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Ethnoscience Approach to Improve Science Literacy on Chemical Bonding: A Thematic Synthesis

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Abstract: This study aims to comprehensively examine the implementation of the ethnoscience approach in teaching chemical bonding and its contribution to improving students' science literacy, particularly at the high school level. The ethnoscience approach is believed to be able to connect abstract scientific concepts with local cultural values, practices, and artifacts, thereby making learning more contextual, meaningful, and relevant to students' lives. The research method employed is a systematic literature review, utilizing the PRISMA framework. The initial search process identified 100 articles from various reputable databases. These articles were selected based on predefined inclusion and exclusion criteria, resulting in 20 articles that met the criteria for in-depth analysis. The analyzed articles were published between 2022 and 2025 and indexed in SINTA and Scopus databases. The synthesis results showed that most studies reported an increase in science literacy through the integration of local culture in chemistry learning. The most dominant learning models were project-based learning and inquiry, followed by contextual learning, as well as other approaches that emphasized active student involvement. Ethnoscience integration was applied at various levels, with a primary focus on junior high and senior high schools, and to some extent on teachers or general contexts. The forms of local wisdom used varied, including regional traditions, batik, and wayang, which were generally combined with innovative learning media to connect chemical concepts with socio-cultural realities. The main findings confirm that the ethnoscience approach not only contributes to improving students' conceptual understanding, critical thinking skills, and scientific attitudes but also fosters awareness and appreciation of local culture. This pattern also reflects the trend of culture-based learning innovation in Indonesia, which is increasingly relevant in addressing the demands of the Merdeka Curriculum. Thus, the application of ethnoscience is recommended as an effective strategy to enhance science literacy while preserving the nation's cultural values.

Keywords: systematic literature review, science literacy, chemical bonds.

▪ INTRODUCTION

Science literacy refers to an individual's ability to interpret, critically evaluate, and apply scientific knowledge in everyday contexts (Kumar et al., 2024). In Indonesia, the level of science literacy remains relatively low, as evidenced by unsatisfactory results from international assessments, such as PISA. This situation underscores the need for reforms in the education system to promote a more comprehensive understanding of scientific concepts and their application in real life (Bilad et al., 2024). However, based on the 2022 PISA results, the science literacy level of Indonesian students is still below the international average, ranking 71st out of 81 countries with a score of 383 (OECD, 2023). This finding suggests that the learning process implemented thus far has not been entirely successful in equipping students with practical scientific skills. Therefore, an

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innovative and contextual learning approach is needed, one that not only emphasizes cognitive aspects but also considers the social and cultural dimensions of learners.

In line with these urgent needs, several recent international studies have highlighted the importance of a science learning approach that is responsive to developments in the 21st century. Zidny & Eilks (2020) stated that current science literacy must include functional, critical, and sociocultural aspects to address global issues such as sustainability and scientific misinformation. Additionally, according to Sumarni et al. (2023), an ethnoscience approach can enhance chemistry literacy by integrating local culture and conceptual understanding. A similar finding was reported by Wardani et al. (2024), who demonstrated that culturally responsive teaching based on ethnoscience contexts is effective in strengthening understanding of abstract chemistry concepts, such as chemical bonds. Therefore, a literature review is necessary to explore the relationship between ethnoscience and the enhancement of science literacy, particularly in abstract chemistry topics.

Chemistry, as a branch of natural science, studies the properties, structure, and changes of substances, as well as the underlying principles (Effendy, 2016). In the field of chemistry, there are three levels of representation: macroscopic representation, which involves direct observation through the senses; submicroscopic representation, which deals with invisible particles such as atoms, ions, and molecules; and symbolic representation, which uses formulas or models to describe these particles (Gkitzia et al., 2020). Addressing the challenge of low science literacy among students, Çalık & Wiyarsi (2024) revealed that interventions based on socio-scientific issues significantly improved students' science literacy, with an effect size of 1.018. This socially and culturally relevant learning helps students understand and apply scientific concepts in a more meaningful way. Furthermore, Widarti et al. (2024) emphasize that integrating ethnoscience elements, such as local cultural practices and activities based on local wisdom, into chemistry learning has a positive impact on the improvement of students' chemistry literacy. Context-based learning, including the ethnoscience approach, has been proven to support students' cognitive, affective, social, and psychomotor development in chemistry learning (Çalık & Sürmeli, 2023). Therefore, the ethnoscience approach helps students connect abstract chemistry concepts with their daily social and cultural experiences, making it an effective and contextual learning strategy.

Ethnoscience is an approach that integrates modern science with local wisdom by transforming traditional knowledge into scientific concepts, thereby supporting meaningful and contextual learning processes (Khusniati et al., 2023). This aligns with Vygotsky's sociocultural theory (1978), which emphasizes the importance of culture and social interaction in cognitive development through the concept of the Zone of Proximal Development (ZPD). Through this approach, students can construct a scientific understanding that is grounded in their cultural background. Research by Wirdarti et al. (2025) shows that integrating local culture can enhance science literacy and student engagement. Similar findings were also reported by Putra et al. (2025), who stated that the application of ethnoscience elements strengthens students' conceptual understanding of abstract material. Thus, ethnoscience is relevant as a learning strategy that connects scientific concepts with students' socio-cultural contexts.

The current national education policy focuses on implementing the Merdeka Curriculum, which emphasizes a holistic and student-centered approach through open access to various learning resources to support concept mastery and competency improvement (Novia et al., 2023). One of the main innovations of this curriculum is the strengthening of character education through the development of the Pancasila student profile (Hasibuan et al., 2023). In this context, integrating local wisdom as a learning resource is one way to implement the dimensions of the Pancasila learner profile (Widana et al., 2023). Local wisdom plays a crucial role in helping students understand science comprehensively and in context, enabling them to scientifically relate their learning to their surroundings.

Chemistry is a discipline that studies the structure, properties, and transformation of matter, including the energy involved in each of its processes (Wirdarti et al., 2021). The complexity and level of abstraction of some chemistry concepts often pose challenges in the learning process, as they can lead to conceptual difficulties and differing perceptions among students (Schütt et al., 2019). Additionally, chemistry is closely related to various dimensions of life, not only in a scientific context but also encompassing social and cultural aspects (Salsabila et al., 2024). Ethnoscience is an educational approach that connects local wisdom, regional potential, and natural phenomena with science within an educational context (Sari et al., 2023). The ethnoscience approach aligns with the Merdeka Curriculum because it connects chemical concepts with local culture through exploration of the surrounding environment. Through this approach, students are encouraged to study science by exploring their surroundings with materials, models, media, and learning outcomes.

This study aims to examine the implementation of the ethnoscience approach in teaching chemical bonding material to improve students' science literacy. Through this study, it is hoped that a comprehensive understanding of the effectiveness of ethnoscience in connecting abstract chemistry concepts with the local cultural context of students will be obtained, allowing learning to become more meaningful, relevant, and contextual.

▪ METHOD

Research Design

This Systematic Literature Review (SLR) was conducted in adherence to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. PRISMA was selected for its comprehensive framework, which ensures transparency, replicability, and methodological rigor throughout the review process. By providing a clear and standardized structure, PRISMA facilitates the systematic identification, evaluation, and synthesis of relevant literature, making it particularly suitable for this study's objective of examining how ethnoscience-based instruction in chemical bonding supports students' science literacy.

Search Strategy

The literature search was conducted using Scopus, SINTA, Web of Science (WoS), DOAJ, and Google Scholar due to their extensive coverage of educational and science education research. To capture the most relevant studies, we employed a precise strategy targeting titles/abstracts/keywords: "ethnoscience" AND "science literacy" AND "chemical bonding". The search was restricted to 2019–2025 to reflect the most recent developments in ethnoscience-informed chemistry teaching. The initial search yielded 100 records.

To ensure the review focused on high-quality and relevant studies, we applied predefined inclusion and exclusion criteria. Inclusion prioritized empirical studies (quantitative, qualitative, or mixed) that explicitly addressed ethnoscience, science literacy, and chemical bonding, reported an instructional intervention or application, were published between 2022-2025, and were open access for full appraisal. Exclusion removed reviews/conceptual papers without empirical data, studies not directly relevant to the three focal constructs, and items without full-text availability.

Screening proceeded in multiple stages to enhance objectivity and minimize bias. First, duplicates (n = 17) were removed from the 100 retrieved records, resulting in 83 records for screening. Next, titles and abstracts of these 83 records were assessed for relevance, resulting in 43 exclusions. Subsequently, 40 full texts were evaluated for eligibility; 20 were excluded because they did not meet the inclusion criteria. Ultimately, 20 empirical studies were included in the final synthesis. Throughout the process, a reference manager, Zotero, was used to ensure accurate tracking and eliminate duplicate records. The PRISMA workflow of this study is visualized in Figure 1.

Identification
Initial search using keywords “ethnoscience” AND “science literacy” AND “chemical bonding” in Scopus, SINTA, WoS, DOAJ, and Google Scholar databases
Records identified from database searching (n = 100) Duplicates removed (n = 17) Records after duplicates removed (n = 83)

↓

Screening
Articles screened by title and abstract relevance to ethnoscience, science literacy, and chemical bonding topics
Records screened by title and abstract (n = 83) Records excluded (n = 43)

↓

Eligibility
Full text evaluation to ensure articles met inclusion criteria (empirical, 2019–2025, open access, relevant to ethnoscience-based learning)
Full-text articles assessed for eligibility (n = 40) Full-text articles excluded, articles did not meet criteria (n = 20)

↓

Inclusion
Final studies included in the synthesis for analysis
Studies included in final synthesis (n = 20)

Figure 1. Article selection process using PRISMA flow diagram

Inclusion and Exclusion Criteria

Data extraction was conducted systematically using a predefined template to ensure accuracy and consistency. From each study, we collected information on the research design, participants/educational level (e.g., junior high, senior high, or teachers), the ethnoscience context or medium employed (e.g., batik, wayang, local traditions; CRT+chemistry ethnoscience; electronic modules), instruments and outcomes related to science/chemistry literacy and conceptual understanding of chemical bonding, as well as the key findings. To minimize bias and maintain reliability, the extraction sheets were cross-checked, and discrepancies were resolved through team discussion.

A thematic analysis was then applied to synthesize the evidence and identify recurring patterns across studies. Following in-depth reading and coding, the codes were organized into overarching themes that illustrate how ethnoscience contributes to enhancing scientific literacy and conceptual understanding of bonding, such as mapping macro, submicro, and symbolic representations, reducing cognitive load, and fostering affective or motivational impacts. Coding emphasized pedagogical models (inquiry/PjBL, culturally responsive teaching), contexts/media (batik, wayang, local illustrations), assessment quality (validity, readability, and measurement of higher-order thinking), and implementation challenges (inclusivity and risk of misinterpretation). Where appropriate, coding was organized using qualitative analysis tools or worksheets to support auditability.

Data Analysis

Finally, the thematic findings were narratively synthesized to provide an integrated account of trends, variations in approach, and implications for chemistry learning. Studies were grouped by methodology, context/media focus, and outcomes to address the research questions on literacy improvement, conceptual change in chemical bonding, assessment quality, and practical barriers or enablers. This narrative synthesis explains what works, for whom, and under what conditions in ethnoscience-based teaching of chemical bonding.

▪ RESULT AND DISSCUSSION

This section begins by presenting the main findings of the most recent studies on ethnoscience-based chemistry teaching, as well as describing the current landscape of strategies aimed at strengthening students' scientific literacy. Among the 20 studies included, the literature consistently reports an increase in literacy and conceptual understanding when local cultural knowledge is integrated into chemistry teaching, particularly through project-based and inquiry-based learning, followed by a contextual approach that encourages active engagement and links macro- and micro-symbolic representations. Integration generally employs various forms of local wisdom (e.g., batik, wayang, regional traditions) and culturally sensitive means of communication to connect abstract concepts to everyday reality, aligning with national curriculum priorities and promoting cultural awareness.

Table 1. Characteristics of included studies

No.	Author (Year)	Context / Level	Sample Size	Aim	LessonTopic
1.	Istyadji & Sauqina (2023)	(General) systematic theoretical review	- 290 Scopus articles - 46 articles on scientific literacy instruments - 43 articles on theoretical frameworks in instrument creation	- Conducting a systematic literature review to identify trends in the development of scientific literacy assessment instruments - Reviewing the theoretical framework used in	An overview of the development of scientific literacy instruments

No.	Author (Year)	Context / Level	Sample Size	Aim	LessonTopic
				the development of the instrument - Analyzing how the framework is used and opportunities for further study in the future	
2.	Masayu (2022)	Senior High School	5 high schools, a total of ±150 students	Analyzing the application of the ethnoscience approach in chemistry learning to improve students' science literacy	Salt hydrolysis, Reaction rate, Heat, Colloid
3.	Gudesma et al. (2024).	Junior High School	Limited trial: 5 students Extensive trial: 22 students	Developing Palembang City ethnoscience-based science e-modules to improve students' science literacy skills.	Physics: Newton's Laws (I, II, III)
4.	Ismail et al. (2024).	Senior High School	30 - 40 students	Integration of ethnoscience to improve learning outcomes, science literacy, and Pancasila values	Chemistry (tape fermentation, batik, shrimp paste)
5.	Suja (2022)	Conceptual, theoretical studies in science education	No sample (literature review article)	Describing efforts to revitalize ethnoscience through inventory, reconstruction, redefinition, and reinterpretation to support science literacy	Chemical concepts in the context of ethnoscience, for example: natural additives, salt production processes, traditional spices, traditional medicines, natural pesticides, and other local cultural practices.
6.	Ware et al (2024)	Senior High School	72 students	Understanding the influence of ethnoscience-based media on students' chemistry learning outcomes and science literacy	Chemical Bonding
7.	Darmawati et al (2025)	Senior High School	60 students	Analyzing the effectiveness of ethnoscience-based worksheets on students' science literacy skills	Electrolyte and Non-Electrolyte Solutions
8.	Imaltin (2024)	Senior High School	14 articles (2019 - 2023)	Reviewing the development of	Various chemistry topics:

No.	Author (Year)	Context / Level	Sample Size	Aim	LessonTopic
				chemistry literacy-based testing instruments in Indonesia	Thermochemistry, Buffer Solutions, Solutions, Stoichiometry, Acids and Bases, Energetics, Salt Hydrolysis, Colloids, Chemical Bonds, Chemical Equilibrium
9.	Rofingah & Fadly (2024)	Senior High School	64 students	Determining the effectiveness of using ethnoscience-based student worksheets in improving student learning outcomes and science literacy	Electrolyte and Non-Electrolyte Solutions
10.	Maulida & Sunarti (2022)	Senior High School	32 students	Developing and testing the feasibility of ethnoscience-based student woorksheets to improve conceptual understanding and science literacy	Salt Hydrolysis
11.	Jumriati & Allo (2024)	Senior High School	66 students	Analyzing the effect of ethnoscience-based learning media on students' science literacy	Chemical Bonding
12.	Mulyono et al (2024)	Senior High School	70 students	Determining the effectiveness of ethnoscience-based worksheets on student learning outcomes and literacy	Acid-base
13.	Olim et al (2024)	Senior High School	68 students	Analyzing the effect of ethnoscience-based learning on students' science literacy and scientific attitudes	Colloid
14.	Lai & Fong (2024)	Senior High School	30 students	Developing valid, practical, and effective ethnoscience-based learning media to improve students' science literacy	redox reactions
15.	Mashami et al (2025)	Senior High School	72 students	Analyzing the effect of ethnoscience-based learning on students' science literacy skills	thermochemistry

No.	Author (Year)	Context / Level	Sample Size	Aim	LessonTopic
16.	Hidayati & Julianto (2025)	Senior High School	64 students	Assessing the effect of ethnoscience-based teaching materials on students' conceptual understanding and scientific attitudes	acids and bases
17.	Wardani et al (2024)	Senior High School	108 students	Analyzing the application of chemistry learning with differentiation based on students' learning styles	chemical bonding
18.	Normayanti & Zamhari (2022)	Senior High School	30 students	Developing valid, practical, and effective ethnoscience-based chemistry modules to improve students' science literacy	Buffer Solution
19.	Candrawulan et al (2023)	Senior High School	62 students	Understanding the impact of ethnoscience-based worksheets on student learning outcomes and science literacy	Colloid
20.	Supriatna et al (2025)	Systematic Literature Review (SINTA 2 article, 2020-2024)	8 selected articles from 2,280 initial searches	Describing trends in the development of ethnoscience-integrated science teaching modules to strengthen scientific concepts and science literacy	Concept of Particles & Chemical Changes

Table 2. Interventions, instruments, and findings

No.	Author (Year)	Intervention / Design	Instruments	Main Finding	Notes
1.	Istyadji & Sauqina (2023)	Systematic Theoretical Review of articles on scientific literacy instrument development	Articles containing scientific literacy instruments, such as those based on PISA, TOSLS (Test of Scientific Literacy Skills), and other frameworks (43 articles using theoretical frameworks)	- There were 46 science literacy instruments successfully identified from the initial 290 articles. Forty-three of these articles were clearly based on a specific theoretical framework. - The trend in instrument development tends to adopt international	This article is not an empirical study with students, but rather a conceptual review. It focuses on analyzing the framework used to develop measurement tools for science literacy.

No.	Author (Year)	Intervention / Design	Instruments	Main Finding	Notes
				frameworks (PISA, TOSLS).	
2.	Masayu (2022)	Ethnoscience Approach	- Science literacy tests (pre-test and post-test) cover aspects of context, competence, and chemistry literacy. - N-Gain as an analysis of improvement - In students' observation	- Experimental classes using an ethnoscience approach showed a significant increase in science literacy in the moderate to high category (average N-gain of 0.58–0.67) compared to control classes (0.28–0.56). - The largest increase was in the scientific problem identification indicator, while the smallest increase was in the scientific knowledge utilization indicator.	- Ethnoscience helps students connect chemistry concepts with local culture (e.g., batik, traditional foods, natural phenomena), making them more meaningful. - Students' chemistry literacy improves as they actively engage in problem solving.
3.	Gudesma et al (2024)	Research and Development (R&D) uses the 4D model (Definition, Design, Development, Deployment)	- literacy test (12 multiple-choice questions, pretest-posttest) - Student response questionnaire - Material and media validation experts	- The e-module is declared valid and practical: Practicality score of 90% (limited trial), 85.61% (extensive trial). - N-Gain: 0.64 (limited trial), 0.68 (extensive trial) → moderate category	- The research subjects were limited to female students at one school. - Further development of other science subjects and broader contexts is recommended
4.	Ismail et al. (2024).	STEAM, Inquiry, Discovery, Ethnoscience-based PBL/PjBL	Tests, worksheets, observations, questionnaires	Improving learning outcomes, conceptual understanding, critical thinking, and cultural appreciation	- Effective for contextualizing abstract concepts, including chemistry - Relevant to local wisdom-based projects

No.	Author (Year)	Intervention / Design	Instruments	Main Finding	Notes
5.	Suja (2022)	Conceptual literature review with a descriptive analysis approach	Sources and previous research results	Revitalizing ethnoscience through three stages (inventory, reconstruction-redefinition, reinterpretation) can improve science literacy by making learning more contextual and meaningful.	The article emphasizes the importance of integrating local and scientific knowledge, ensuring that students remain connected to their cultural roots and develop a scientific mindset.
6.	Ware et al. (2024).	Quasi-experiment with pretest-posttest designs	Learning outcome tests (essays), science literacy tests, and observations	Ethnoscience-based media has a significant positive effect on improving science literacy and student learning outcomes compared to conventional learning.	Research confirms that integrating local culture makes the concept of chemical bonds easier to understand and more meaningful.
7.	Darmawati et al (2025)	Quasi-experiment with pretest-posttest designs	Science literacy tests, questionnaires, and observations	Ethnoscience-based worksheets significantly improve students' science literacy compared to the control class.	Research confirms the importance of integrating local wisdom into chemistry materials to strengthen the understanding of abstract concepts.
8.	Imaltin (2024)	Systematic Literature Review (SLR)	Research articles 2019–2023 (Google Scholar & Publish or Perish)	Chemistry literacy tests are generally valid, reliable, and can improve students' chemistry literacy. However, the scope of the material remains limited, and the number of studies is still relatively small.	There is a need to develop instruments on other chemistry topics and to align them with the latest curriculum.
9.	Rofingah & Fadly (2024)	Quasi-experiment with pretest-posttest designs	Learning outcome tests, science literacy tests, and student response questionnaires	Ethnoscience-based student worksheets significantly improve student learning outcomes and science literacy compared to conventional learning.	The article emphasizes that ethnoscience-based student worksheets make learning more contextual, interesting, and meaningful.

No.	Author (Year)	Intervention / Design	Instruments	Main Finding	Notes
10.	Maulida & Sunarti (2022)	Research and Development (R&D) uses the 4D model (Definition, Design, Development, Deployment)	Expert validation, student response questionnaires, and concept comprehension tests	Ethnoscience-based worksheets are valid, practical, and effective in improving students' conceptual understanding and science literacy.	The article emphasizes the importance of integrating local culture to help students more easily understand abstract chemistry concepts.
11.	Jumriati & Allo (2024)	Quasi-experiment with pretest-posttest designs	Science literacy tests, observations, questionnaires	Ethnoscience-based learning media significantly improve students' science literacy compared to conventional learning.	The article emphasizes that utilizing local cultural contexts helps students understand abstract chemical bonding concepts.
12.	Mulyono et al (2024).	Quasi-experiment with pretest-posttest designs	Learning outcome tests, science literacy tests, and student response questionnaires	Ethnoscience-based worksheets are effective in significantly improving students' learning outcomes and science literacy compared to traditional learning methods.	The article emphasizes that integrating local cultural contexts into student worksheets makes learning more interesting and easier to understand.
13.	Olim et al. (2024).	Quasi-experiment with pretest-posttest designs	Science literacy tests, scientific attitude questionnaires, and observations	Ethnoscience-based learning significantly improves students' science literacy and scientific attitudes compared to the control class.	The article emphasizes the importance of linking colloid concepts to local cultural practices to increase the relevance of learning.
14.	Lai & Fong (2024)	Research and Development (R&D) using the ADDIE model	Expert validation, student response questionnaires, and science literacy tests	Ethnoscience-based learning media are valid, practical, and effective in improving science literacy.	The article emphasizes the need to integrate local culture into learning media, making chemistry concepts more contextual.
15.	Mashami et al (2025).	Quasi-experiment with pretest-posttest designs	Science literacy tests, questionnaires, and observations	Ethnoscience-based learning significantly improves students' science literacy compared to conventional learning.	The article emphasizes that linking thermochemical material to local cultural practices makes concepts easier to understand.

No.	Author (Year)	Intervention / Design	Instruments	Main Finding	Notes
16.	Hidayati & Julianto (2025)	Quasi-experiment with pretest-posttest designs	Concept comprehension tests, scientific attitude questionnaires, and observations	Ethnoscience-based teaching materials have been proven to improve students' conceptual understanding and scientific attitudes compared to conventional learning.	The article emphasizes that using local cultural contexts helps students better understand abstract concepts related to acids and bases.
17.	Wardani et al (2024).	Qualitative descriptive research with a differentiation approach	Learning style questionnaire, learning outcome test, observation	Chemistry learning with effective differentiation enhances conceptual understanding by adapting to students' diverse learning styles.	The article emphasizes the importance of tailoring learning strategies to students' needs, although it does not explicitly link this to ethnoscience.
18.	Normayanti & Zamhari (2022)	Research and Development (R&D) with the 4D model	Expert validation, student response questionnaires, and science literacy tests	Ethnoscience-based chemistry modules are valid, practical, and effective in improving science literacy.	The article emphasizes that integrating ethnoscience into the module makes learning more contextual and relevant to everyday life.
19.	Candrawulan et al (2023).	Quasi-experiment with pretest-posttest designs	Learning outcome tests, science literacy tests, and student response questionnaires	Ethnoscience-based worksheets significantly improve student learning outcomes and science literacy compared to control classes.	The article emphasizes that incorporating local cultural context into colloid material makes learning more meaningful.
20.	Supriatna et al (2025)	Systematic Literature Review using the PRISMA model (4 stages: identification, selection, eligibility, inclusion)	Journal articles (2020-2024) indexed in SINTA 2	Ethnoscience-based teaching modules have been proven to be valid, practical, and effective in enhancing science literacy and fostering an appreciation of local culture. However, research is still limited to certain areas (Kerinci, Bugis,	The study recommends the development of modules based on Sundanese local wisdom, as there has been no research that integrates Sundanese culture explicitly into science modules.

No.	Author (Year)	Intervention / Design	Instruments	Main Finding	Notes
				Sasak, Ponorogo, Malang, Sijunjung, Papua).	

Theme 1: Effectiveness and Implementation of Ethnoscience-Based Approaches in Improving Science Literacy and Classroom Learning Practices

The results of 20 existing studies show that integrating local culture into chemistry, particularly the concept of bonding, can improve students' science literacy. Existing research consistently highlights the effectiveness of ethnoscience-based approaches in improving students' scientific literacy, conceptual understanding, motivation, and Higher-Order Thinking Skills (HOTS). In the context of middle and high schools, integrating local wisdom into science teaching has been shown to create meaningful and contextually relevant learning experiences that are aligned with students' cultural backgrounds.

A recurring finding is a significant increase in science and chemistry literacy when ethnoscience is integrated into teaching materials and teaching models. For example, the use of culturally sensitive teaching integrated with ethnochemistry in chemistry lessons on bonding has shown that students' literacy levels increased substantially, with most students achieving moderate to high levels of proficiency in various content, contexts, and HOTS indicators (Wardani et al., 2024). Similarly, a systematic bibliometric analysis reveals that the ethnoscientific approach yields a high gain effect (N-gain = 0.67) on students' chemistry literacy skills, underscoring its significant impact (Masayu, 2024).

The application of various communication models and tools increasingly demonstrates the flexibility of ethnoscience. The ethnoscience-based e-learning module in Palembang has proven to be effective, practical, and capable of moderately improving literacy skills (N-gain ≈ 0.68), making it an easily accessible tool for self-directed learning (Gudesma et al., 2024). Creative cultural media, such as "WATAK" (chemical paper puppets), contextualize the abstract concept of chemical bonds through local traditions, thereby achieving high validation from experts (94.44%) and strong engagement from students (85%) (Normayanti & Zamhari, 2022). Visual materials, such as naturalistic illustrations, also enhance analytical thinking in the context of science literacy, demonstrating high feasibility and student enthusiasm (Rofingah & Fadly, 2024).

Innovation in assessment is also important for the implementation of ethnoscience. Integrated assessment tools that combine literacy and HOTS with cultural context, such as Sikka local wisdom in the field of acids and bases, achieved very high validity (Aiken's V = 0.85) and readability (83.7%), providing students with contextualized but rigorous assessment tools (Ware et al., 2024). Similarly, assessment tools developed in the context of Madura batik were validated (Aiken's V = 0.87). They received very positive feedback from students (80-84%), demonstrating that contextual assessment promotes deeper engagement with chemistry concepts (Darmawati et al., 2025). A broader systematic review confirms that, although these tools are effective in improving literacy, their availability and diversity are still limited, with relatively few contextual assessment tools developed in various fields of chemistry (Imaltin, 2024; Istyadji & Sauqina, 2023).

Various studies have proven the effectiveness of this model: Students who participate in ethnoscience learning demonstrate higher reading and writing abilities (both in general and in chemistry), greater motivation, better conceptual understanding (especially in complex topics such as bonds, acids and bases, and mixtures), and better development of critical thinking skills (HOTS) (Mashami et al., 2025; Hidayati & Julianto, 2025; Ismail et al., 2024). The diversity of models, ranging from discovery-based frameworks (Mulyono et al., 2024) to STEAM integration and differentiated learning, as well as augmented reality tools (Olim et al., 2024), demonstrates the flexibility of ethnoscience pedagogy in various curriculum and technology contexts.

There is evidence that the ethnoscience approach is effective and flexible for improving reading and writing skills, motivation, and higher-order skills at various levels of education. The strength of this approach lies in its contextual diversity: linking chemistry to local knowledge, cultural media, and community practices increases student engagement and understanding. However, there are still gaps in the widespread application of this approach across subjects and disciplines, in the development of validated tools, and in the training needed for teachers to implement it consistently in the classroom.

Theme 2: Challenges, Global Perspectives, and Reducing Impact

Although chemistry teaching enriched with ethnoscience consistently increases student engagement and literacy, three recurring obstacles hinder its implementation in the classroom: finding an inclusive and accurate cultural context, preventing misunderstandings when translating local knowledge into scientific models, and securing the resources, assessments, and teacher training necessary for sustainable implementation. At the same time, international experiences from Ghana, Norway, and Canada show strikingly similar patterns and offer practical solutions.

The biggest challenge in applying ethnoscience is identifying and maintaining cultural contexts that are not only locally relevant but also encompass diverse identities and perspectives. Research on integrating ethnoscience into science education shows that local knowledge is heterogeneous and context-dependent. If teachers focus solely on symbolic traditions, there is a risk that students from diverse contexts will not feel represented, and their connection to science will become purely symbolic (Ismail et al., 2024). Therefore, ethno-science-based tasks should draw on a variety of cultural practices whose authenticity and relevance to scientific concepts have been verified so that they are not viewed as unique cultural representations.

The second problem, closely related to the first, concerns conceptual accuracy. Studying chemistry already requires students to coordinate between macroscopic, microscopic, and symbolic levels; poor translation between cultural practices and scientific concepts can reinforce alternative concepts (e.g., using two-dimensional diagrams to represent three-dimensional molecular properties) (Olim et al., 2024). As noted in the review, time constraints and limited teacher training often lead schools to use quick visualizations that do not take the chemical triangle into account, thereby increasing rather than reducing the risk of misunderstanding.

The third hurdle relates to potential: teachers, teaching materials, and assessment. In many education systems, teachers express interest in context-based e-learning modules and culturally embedded tasks, but also report limited preparation time, sparse examples, and uneven access to digital tools or devices (e.g., AR), which limits opportunities for exploration outside traditional formats such as lectures or textbooks (Olim et al., 2024). Furthermore, measurement remains a problem: a global theoretical review of instruments for measuring scientific literacy found that only 46 of 290 developments analyzed used 12 conceptual models, highlighting the diversity of constructs and the need to strengthen validity and reliability in instructional decisions (Istyadji & Sauqina, 2023).

Several studies indicate that the issue of integrating local knowledge into science education is not limited to the national level, but is also a global phenomenon. Although studies conducted in Indonesia emphasize the importance of cultural diversity as a source of ethnoscience (Ismail et al., 2024; Suja, 2022), similar findings are observed in an international context, where the gap between school science and indigenous knowledge is a major obstacle. Integration can be effective if it is supported by clear curriculum guidelines and teachers' willingness to create coherent lessons.

International comparisons show that this barrier is not unique. In Ghana, research and policy commentary have repeatedly noted that school knowledge is often “separate” from indigenous knowledge; when teachers consciously integrate local practices, student attitudes and performance improve, but only when there are clear curriculum guidelines and support from teachers (Naah, 2024). Research on teacher training has also shown that future teachers value the integration of IP, but need structured models and examples to create coherent lessons.

A look at Norway highlights the role of technology in science education. The game “AR Table Mystery,” developed for regional science centers, demonstrates the potential of immersive media in illustrating the concept of the periodic table, while also highlighting the importance of technical skills, infrastructural support, and the role of the teacher as a facilitator in ensuring a truly meaningful learning experience (Boletsis & McCallum, 2013). Highly interactive media can therefore present both opportunities and challenges, depending on the availability of school resources and a supportive professional environment (Olim et al., 2024). This concept highlights two prerequisites for implementing ethnic studies: the willingness of teachers to act as cultural mediators and the provision of metacognitive tools to help students navigate different perspectives on knowledge. These findings suggest concrete strategies for risk mitigation:

1. Diversification and consistency of contexts. Instead of a single culture or a single symbolic craft, schools can draw from a “context bank” that includes a variety of local practices, sorted according to the principles of fragmentation, connection, and integration to create conceptual depth and inclusivity (Ismail et al., 2024).
2. Co-design with the local community. Co-developing materials with artisans, parents, and scholars from the community increases authenticity and reduces stereotypes. A study conducted in Ghana with prospective teachers shows that using everyday practices (e.g., agriculture, crafts) illustrates the path “from the known to the unknown” and strengthens learners' identity and independence (Naah, 2024).
3. Strengthen assessment. Use proven frameworks (e.g., PISA strands) and clearly communicate validity (e.g., Aiken's V) when developing context-based literacy skills to reduce construct shifts across subjects and domains (Istyadji & Sauqina, 2023).
4. Introduce technologies incrementally. Begin with low-tech contextualization (electronic modules, local illustrations) and then test high-tech tools (AR) with teacher guidance and school support in terms of equipment, time, and problem-solving (Olim et al., 2024).

In Indonesia and abroad, the main challenge is no longer whether ethnoscience is effective, but how to implement it fairly and consistently. This includes creating inclusive contexts, preventing misinterpretations in model translation, equipping teachers with adequate preparation, and assessing learning with valid instruments. Experiences in Ghana underscore the importance of curriculum alignment and teacher readiness, while action research in Norway highlights the need for resources and effective instructional design. However, what remains underdeveloped is large-scale teacher training programs that can truly enhance their ability to bridge cultural differences, provide fair assessments of scientific literacy across various chemistry topics, and evaluate the cost–benefit of applying advanced technologies in regular schools. Until that is achieved, collaborative approaches that take diverse contexts into account and build capacity gradually remain the most realistic path to generating real impact.

Theme 3: Implications of Ethnoscience Education in the Independent Curriculum

In general, studies indicate that chemistry pedagogy based on ethnoscience not only enhances cognitive outcomes but also strengthens cultural identity, fosters Pancasila-based character values, and supports the development of 21st-century skills. Research that connects chemistry learning with local practices such as the use of natural dyes, fermentation, or traditional material processing has shown improvements in scientific literacy, higher-order thinking, learning motivation, and student participation. These effects arise because learning feels closer to students' lived experiences rather than abstract, imported concepts (Suja, 2022; Wardani et al., 2024; Lai & Fong, 2024). A recent systematic review further emphasizes that ethnoscience situates inquiry within students' real-world contexts, thereby stimulating critical thinking, creativity, collaboration, and scientific communication (Istyadji & Sauqina, 2023). These findings demonstrate that cultural identity and skill development reinforce each other when culture is treated as a design principle rather than an add-on.

This mechanism is closely tied to representational aspects. Chemistry learning requires the integration of macroscopic, submicroscopic, and symbolic levels. By starting from cultural artifacts or familiar practices, students more easily articulate their observations (macro), reason about unseen structures and mechanisms (submicro), and consolidate their understanding with symbols, formulas, or equations (symbolic). Research on culturally responsive chemistry teaching, particularly in bonding topics, illustrates this pathway: students first engage in meaningful practices, then reconstruct them through particle models and bonding frameworks, and finally represent patterns using diagrams or equations; as a result, their literacy profiles show consistent improvement across content, context, and higher-order indicators (Wardani et al., 2024). Complementary design studies also reveal that visual-interactive media can reduce cognitive load at the submicroscopic level and help novices grasp abstract phenomena, provided that these media are explicitly connected to students' contexts and the chemistry triangle (Jumriati & Allo, 2024). In the same spirit, inquiry models adapted to ethnoscience highlight essential 21st-century scientific practices, asking questions, modeling, and evidence-based argumentation while recognizing local knowledge as a legitimate starting point for structured scientific inquiry (Candrawulan et al., 2023).

The cognitive benefits of ethnoscience are closely aligned with character education. Ethnoscience activities are inherently communal, as they encourage students to conduct inquiries with their families and communities on topics such as local crafts, food, medicine, and environmental practices. When framed as “boundary crossing” rather than assimilation, these activities cultivate values of respect (humanity), solidarity (unity), dialogical reasoning (democracy), and concern for the common good (social justice). In the context of sustainability and risk discussions, they also open space for spiritual awareness of creation and responsibility (divinity) (Suja, 2022; Ismail et al., 2024; Supriatna et al., 2025). Frequently, students are asked to consider real-world trade-offs, for instance, between the speed of synthetic dyes and the safety of natural alternatives, prompting ethical reflection that integrates scientific evidence with values (Mashami et al., 2025). Thus, ethnoscience-based learning designs not only strengthen literacy but also provide structured practice in ethical decision-making, collaboration, and problem-solving oriented toward the common good.

A concrete example can be found in a chemistry unit on color rooted in local batik traditions. Students begin with direct observation or video ethnography in community workshops, documenting processes, tools, and decisions in dye preparation and mordanting (macroscopic level). They then explore particle-level mechanisms: why certain dyes bond more strongly with fibers, the role of ionic, covalent, and hydrogen bonding, as well as metal mordants in stability, and construct simple molecular models to predict chromophores and functional groups (submicroscopic level). Next, they translate these explanations into conventional representations, including structural formulas of common natural dyes, net ionic equations for mordanting, and simple equilibrium expressions for dye–fiber interactions (at a symbolic level). The sequence concludes with a reflective seminar on ethics and the environment, where students evaluate accessibility, safety, and waste profiles of natural versus synthetic dyes, propose more eco-friendly adjustments (e.g., reducing energy input, recycling mordant solutions), and link their proposals to Pancasila values such as social justice in protecting artisans’ health and local waters. This single trajectory integrates cultural identity, conceptual understanding, and 21st-century skills (4C), enabling students to analyze, model chemically and visually, negotiate ideas in teams, and communicate well-reasoned positions to authentic audiences such as workshop owners or local policymakers.

The Independent Curriculum explicitly emphasizes literacy, character development, and the Pancasila Student Profile, alongside project-based learning and diverse learning pathways. Ethnoscience naturally supports these aims by situating projects in meaningful local contexts, demanding evidence-based reasoning, and legitimizing differentiated entry points ranging from field documentation and modeling to experimentation and community coordination. To broaden implementation, policy should encourage schools to: (i) establish a context bank that documents local practices linked to core concepts and assessed competencies, (ii) provide professional development through micro-certifications on cultural mediation, macro, submicro, symbolic integration, and assessment literacy, and (iii) strengthen co-design partnerships with artists, parents, universities, and local industries. Assessment policy should also recognize valid, context-rich instruments that target competencies comparable to those assessed by PISA, while remaining sensitive to cultural content (Maulida & Sunarti, 2022; Darmawati et al., 2025; Istyadji & Sauqina, 2023). Technology adoption should proceed gradually: starting with relevant yet straightforward tools such as e-modules, local illustrations, or household-scale experiments, and progressing to AR/VR and data logging where infrastructure and teacher readiness are sufficient, particularly to clarify submicroscopic levels and support collaborative inquiry (Olim et al., 2024; Mulyono et al., 2024).

Overall, the significance of ethnoscience education is integrative: it connects conceptual rigor with cultural identity formation and character education, while cultivating the competencies envisioned by the Independent Curriculum and Pancasila values. Empirical evidence already demonstrates notable improvements in literacy and motivation when culture is effectively integrated into instructional design. However, systemic support remains underdeveloped, particularly in areas such as professional development for teachers in cultural mediation and representation, the development of cross-context assessment instruments with strong validity, and sustained school community partnerships to maintain an inclusive and up-to-date task bank. With these elements in place, ethnoscience can shift from being a niche enrichment program to a central pathway for realizing the Independent Curriculum's vision of science learning that is inclusive, literate, and rooted in cultural values.

▪ CONCLUSION

Based on a synthesis of 20 articles, it was found that the ethnoscience approach plays a significant role in chemistry learning, particularly in the context of chemical bonding. This approach not only contributes to improving students' science literacy but also enriches the meaning of learning through the integration of contextual local culture. The main findings indicate that studies specifically integrating ethnoscience into the topic of chemical bonding are still limited. Most research focuses on developing culturally-based teaching materials, is dominated by high school levels, and employs research designs such as literature reviews and Research and Development (R&D). The main themes emerging from the synthesis include increased learning engagement, strengthened understanding of chemical concepts through cultural analogies, and the relevance of learning to students' lives.

This research has important implications for educational practice, namely the need for a systematic strengthening of the ethnoscience approach in abstract science topics such as chemical bonding. However, limitations in the number of specific studies and the dominance of non-experimental research methods indicate the need for further studies that are more diverse in terms of methodology and context. Therefore, further research is recommended to include quasi-experimental or mixed-method designs with direct measurements of improvements in science literacy. Additionally, the development of locally based cultural media should be expanded to more diverse levels and regions to comprehensively measure its effectiveness. Thus, this study makes an important contribution to educators, researchers, and policymakers by guiding the development of culturally based, locally relevant chemistry education that impacts improvements in students' science literacy in Indonesia.

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