual chemistry learning while simultaneously fostering students' awareness of cultural values, so that they not only understand science but also contribute to the preservation of cultural heritage and their future preparedness. Chemistry education aims not only to improve their understanding of scientific concepts but also to shape students with character, culture, and readiness to face the challenges of the 21st century (Hadinugrahaningsih et al., 2017). This transformation emerges as an effective approach to achieving goals in the form of beliefs, attitudes, and emotions through reflection, which is important for students. This approach encourages the development of holistic

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competencies, equipping students to become agents of change in society. Several transformation-based learning approaches have been developed, such as green chemistry (Anastas & Eghbali, 2010), Culturally Responsive Teaching (Vavrus, 2008), and STEAM (Science, Technology, Engineering, Art, and Mathematics) (Khine & Areepattamannil, 2019).

These approaches not only enrich chemistry understanding but also hone 21st-century skills, such as critical thinking, creativity, collaboration, and environmental awareness. However, their implementation requires a paradigm shift in the learning process, including the role of lecturers as facilitators of transformation and integration of students' cultural contexts (Rahmawati et al., 2018). One approach that can bridge this gap is ethnochemistry, which connects abstract chemical concepts with local wisdom and everyday cultural practices (Ridwan et al., 2025). Thus, chemistry learning, often considered difficult by students due to its abstract nature and lack of relevance to everyday life, can be made more contextual and meaningful. Ethnochemistry, as an approach that combines chemistry with local wisdom, offers a contextual solution to address this problem by connecting chemical concepts with cultural practices (Chibuye & Singh, 2024). Ethnochemistry is a field of ethnoscience that studies chemical practices within a local cultural context. This approach has the potential to bridge the gap between abstract chemical concepts and students' social realities. In this situation, ethnochemistry utilizes Vygotsky's social constructivist theory by placing learning within a culturally meaningful context. This approach is consistent with the idea that knowledge is co-constructed through social interactions and supported by cultural tools (e.g., local practices, language), which enable students to connect abstract ideas with their familiar life experiences, making learning more relevant and helping students understand the material more realistically and meaningfully.

Several studies have shown that ethnochemistry-based learning can enhance conceptual understanding, increase learning motivation, and foster students' respect for the local culture around their homes. For example, learning the reaction kinetics of tape fermentation or analyzing acid-base solutions in herbal medicine production can help students master material previously considered complex. Furthermore, an ethnochemistry approach will foster students' critical and creative thinking skills through projects based on local wisdom. Thus, ethnochemistry not only facilitates chemistry learning but also preserves cultural heritage and creates an inclusive, sustainable, and culturally relevant education.

The development of ethnochemistry as a field of study that bridges modern science with local wisdom can be strengthened through a systematic literature review approach that allows researchers to comprehensively and systematically identify, evaluate, and synthesize empirical findings from various studies on traditional chemical practices. This approach is important because ethnochemistry is a multidisciplinary field, involving aspects of chemistry, cultural anthropology, ecology, and education, thus requiring an in-depth analysis of the patterns, challenges, and opportunities that arise from integrating local knowledge into science learning.

Ethnochemistry has developed as an innovative approach in chemistry education, combining local wisdom with scientific concepts to improve students' understanding, motivation, and chemical literacy. Based on the analysis of published articles, which served as the primary data in this study, several findings were obtained, including the

integration of culture in learning (Wahyudiati, 2022; Irawati, et al., 2023), which have successfully integrated local wisdom (Sasak, Javanese, Malay, and Banjar customs) into chemistry learning materials such as chemical bonds, acids and bases, and chemical kinetics. The ethnochemistry-based Culturally Responsive Teaching (CRT) approach can also significantly improve cognitive learning outcomes (Wardani et al., 2023) and chemical literacy (Ridwan et al., 2025). In the development of interactive media such as Adobe Flash, VR, e-modules, and domino card games based on ethnochemistry, interactive media have been proven valid and effective (Heliawati et al., 2022; Pamungkas et al., 2024). Furthermore, the development of a Two-Tier Multiple Choice Question (TTMC) instrument based on VR and ethnochemistry was also able to detect students experiencing misconceptions (Ningtyas et al., 2025). Problem-based learning (PBL) models with an ethnochemical context have also been reported to improve problem-solving skills (Gultom & Rohaeti, 2024) and scientific explanations (Wiratma & Yuliamiastuti, 2023)

The SLR in this study contributes to the literature, including: 1). Expanding the scope, namely by adding the latest research results that have not been covered in previous meta-analyses, such as the use of AI (Yamtinah et al., 2025), VR (Ningtyas et al., 2025) and exploring new cultural contexts that have not been widely discussed (Chibuye & Singh, 2024); 2). Updating previously obtained findings based on evidence of the effectiveness of ethnochemistry, for example, integrating ethnochemistry and STEM into the curriculum (Chibuye & Singh, 2024) or (Pebrianti et al., 2024), which highlight the challenges of implementing ethnochemistry in learning, especially related to internet access for e-modules or teacher training; 3). Challenging the conclusions of previous studies, as reported by Harianto et al. (2025), indicates that chemical literacy remains low, despite the implementation of the ethnochemical approach. This SLR not only consolidates recent findings but also identifies research gaps, such as the need for more inclusive and adaptive learning designs for diverse cultural contexts. Furthermore, the SLR can serve as a basis for innovative curriculum development, teacher training, and more inclusive education policies. Thus, SLR not only strengthens the theoretical foundations of ethnochemistry but also ensures that scientifically valuable traditional practices can be ethically and sustainably integrated into modern education systems, while preserving cultural heritage threatened by globalization.

Ethnochemistry, an approach that connects chemical concepts with local culture, is becoming increasingly necessary in education to create more relevant and meaningful learning experiences. By integrating local traditions and wisdom, for example, by analogizing learning about chemical bonds with the Merariq tradition of the Sasak people of Lombok (Sutrisno et al., 2020), students can understand abstract chemistry concepts in a more concrete and contextual way. This approach has been demonstrated to improve scientific literacy and 21st-century skills, including critical thinking and problem-solving skills. Furthermore, ethnochemistry also plays a role in preserving traditional knowledge that encompasses chemical principles but has not been widely and scientifically documented. The SLR can also identify research gaps, particularly in underexplored areas, while also encouraging the development of innovative learning media such as e-modules, educational games, or culture-based augmented reality. In the context of education policy, ethnochemistry aligns with independent curricula that emphasize project-based and contextual learning. By conducting an SLR, findings from various

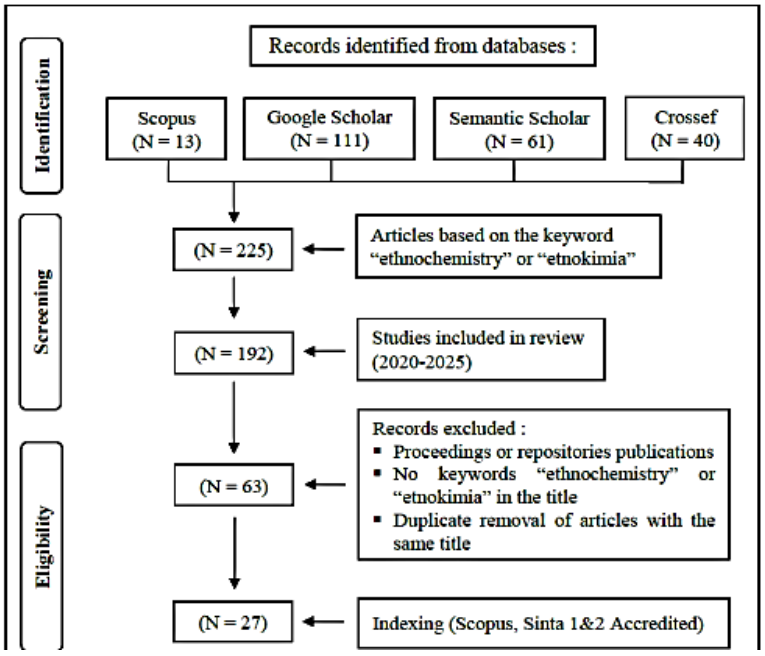
studies can be consolidated to provide recommendations for teachers, researchers, or policymakers. Furthermore, a global perspective on the application of ethnochemistry in countries such as Zambia (Chibuye & Singh, 2024) or Nigeria (Anari et al., 2024) can enrich implementation strategies in Indonesia. Thus, SLR on ethnochemistry not only strengthens the theoretical and practical foundations but also opens up opportunities for cross-disciplinary and cross-cultural collaboration, thereby making chemistry education more inclusive, engaging, and impactful.

In this article, a systematic synthesis of research reports will be conducted through a comprehensive search of the Scopus, Google Scholar, Semantic Scholar, and Crossref databases, covering the period from 2020 to 2025, using the keywords "ethnochemistry" or "etnokimia". This study aims to answer two main questions: 1) What is the impact of ethnochemistry on learning?2) What is the strategy for developing ethnochemistry to support inclusive and multicultural chemistry learning? By exploring these two aspects, this article aims to contribute to the enrichment of knowledge about culture-based approaches in science education, especially chemistry or chemistry education.

▪ METHOD

Research Design

This study used a systematic literature review (SLR) method to analyze the impact and strategies for developing ethnochemistry in chemistry education. SLR was chosen for its ability to evaluate and integrate research findings in a structured manner, resulting in comprehensive conclusions supported by empirical evidence. The research process followed the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analysis) procedural steps to ensure transparency and reproducibility. The primary focus of this study is to explore, filter, and analyze in-depth selected and relevant literature to answer the research questions.



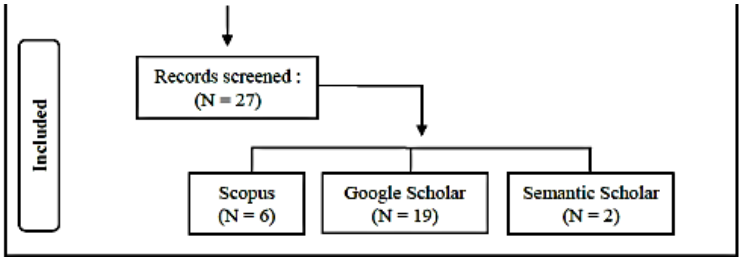


Figure 1. The process of search and selection articles

Search Strategy

The literature search process was conducted using indexed databases, including Scopus, Google Scholar, Semantic Scholar, and Crossref, with the keyword "ethnochemistry" and a publication year limit of 2020-2025 to ensure the relevance of the articles found. Harzing's Publish or Perish search engine was used to collect an initial 225 articles. After filtering the articles by year, the number was reduced to 192. The selection process then continued by applying specific criteria, including focusing on articles with keywords in the title of the found articles, eliminating duplicate articles found with the same title, and considering Scopus indexing or Sinta 1 and 2 accreditation. The final search results obtained 27 articles that were declared eligible for further analysis. The selection process is illustrated in Figure 1.

Inclusion and Exclusion Criteria

The articles selected for this study included empirical research articles, case studies, and literature reviews published in SINTA-accredited journals or reputable international journals. Articles categorized as proceedings or repositories were not used as data sources. Furthermore, additional requirements for data sources include the presence of the keyword "ethnochemistry" or "etnokimia" in the article title and the removal of duplicate articles with identical titles. Articles that did not meet accreditation standards or were irrelevant to the research topic were not included as data sources.

Data Analysis

Data analysis in this study used a qualitative approach with thematic synthesis techniques (Thomas & Harden, 2008). The qualitative approach to thematic synthesis is a systematic analysis approach to identifying, organizing, and interpreting themes that emerge from qualitative data (based on articles obtained in this study) with the aim of finding patterns or deep meanings related to how ethnochemistry is integrated into chemistry learning through a cultural perspective. This method is very suitable for research that aims to understand the complexity of the local context and its impact on learning. In this study, the process of identifying ethnochemical themes is more dominated by inductive methods, as some themes emerge from the exploration of specific local wisdom and are then connected to chemical concepts. In addition, this approach can also be used to identify thematic patterns based on the two questions addressed in this study. Through this method, the systematic literature review (SLR) conducted not only strengthens the theoretical basis of ethnochemistry but also produces practical recommendations for educators and policymakers in integrating local wisdom into the chemistry curriculum in a sustainable manner.

▪ RESULT AND DISSCUSSION

Ethnochemistry is a field of chemistry that examines the application of chemical knowledge and practices within a cultural context. This approach offers a learning framework through the integration of three cultural dimensions: 1) ethnochemical philosophy as a value system, 2) processes as practical activities, and 3) materials used in ethnochemistry as concrete objects. More than simply an alternative pedagogical approach, ethnochemistry plays a crucial role in creating inclusive, culturally relevant, and sustainable chemistry education. Ethnochemistry is not only a crucial foundation for inclusive chemistry education, but it has also been shown to have a significant impact on the learning process. The following study will examine the impact of ethnochemistry on chemistry learning, based on an analysis of 27 collected articles.

Innovative Strategies in Fundamentally Transforming Chemistry Learning

An ethnochemical approach to education is an innovative strategy for fundamentally transforming chemistry learning. Through an ethnochemical approach, abstract chemical concepts can be connected to students' cultural contexts, thus facilitating their understanding. Integrating local wisdom with cultural practices in the curriculum not only deepens students' conceptual understanding (Ridwan et al., 2025) but also strengthens their connection to the material being studied. Sutrisno et al. (2020) and Wahyudiati (2022) have reported on how the "Merarik" tradition and Sasak cultural practices can be utilized to explain complex concepts related to chemical bonding. This aligns with constructivist theory, which suggests that students' understanding will be stronger when they are able to connect what they learn to real-life contexts.

Some examples of innovations that have been developed such as digital and interactive media, educational games, contextual modules, and innovative learning models. Heliawati et al. (2022) developed Adobe Flash-based learning media using an ethnochemical approach, which was able to improve students' scientific literacy. Meanwhile, Dewi et al. (2024) created an ethnochemical-based e-module that proved effective in improving students' understanding and environmental problem-solving skills. Ningtyas et al. (2025) also designed a Virtual Reality (VR)-based assessment instrument to detect student misconceptions on the topic of reaction rates, with very high validation. In addition to digital media, educational games are also an interesting form of innovation. Putera (2023) developed a chemical domino card game that integrates the ethnochemistry of Madurese herbal ingredients. This medium was deemed highly valid (both in terms of material and media) and received a positive response from students.

On the other hand, contextual modules and worksheets can also demonstrate their effectiveness in learning. Asda et al. (2023) and Pebrianti et al. (2024) have developed PBL-based acid-based worksheets and modules using an ethnochemical approach, which has been proven to improve scientific literacy and received positive responses from students. Anggreni et al. (2023) also successfully developed an acid-base-based microblog based on Malay ethnochemistry, which can increase students' interest in culture and chemistry. Gultom & Rohaeti (2024) also found that the application of an ethnochemistry-based PBL model was very effective in improving problem-solving skills. Meanwhile, Wardani et al. (2023), who employed an ethnochemistry-based CRT (Culturally Responsive Teaching) approach, have demonstrated improvements in student learning outcomes. Similarly, Wiratma & Yuliamiastuti (2023) successfully enhanced

students' scientific explanation skills through task-based learning with an ethnochemical context of Balinese medicinal plants.

Based on these various reports, it can be concluded that the ethnochemical approach not only enriches chemistry teaching materials but also makes learning more relevant and meaningful for students. The success of the ethnochemical approach in chemistry learning certainly requires careful planning to ensure the suitability of the material taught in the context of the students' cultural backgrounds. This is in accordance with the findings reported by Wardani et al. (2024), who stated that students' chemical literacy tends to remain low when cultural connections are not well-designed into the learning process. Therefore, the results of this study also recommend that curriculum planning be carried out carefully and thoroughly to ensure that culture-based learning becomes meaningful. Thus, the ethnochemical approach can be a transformative solution in creative and sustainable chemistry learning.

Effective in Developing Scientific Literacy, Conceptual Understanding, and 21st-Century Skills

The ethnochemical approach has been demonstrated to play a significant role in the development of 21st-century skills, particularly in improving students' scientific literacy, conceptual understanding, problem-solving skills, critical thinking skills, and creativity. Studies by Heliawati et al. (2022) and Gultom & Rohaeti (2024) showed that a problem-based learning (PBL) framework with an ethnochemical approach significantly increased student engagement in learning. Furthermore, the ethnochemical approach also significantly contributes to student motivation and participation. Research by Wahyudiati (2022) and Wardani et al. (2023) has noted an increase in student enthusiasm when chemistry learning integrates cultural examples close to students' daily lives. Several other studies have also demonstrated the effectiveness of the ethnochemical approach in improving students' conceptual understanding and chemical literacy. Wardani et al. (2023) have reported an increase in green chemistry learning outcomes. Dewi et al. (2024) found that the use of ethnochemical-based e-modules in learning has successfully improved students' chemical literacy and environmental problem-solving abilities. Similar findings were also reported by Ridwan et al. (2025), who highlighted an increase in chemical literacy in five aspects, including conceptual understanding and higher-order thinking skills (HOTS). This suggests that an ethnochemical approach, combined with learning methods such as PBL or innovative media, can create more meaningful and contextual learning experiences.

Furthermore, the development of 21st-century skills such as problem-solving, critical thinking, and creative thinking has been proven effective with an ethnochemical approach to learning. This is consistent with a report by Gultom & Rohaeti (2024), which stated that the ethnochemical-based PBL model is very effective in improving students' problem-solving abilities. In separate reports, Ridwan et al. (2025) and Wahyudiati & Qurniati (2023) also stated that the ethnochemical approach in learning plays a crucial role in developing students' critical thinking skills by connecting the chemistry concepts they learn with their local culture. Furthermore, student creativity is also evident when using innovative media such as ethnochemical-based domino card games (Putera, 2023) or microblogs that integrate chemistry concepts with cultural wisdom (Anggreni et al.,

2023). These findings certainly serve as evidence to strengthen ethnochemistry's position as a holistic approach relevant to the demands of 21st-century education.

In contrast, Harianto et al. (2025) revealed that students' scientific literacy did not improve despite using an ethnochemical approach. This indicates the importance of different strategies, such as integrating ethnochemistry with other innovative learning methods, to maximize the impact of the ethnochemical approach in learning. Thus, this approach not only provides a strong foundation but also requires interdisciplinary innovation to achieve optimal results. Furthermore, increasing teacher capacity through special training to design culturally responsive learning, especially in integrating ethnochemistry into the curriculum, also plays a vital role in supporting the successful implementation of the ethnochemical approach optimally in the classroom. Furthermore, this success also requires support in the form of exploring the potential of ethnochemistry in a broader context and diverse cultural variations. Thus, an ethnochemical approach to learning can not only enrich chemistry learning but can also prepare students' skills to face very complex and dynamic global challenges.

A Universally Adapted Local Cultural Preservation Tool for Inclusive and Meaningful Chemistry Learning

The ethnochemical approach has proven to be an effective tool for preserving local culture while enriching inclusive and meaningful chemistry learning. Various studies have shown that integrating local wisdom into the chemistry curriculum not only enhances students' scientific understanding but also safeguards cultural heritage from extinction. For example, Gani et al. (2022) reported that they documented 54 types of traditional medicinal plants in Aceh, revealing chemical compounds such as flavonoids and alkaloids that underlie traditional healing practices. This not only provides an opportunity to scientifically validate local knowledge but also ensures that current generations remain connected to their cultural roots.

However, research conducted by Sukrisno et al. (2025) reminds us of the importance of balancing cultural content with scientific depth, as increasing students' cultural awareness needs to be accompanied by a deep understanding of chemistry. In Lombok, the Merariq tradition of the Sasak people has been successfully linked to the concept of chemical bonds (Wahyudiati & Qurniati, 2023), while in Kalimantan, 18 types of Banjar ethnochemistry, such as Sasirangan and Tapai Gambut, have been integrated into high school chemistry lessons (Irawati et al., 2023). Furthermore, in Zambia, traditional practices such as alcohol production are part of the country's chemistry curriculum, which also protects local knowledge from the threats of globalization (Chibuye & Singh, 2024). Meanwhile, innovative learning media such as microblogs based on Malay ethnochemistry (Anggreni et al., 2023) and the Madurese herbal domino card game (Putera, 2023) also strengthen the reasons for the effectiveness of the ethnochemistry approach in making learning more engaging and culturally relevant.

The key factors that support the success of the ethnochemical approach in learning include: 1) Cultural relevance to chemical concepts (the learning content studied is closely related to the culture in students' daily lives, such as medicinal plants or local traditions that occur around students, which can help facilitate understanding of abstract chemical concepts), 2). The use of creative media (The use of e-modules, games, or digital platforms such as microblogs can facilitate the dissemination of traditional community

knowledge and document the existence of the culture, 3). Contextual learning models (Learning approaches such as PBL or task-based learning will allow students to explore chemical concepts through cultural media that exist in their surroundings). With the right and constructive strategy, the ethnochemical approach not only acts as a bridge between science and culture but is also able to answer the challenges of modern education that demand inclusivity and meaningfulness. Through scientific documentation, curriculum integration, and the use of technology, ethnochemistry can be a solution in efforts to preserve cultural heritage while advancing chemistry education in various regions of the world.

Development of Innovative Teaching Materials in Ethnochemistry Learning

The development of innovative technology-based teaching materials has opened up new opportunities for integrating ethnochemistry into chemistry learning. One example is the Adobe Flash media developed by Heliawati et al. (2022), which has proven effective in improving students' scientific literacy. The medium is designed to utilize local wisdom in visualizing abstract chemical concepts, making chemistry learning more contextual and engaging. The technology-based media developed offer an easy and dynamic way to visualize abstract concepts in chemistry, thus facilitating student understanding. However, its effectiveness will depend heavily on the available infrastructure and the teacher's ability to integrate cultural elements into abstract chemical concepts. This finding is consistent with the research of Ridwan et al. (2025), which states that technology has a significant impact when integrated into the community's cultural narrative, ensuring that learning remains relevant and engaging. The Virtual Reality (VR) technology proposed by Pamungkas et al. (2024) and Ningtyas et al. (2025) offers a comprehensive and in-depth approach where the VR-based Two-Tier Multiple Choice (TTMC) instrument that has been developed is valid and effective in detecting student misconceptions and is able to improve conceptual understanding through cultural context.

However, the effectiveness of technology implementation will depend heavily on two main factors: adequate infrastructure and teacher competence in integrating technology into learning. Ridwan et al. (2025) also expressed the same sentiment, stating that technology will have a significant impact on learning if it is accompanied by a strong cultural narrative. Their study showed that ethnochemical integration has successfully improved students' chemical literacy in various respects, including higher-order thinking skills (HOTS) and affective skills, due to its ability to connect abstract concepts with local cultural contexts.

Challenges that often arise include gaps in infrastructure, particularly limited internet access (Dewi et al., 2024), and the need for teacher training, particularly in mastering technological tools and culture-based methodologies (Chibuye & Singh, 2024). Furthermore, the successful implementation of ethnochemistry requires a thorough understanding of local culture and careful adaptation of the curriculum. This is consistent with research conducted by Wahyudiati (2021), who reported that integrating Sasak and Javanese local wisdom into chemical bonding materials not only improves student understanding but also increases their learning motivation. However, this approach must also maintain a balance between cultural relevance and the scientific depth of the knowledge being studied. This is consistent with research by Pebrianti et al. (2024) and Asda et al. (2023), who developed modules and worksheets based on Problem-Based

Learning (PBL) with ethnochemistry that were proven valid and practical, while still emphasizing the need for strict supervision so that the cultural content explored does not obscure the objectives of chemistry learning.

Thus, the development of innovative teaching materials in ethnochemistry requires multidisciplinary collaboration involving chemists, educators, and anthropologists to ensure that technology and culture can synergize without sacrificing academic integration. Meanwhile, follow-up recommendations, especially for future research, include the development of modules for chemistry materials covering various topics (Pebrianti et al., 2024), teacher training (Gani et al., 2022), and the exploration of undocumented local wisdom (Irawati et al., 2023). With a holistic approach, ethnochemistry will not only enrich chemistry learning but also preserve cultural heritage as a valuable natural laboratory in efforts to realize the desired chemistry learning objectives.

Thus, the ethnochemical approach to chemistry learning has a significant impact, offering a variety of benefits, from improved learning outcomes to cultural preservation. However, its success will depend heavily on a well-designed curriculum, teacher training, and ongoing and continuous evaluation. Future research could include a comprehensive exploration of the synergy between the ethnochemical approach and the latest technology and other learning methods, as well as a long-term evaluation of the retention of students' knowledge and attitudes toward chemistry. By addressing all these aspects, educators can harness the potential of the ethnochemical approach to create engaging, effective, and inclusive learning environments. Thus, a comprehensive exploration will emphasize the transformative power of ethnochemistry and its position as a crucial variable in modern education that values cultural diversity while enhancing students' scientific literacy. As education advances rapidly, collaborative forms of cultural integration and scientific innovation will significantly contribute to shaping more meaningful learning in the future.

After understanding the impact of the ethnochemical approach on learning, the next important step is to develop effective strategies for implementing the ethnochemical approach in inclusive and multicultural chemistry education. To develop such effective strategies, an in-depth exploration of ethnochemical development strategies that support inclusivity and multiculturalism in chemistry learning is necessary. The analysis of 27 articles from various studies indicates that realizing inclusive and multicultural learning requires a comprehensive development strategy.

Integration of Local Wisdom and its Theoretical Relevance in Chemistry Learning

One important innovative strategy in chemistry learning is the integration of local wisdom with theoretical concepts in chemistry learning, known as ethnochemistry. When examined in terms of its theoretical relevance, the integration of local wisdom in chemistry learning has covered various topics, including chemical bonds, colloids, thermochemistry, colligative properties of solutions, and chemical kinetics. This learning approach not only makes learning more contextual but can also enrich students' understanding by connecting chemistry with culture and its practices in real life, thus making the learning more meaningful (Ridwan et al., 2025). In addition, Sutrisno et al. (2020) and Wahyudiati & Qurniati (2023) have also successfully explored learning by demonstrating the "Merariq" tradition (Sasak wedding), which can be analogized with the concept of chemical bonds, such as ionic bonds and covalent bonds. This form of analogy

will help students visualize the abstract concepts of chemistry they are learning by relating them to the cultural context they are familiar with in their daily lives. In addition, Wahyudiati (2022) has also explored the use of metals in traditional Sasak and Javanese tools as teaching materials to explain the chemical properties of materials, which also strengthens the relevance of learning to everyday life.

The development of ethnochemistry is also supported by innovative learning media, such as a domino card game based on Madurese herbal medicine (Putera, 2023) or an acid-base module based on Problem-Based Learning (PBL) (Pebrianti et al., 2024). These media not only improve scientific literacy but also preserve local culture. Furthermore, technologies such as Virtual Reality (Ningtyas et al., 2025) are used to detect student misconceptions on the topic of reaction rates through a culture-based approach. However, the application of ethnochemistry cannot always be generalized to all cultures. Wahyudiati (2022) suggests that the integration of Islamic values into ethnochemistry may be less relevant when applied to non-Muslim communities, demonstrating the importance of flexibility in contextualization. Therefore, this challenge can be overcome by selecting local wisdom that is both universal and easily adaptable. For example, the use of traditional medicinal plants (Gani et al., 2022) or the salt-making process (Muti'ah et al., 2023) incorporates concepts from analytical chemistry and organic chemistry. This evidence also demonstrates that local wisdom is not only cultural but also scientific in nature. Thus, integrating local wisdom into chemistry learning has significant potential to enhance student engagement and conceptual understanding, provided it is tailored to the cultural context and supported by creative learning methods and media. This approach not only enriches learning materials but also opens up opportunities for more inclusive and sustainable curriculum development. Through this approach, students learn chemistry not only as an abstract science but also see its relevance to everyday life, thereby fostering an appreciation for their cultural heritage.

Implement Culture-Based Learning Methods and Evaluate Their Effectiveness Periodically

The development of ethnochemistry-based learning strategies depends not only on integrating local culture into the chemistry curriculum but also on the effectiveness of the learning approach. The ethnochemistry Problem-Based Learning (PBL) model is effective in improving students' problem-solving skills (Gultom & Rohaeti, 2024). Similarly, the use of digital media such as Adobe Flash (Heliawati et al., 2022) has shown effective results in improving scientific literacy. The findings of this study align with the theory of contextual teaching and learning (CTL), where students' active involvement in real-world problems can strengthen their understanding, such as the practice of salt making (Muti'ah et al., 2023) or the use of medicinal plants (Gani et al., 2022), which can deepen students' understanding of chemical concepts.

On the other hand, the use of technologies such as Virtual Reality (VR) (Pamungkas et al., 2024) has been able to detect misconceptions and improve students' conceptual understanding through cultural context. These facts also serve as evidence of the emergence of very promising innovations in learning. However, a meta-analysis by Gultom & Rohaeti (2024) found evidence that the effectiveness of PBL will depend heavily on teacher readiness and resource availability. This condition certainly requires support in the form of adequate infrastructure, especially for schools located in remote

areas with limited internet connectivity (Dewi et al., 2024). Furthermore, the role of stakeholders, including collaboration with the local community (Gani et al., 2022) and teacher training (Konyefa & Okigbo, 2021), is also a crucial factor and key to the success of the ethnochemistry development strategy.

However, research by Harianto et al. (2025) suggests that students' chemical literacy remains at an "inadequate" level, despite using an ethnochemical approach. This highlights the need for a comprehensive approach that integrates culture, innovative learning, and teacher capacity development. This means that cultural integration alone is insufficient without the support of qualified teachers.

As a recommendation for future research, it is crucial to focus on developing more adaptive ethnochemistry-based teaching materials, such as e-modules (Dewi et al., 2024) or a chemistry domino card game (Putera, 2023), and to explore integration with other innovative learning models to strengthen their applicability. Thus, ethnochemistry strategies will be able to reach their maximum potential when supported by three pillars: a relevant cultural context, proven effective learning methods, and adequate infrastructure.

Improving the Quality of Human Resources and the Capacity of Stakeholders Through Collaboration with Local Communities

The integration of local knowledge in education, particularly in chemistry, has become a focus of recent research aimed at improving the quality of human resources (HR) and enhancing stakeholder capacity. One effective approach is through ethnochemistry, which combines chemistry with traditional community knowledge. Chibuye & Singh (2024) reported on the integration of local knowledge in Zambia into the secondary school chemistry curriculum. They emphasized the importance of teacher training to master teaching methods involving ethnochemistry. Furthermore, the implementation of ethnochemistry also requires teachers to play a crucial role as mediators between scientific knowledge and local wisdom, while collaborating with local communities (Ridwan et al., 2025) to collect and validate traditional knowledge within an authentic cultural context.

The biggest challenge, which often becomes a barrier, is how to address the gap in understanding between teachers, researchers, and local communities regarding indigenous knowledge systems so that the resulting knowledge is accurate and useful (Gani et al., 2022). Furthermore, stakeholder engagement is often hampered by a communication gap between academics and indigenous leaders, as seen in traditional salt-making activities (Muti'ah et al., 2023).

On the other hand, inclusivity and gender equality also need to be considered. Wahyudiati (2024) found that a gender-based ethnochemical approach improved problem-solving skills in female students. However, caution should be exercised regarding the emergence of gender bias when the culture used as a reference is patriarchal, such as some Javanese or Sasak cultural traditions. Therefore, an ethnochemical approach requires a rigorous screening process to ensure that the cultural values integrated into the learning do not reinforce patriarchal assumptions. Therefore, implications for research and development suggest that ethnochemical research in certain regions remains limited (Aldiansyah et al., 2023), resulting in an imbalance in cultural representation.

Integration of Technological Innovation in Ethnochemistry Learning

Technological developments have brought significant transformations to education, including chemistry. One increasingly popular approach is ethnochemistry, which combines local knowledge with modern chemical concepts. Integrating technological innovations into ethnochemistry learning not only makes the learning process more engaging but also enhances student learning effectiveness. Recent studies have demonstrated how technologies such as Adobe Flash, Virtual Reality (VR), Artificial Intelligence (AI), e-Modules, Microblogs, and technology-based games have been utilized for this purpose.

Heliawati et al. (2022) developed Adobe Flash-based learning media that integrated local knowledge to improve students' scientific literacy. The results showed significant improvement and received positive responses. These findings certainly indicate that the use of Adobe Flash can be an effective tool in delivering chemical material interactively and contextually. Virtual Reality (VR) is also a technology that is being explored quite extensively. For example, Pamungkas et al. (2024) successfully developed a VR-based two-tier multiple-choice (TTMC) instrument to detect student misconceptions on the topic of chemical bonds. The instrument developed was proven valid and effective in identifying student misconceptions. Another study, conducted by Ningtyas et al. (2025), also successfully developed a VR-based TTMC on the topic of reaction rates. The instrument developed had a high level of content validation and was categorized as very effective in detecting student misconceptions. Artificial intelligence (AI) is also beginning to be applied in ethnochemistry learning, as reported by Yamtinah et al. (2025), who conducted a validity evaluation of an AI-based scientific literacy instrument that integrated ethnochemistry concepts, where the instrument was developed and categorized as valid and therefore suitable for measuring students' understanding of the fundamental laws of chemistry.

In addition, ethnochemistry-based e-modules have also proven effective, as reported by Dewi et al. (2024), who found that the use of e-modules not only improves students' chemical literacy but also their ability to solve environmental problems. Meanwhile, Anggreni et al. (2023) utilized microblogs, such as Instagram, to develop acid-base materials based on Malay ethnochemistry. This microblog was categorized as valid and received a positive response from students. Another innovation has also been successfully developed by Putera (2023), who designed a chemical domino card game with integrated barcode technology. This medium was declared very valid for both material and media and received a very good response from students. This shows that a game-based approach can be an interesting alternative to learning chemistry.

Thus, overall, the integration of technology in ethnochemistry learning has proven beneficial in enhancing student understanding, detecting misconceptions, and making learning more interactive and contextual. These findings are not only relevant for chemistry curriculum development but also provide a foundation for further research on the use of technology in science education. As technology continues to advance, opportunities to create more innovative and effective learning methods will remain abundant.

Although the ethnochemical approach is considered capable of enriching chemistry learning while preserving local culture, the existing literature still contains several methodological weaknesses. Many studies do not use a control group. For example, the

research of Wardani et al. (2024) and Harianto et al. (2025) employed a descriptive design or a post-test-only approach without a control group, making it difficult to determine whether the increase in learning outcomes was truly due to ethnochemical interventions or other factors. In addition, the sample size is often small and limited to a single community. For example, the research by Wahyudiati (2024) involved 44 students, Wardani et al. (2024) involved 36 students, and Harianto et al. (2025) involved only 22 students. Consequently, the conclusions of the study may reduce the generalizability of the findings. Another problem is the lack of reporting on the validation and reliability of measurement instruments, such as questionnaires or tests, which can interfere with the credibility of the results, as reported by Wardani et al. (2024). They did not explain the validation process of the chemical literacy test. The lack of study replication also weakens claims about the long-term effectiveness of this approach. This is based on research reports provided by Wahyudiati & Qurniati (2023) and Wahyudiati (2022), which focus solely on the local wisdom of Sasak in Java, without replication in different local wisdom contexts. However, this weakness does not negate the potential of ethnochemistry, but rather emphasizes the need for increased methodological rigor in future research, such as the use of larger samples, controlled experimental designs, and standardized instruments, so that its benefits in chemistry education can be proven more empirically.

Thus, it can be generally concluded that the ethnochemical development strategy has paved the way for more inclusive and meaningful chemistry learning. However, its success will depend heavily on a balance between innovation, cultural critique, and a commitment to bridging theory and practice. By broadening the scope of research, deepening multidisciplinary collaboration, and adopting a critical approach to technology and culture, the ethnochemical approach to learning can become a transformative model in science education.

▪ CONCLUSION

This study affirms the transformative potential of ethnochemistry in bridging the gap between abstract chemical concepts and culturally grounded learning experiences. Through a systematic synthesis of empirical evidence, the study reveals that ethnochemistry acts as a catalyst for holistic education, not only deepening conceptual understanding and 21st-century skills but also fostering cultural identity and inclusivity. However, the effectiveness of this approach depends on addressing systemic challenges, such as uneven cultural representation, inadequate teacher preparedness, and limited infrastructure. To realize the comprehensive potential of ethnochemistry, future efforts should prioritize multidimensional integration that embeds local wisdom into the curriculum through a collaborative framework involving communities, educators, and policymakers. Innovations such as AR/VR and PBL models should be leveraged to contextualize learning, while teacher training programs should emphasize cultural learning alongside scientific content. Equally important is the need for ethnochemistry to undergo a paradigm shift from viewing chemistry as a universal science to one that recognizes it as a dynamic interaction between global knowledge and local practices. Such interactions not only enrich science education but also preserve intangible cultural heritage, positioning ethnochemistry as a foundation for sustainable and globally relevant learning. Ultimately, this research also supports ethnochemistry as a learning tool and a transformative lens that redefines chemistry education to be inclusive, culturally

responsive, and socially impactful. Future research should explore long-term outcomes and cross-cultural adaptation to strengthen its theoretical and practical foundations.

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