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Analysis of Scientific Literacy and Cultural Civic Literacy in Ethnochemistry-Based Atomic Learning

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Abstract: Formal chemistry learning frequently encounters obstacles in the form of student misconceptions and a disconnect between abstract concepts and everyday life, contributing to Indonesia's low scientific literacy scores in PISA 2022. This study examines the reconstruction of ethnochemistry as an integrative learning approach for atomic concepts and analyses its contribution to facilitating scientific literacy while revitalising students' cultural and civic literacy. Employing a descriptive qualitative narrative literature review, data were gathered from credible scientific articles published between 2020 and 2025. The findings indicate that ethnochemistry effectively reconstructs abstract atomic structure concepts into concrete understanding by integrating local wisdom contexts such as batik-making and traditional fermentation. This approach enhances conceptual understanding, minimises misconceptions, and sharpens science process skills. Furthermore, ethnochemistry-based atomic learning strengthens cultural and civic literacy through the internalisation of character values including mutual cooperation, patriotism, and multicultural awareness and supports the formation of the Pancasila Student Profile. Optimising this approach requires innovation in digital media such as e-flipbooks and Augmented Reality, alongside reinforced implementation of the Merdeka Curriculum. These findings underscore the importance of uniting cognitive and affective dimensions within a cultural framework to nurture a generation that is scientifically literate and strong in national character.

Keywords: Ethnochemistry, Atomic Learning, Scientific Literacy, Cultural and Civic Literacy

Abstrak: *Pembelajaran kimia formal kerap menghadapi hambatan berupa miskonsepsi peserta didik dan keterputusan antara konsep abstrak dengan kehidupan sehari-hari, yang berkontribusi pada rendahnya capaian literasi sains Indonesia dalam PISA 2022. Penelitian ini mengkaji rekonstruksi etnokimia sebagai pendekatan pembelajaran integratif untuk konsep atom dan menganalisis kontribusinya dalam memfasilitasi literasi sains sekaligus merevitalisasi literasi budaya dan kewargaan peserta didik. Dengan menggunakan pendekatan kajian literatur naratif deskriptif kualitatif, data dikumpulkan dari artikel ilmiah kredibel yang diterbitkan antara tahun 2020 dan 2025. Temuan menunjukkan bahwa etnokimia secara efektif merekonstruksi konsep abstrak struktur atom menjadi pemahaman yang konkret melalui integrasi konteks kearifan lokal seperti pembuatan batik dan fermentasi tradisional. Pendekatan ini terbukti meningkatkan pemahaman konsep, meminimalkan miskonsepsi, dan mengasah keterampilan proses sains. Selain itu, pembelajaran atom berbasis etnokimia memperkuat literasi budaya dan kewargaan melalui internalisasi nilai-nilai karakter meliputi gotong royong, cinta tanah air, dan kesadaran multikultural serta mendukung pembentukan Profil Pelajar Pancasila. Optimalisasi pendekatan ini memerlukan inovasi media digital seperti e-flipbook dan Augmented Reality, seiring dengan penguatan implementasi Kurikulum Merdeka. Temuan ini menegaskan pentingnya menyatukan dimensi kognitif dan afektif dalam kerangka budaya guna mencetak generasi yang melek sains sekaligus berkarakter kebangsaan yang kuat.*

Kata Kunci: *Etnokimia, Pembelajaran Atom, Literasi Sains, Literasi Budaya Kewargaan*

INTRODUCTION

Understanding the structure of atoms and their constituent subatomic particles is a fundamental aspect of chemistry. The concept of the atom has undergone transformation from classical models to those grounded in quantum mechanics. However, this shift has not always been accompanied by an updating of basic understanding, resulting in widespread misconceptions. Some students regard traditional atomic models as accurate representations even though more complex quantum mechanical models already exist (Zarkadis et al., 2017). Research conducted by Moneteringtyas et al. (2025) revealed that some students still believe neutrons carry a negative charge because the word 'neutron' is phonetically similar to 'negative', or because of errors in symbolising particle charges. This demonstrates that linguistic and symbolic factors also play a role in the formation of misconceptions. Students frequently develop erroneous understandings, such as assuming that electrons move in fixed orbits like planets or that atoms are inert, indivisible objects. These misconceptions reduce students' interest in learning and make it difficult for them to grasp more complex chemistry concepts at later stages.

One of the goals of education is to strengthen students' capabilities. Student skills are developed through learning processes that encourage them to think and construct understanding of concepts and information. Through literacy, students can develop their reasoning, critical thinking, and analytical skills, which can advance their contribution to the world of work (Astri, 2022). Scientific literacy is not merely the ability to recall formulas or chemical symbols; it is the capacity of individuals to use scientific knowledge to identify questions, acquire new knowledge, and explain scientific phenomena in a logical manner. The aim of scientific literacy is to engage individuals with natural science and to think reflectively when confronted with scientific problems (Putri, 2021). This underscores the importance of chemistry education that can strengthen students' scientific abilities, especially in the field of chemistry. One way to achieve this is by offering chemistry instruction aligned with local wisdom. Chemistry subject matter is widely applicable and plays a role in human life, being closely connected to everyday activities, which is why school-level instruction often takes the form of project-based learning integrated with local culture. Without strong scientific literacy, chemistry learning risks becoming a mechanical process that loses its meaning as a problem-solving instrument.

Education in the modern era does not require only the mastery of scientific knowledge; it also demands the formation of individuals who are culturally sensitive people who can understand, appreciate, and integrate cultural values into social life. Cultural and civic literacy is the ability of individuals to recognise the characteristics of regional culture, understand the various social values that exist, and make ancestral heritage the foundation for active participation in public life. Cultural literacy encompasses the capacity of individuals to understand, appreciate, and interact with diverse cultures (Bu'ulolo, 2021). Cultural and civic literacy not only preserves and develops the national culture but also builds Indonesia's national identity within the global community. The ability to understand diversity and one's obligations as a member of a nation is a competency that every individual in the age of modernisation deserves to possess (Safitri, 2022). Cultural and civic literacy plays an important role in transforming every person into a citizen who is intelligent and of high integrity. Chemistry education should not focus solely on the acquisition of technical knowledge such as understanding the concept of the atom but must also be capable of awakening pride and responsibility in preserving the cultural heritage of the nation. With the understanding that atoms are the fundamental components of all matter, including artefacts and historical objects, students are encouraged to better appreciate their identity within an ever-evolving global context. Chemistry education therefore functions not only as a tool for learning numbers and formulas but also as a medium for strengthening patriotism and instilling noble values in society (Junaedi et al., 2025).

In practice, however, science education and cultural education still tend to proceed separately (Krishantari, 2025). Chemistry instruction is generally more oriented toward the mastery of formal scientific concepts, while cultural aspects are frequently treated only as supplementary elements rather than being substantively integrated into students' knowledge construction processes. This is compounded by the limited use of sociocultural environments as learning resources in chemistry instruction, even though chemistry concepts are closely related to everyday life and the local wisdom of communities (Sanova et al., 2021). As a result, science learning loses the social and cultural context that is actually close to students' lives, even though various cultural practices within society contain scientific values that can potentially serve as contextual and meaningful learning resources. This situation is reflected in Indonesia's low scientific literacy scores in the 2022 Programme for International Student Assessment (PISA). The OECD reported that only approximately 34% of students in Indonesia reached the minimum level of science competency (Level 2), far below the OECD average of 76% (OECD, 2023). These results indicate that the majority of students still experience difficulty in explaining scientific phenomena and interpreting scientific concepts in real-life contexts.

In line with this, several studies have demonstrated that the integration of culture into science learning can bridge the gap between scientific concepts and the realities of everyday life. The integration of ethnoscience through a Culturally Responsive Teaching approach has been reported to connect learning material with local wisdom, thereby enhancing students' conceptual understanding and learning motivation (Munawwarah, 2025). A local context-based learning approach has also been found effective in overcoming the disconnect between abstract chemistry concepts and students' real-world experiences, as evidenced by significant improvements in learning outcomes (Harahap, 2024). Furthermore, community cultural traditions such as customary rituals and local wisdom practices have been found to contain ecological and social scientific values that can be utilised as contextual learning media to strengthen students' science conceptual understanding (Safitri et al., 2026). The use of local culture in contextual learning has also been demonstrated to increase student participation while strengthening the relevance of science content to their cultural identity (Marisa, 2024).

One approach with the potential to integrate chemistry learning with culture is ethnochemistry. Ethnochemistry is the study of chemistry as connected to the local culture of a community (Azizah, 2021). From an ethnoscience perspective, ethnochemistry is understood as an approach that links formal chemistry concepts with community cultural practices, so that chemistry material previously perceived as abstract and remote becomes more accessible to students' lived experiences (Wahyudiati, 2021). This approach enables chemistry concepts, including the concept of the atom, to be explained through real phenomena such as salt production, the use of traditional metals, fermentation, natural dyes, and traditional medicinal practices (Aldiansyah, 2023). Ethnochemistry is thus capable of bridging modern chemistry concepts with locally inherited knowledge, so that students not only understand scientific phenomena concretely but also learn to appreciate the culture of their communities.

In its implementation, ethnochemistry holds great potential for use in teaching the concept of the atom and the structure of matter. Research by Azizah and Premono (2021) demonstrated that various elements of the local wisdom of the Sasak people of Lombok can be integrated into chemistry material, including atomic structure, the periodic table, chemical bonding, and matter and its changes. These local cultural practices can serve as a means of visualising and interpreting submicroscopic concepts that students have long found difficult to understand. Moreover, the application of simple ethnochemistry-based practicals has been regarded as a promising alternative instructional approach, proven to be effective in increasing learning motivation and students' science process skills fostering scientific understanding, promoting critical thinking, and cultivating a deeper scientific attitude (Abu, 2025). Ethnochemistry therefore functions not only as a contextual approach but also as a medium for reconstructing the concept of the atom through cultural experiences that are close to students' lives.

Various prior studies have also demonstrated that integrating culture into science learning has a positive impact on the development of students' thinking abilities and character formation. The development of ethnoscience learning models such as project-based Ethno-STEM has been shown to foster more meaningful conceptual understanding and to enhance higher-order thinking skills, including causal analysis, data processing, evaluation of multiple perspectives, and the creation of new solutions (Asna et al., 2024). Other research has shown that the process of producing songke woven fabric is related to chemistry material such as reaction rates, acid-base chemistry, and chemical bonding in the thread-dyeing stages (Lalang et al., 2023). The integration of Culturally Responsive Teaching based on ethnochemistry has also been reported to develop students' 21st-century skills in the context of hydrolysis material (Arif et al., 2021). Furthermore, the development of ethnochemistry-based teaching materials such as an e-LKPD for critical thinking skills on acid-base material (Ginting & Nurhafidhah, 2025) and an ethnochemistry-based inorganic chemistry practicum textbook (Haryani et al., 2026) demonstrates that the ethnochemistry approach has strong relevance in supporting contextual, adaptive, and locally oriented chemistry learning.

Beyond its impact on the cognitive dimension, the integration of culture in learning also contributes to strengthening students' cultural and civic literacy. Cultural and civic literacy encompasses the ability to understand cultural identity, appreciate diversity, preserve local culture, and demonstrate social responsibility in community life (Nurkhalisa et al., 2023; Widiastuti et al., 2024).

The implementation of cultural and civic literacy in learning is also directed at forming participatory attitudes, cultural awareness, and respect for local values as part of national identity (Safitri & Ramadan, 2022). In the context of ethnochemistry-based atomic learning, indicators of cultural and civic literacy can be reflected through students' ability to identify cultural values in local chemistry practices, appreciate traditional community knowledge, demonstrate concern for cultural and environmental preservation, and connect the concept of the atom and the structure of matter with the socio-cultural phenomena around them (Nurkhalisa et al., 2023; Widiastuti et al., 2024). These indicators can be measured through learning reflections, attitudinal observations, analysis of culture-based projects, and contextual assessments that evaluate the connection between students' chemistry conceptual understanding and their cultural awareness (Safitri & Ramadan, 2022; Andayani et al., 2021). This approach aligns with the concepts of multicultural education and citizenship education, which position education as a means of forming citizens who are not only academically competent but also culturally aware, socially responsible, and capable of living in a diverse society (Purwasari et al., 2023). Ethnochemistry-based atomic learning therefore does not merely help students understand submicroscopic concepts more concretely; it also has the potential to serve as a vehicle for strengthening cultural and civic literacy through the internalisation of local cultural values in science learning.

Although various studies on ethnoscience and ethnochemistry in chemistry learning have developed, research that specifically addresses atomic concept learning through ethnochemistry in relation to scientific literacy and cultural and civic literacy remains relatively limited. Most prior research has focused on the general implementation of ethnoscience, the development of learning media, or improvements in chemistry learning outcomes without integratively linking these to the strengthening of the cultural and citizenship dimensions of students (Munandar et al., 2024; Zulfiani & Handayani, 2024). Existing ethnochemistry research has generally emphasised the development of teaching materials, media, and critical thinking skills for specific topics such as acid-base chemistry, hydrolysis, and reaction rates (Arif et al., 2021; Ginting & Nurhafidhah, 2025). Meanwhile, studies that simultaneously connect the concept of the atom as submicroscopic material with scientific literacy and cultural and civic literacy are rarely encountered. Yet ethnochemistry-based atomic concept learning holds potential not only for improving scientific understanding of abstract concepts such as atomic structure and interactions but also for building cultural awareness, scientific nationalism, and social responsibility in students through the internalisation of local cultural values (Nurkhalisa et al., 2023; Widiastuti et al., 2024). Ethnochemistry can thus be viewed as an integrative approach capable of bridging science concept mastery with the strengthening of cultural identity and citizenship character in a contextual manner.

Based on these conditions, this study contributes a conceptual perspective that integrates atomic concept learning, ethnochemistry, scientific literacy, and cultural and civic literacy within a single, more holistic and meaningful learning framework. This study positions ethnochemistry not only as a contextual approach in chemistry learning but also as a vehicle for strengthening multidimensional literacy encompassing the cognitive, cultural, and civic dimensions. In addition, this article provides a synthesis of how local cultural practices can be reconstructed as learning resources to visualise submicroscopic concepts particularly atomic structure and interactions while simultaneously building students' cultural awareness and social responsibility (Wahyudiati & Fitriani, 2021; Suanda & Wahyudiati, 2023). Based on the foregoing, this study aims to: (1) examine the reconstruction of ethnochemistry as an integrative learning approach for atomic concepts; (2) analyse the role of ethnochemistry in facilitating understanding of atomic structure and its relevance to scientific literacy; (3) investigate the contribution of ethnochemistry-based atomic learning to students' cultural and civic literacy; and (4) explore the implications of ethnochemistry-based atomic concept learning for scientific literacy and cultural and civic literacy.

METHODS

This study employed a literature review approach with a descriptive qualitative research design. This approach was selected to analyse various research findings related to ethnochemistry-based atomic learning in enhancing students' scientific literacy and cultural and civic literacy. A literature review enables the researcher to identify research patterns, compare prior findings, detect contradictions, and identify research gaps pertaining to the integration of local culture in contextual chemistry learning (Wahyudiati, 2021).

The data sources consisted of scientific articles published in national and international journals between 2020 and 2025. The literature search was conducted through the academic databases Google Scholar, Scopus, and Garuda using the keywords 'etnokimia', 'pembelajaran atom', 'literasi sains', 'etnosains', and 'budaya kewargaan'. The use of recent scientific sources aimed to ensure that the data obtained were relevant to current developments in ethnoscience-based chemistry learning research in modern education (Djarwo, 2024).

The literature search was conducted in stages through identification, screening, eligibility, and inclusion. In the identification stage, 126 articles were retrieved from various databases. A screening process was then conducted based on title, abstract, and keyword relevance, resulting in 58 relevant articles. In the eligibility stage, articles were re-evaluated through a full-text review and assessed for alignment with the research focus. The final results showed that 25 articles met the criteria and were used as the primary sources for analysis.

The inclusion criteria for this study were: (1) the article addresses ethnochemistry or ethnoscience in chemistry learning; (2) it covers basic chemistry material, particularly the concept of the atom or other abstract chemistry concepts; (3) it discusses scientific literacy or cultural and civic literacy; (4) it was published in a credible national or international scientific journal; and (5) it was published between 2020 and 2025. The exclusion criteria were: (1) articles without direct relevance to chemistry learning; (2) opinion pieces, short conference proceedings, or non-peer-reviewed works; (3) articles not available in full text; and (4) research with data irrelevant to the study focus. The application of these criteria aimed to ensure the quality and relevance of the sources used (Sanova, 2021).

Data were collected through a documentary study by reviewing all selected articles. The researcher read, identified, recorded, and categorised key information related to the implementation of ethnochemistry-based atomic learning and its effects on the development of students' scientific literacy and cultural and civic literacy. Documentary study enabled the researcher to systematically obtain data from various relevant prior studies (Putri, 2021).

Data were analysed using a qualitative thematic analysis technique comprising four stages: data reduction, theme categorisation, data synthesis, and data interpretation. In the data reduction stage, the researcher selected information relevant to the research focus. Theme categorisation was then carried out based on aspects of ethnochemistry learning, scientific literacy, cultural and civic literacy, learning models, and student learning outcomes. The synthesis stage involved comparing research findings to identify patterns, similarities, differences, and contradictions across studies. The interpretation stage involved constructing a conceptual argument regarding the role of ethnochemistry-based atomic learning in improving scientific literacy and strengthening students' cultural and civic literacy (Wulandari, 2024).

RESULTS AND DISCUSSION

Reconstruction of Ethnochemistry as an Integrative Learning Approach for Atomic Concepts

Ethnochemistry reconstruction is an effort to connect modern chemistry with the cultural practices and local knowledge of a community. In teaching the concept of the atom, ethnochemistry can be used to help students more readily understand abstract material through real phenomena from everyday life (Wahyudiati & Fitriani, 2021). This approach makes learning more connected, meaningful, and accessible because students can see the relationship between chemistry and the culture around them.

The concept of the atom often feels difficult because of its extremely small and invisible nature. Ethnochemistry-based integrative learning can therefore serve as a solution by drawing on traditional practices such as batik-making, cassava fermentation (tape), salt processing, palm sugar production, natural dyeing, and betel lime. In these activities, chemical processes are at work that involve the constituent particles of matter, changes in substances, and interactions between atoms and molecules.

In traditional batik-making, for example, batik wax and natural dyes are used. A teacher can connect the process of dye dissolution and adherence to the fabric with the concepts of atoms, molecules, and chemical bonding. Students can understand that every material is composed of specific atoms with distinctive properties. Another example is the fermentation of cassava in tape production, which involves the activity of microorganisms. Through this experience, students can learn about changes in the arrangement of matter particles and chemical reactions at the atomic level (Munandar et al., 2024).

Ethnochemistry-based integrative learning also contributes to character formation and the preservation of local culture. Students not only learn chemistry theory but also develop an appreciation for the cultural heritage of their region (Almur & Agussalim, 2025). In this way, learning becomes more comprehensive because it unifies knowledge, skills, and attitudes. The implementation of ethnochemistry reconstruction in atomic understanding can be carried out using project-oriented learning models, accessible experimental activities, context-based discussion, and field research. The teacher's role is that of a guide who supports students in connecting cultural phenomena with scientific concepts. This approach is capable of increasing learning motivation, critical thinking skills, and a more comprehensive understanding of chemistry concepts.

In addition to improving conceptual understanding, ethnochemistry-based learning contributes to the preservation of local culture and the formation of students' character. The integration of culture and science makes learning more meaningful because students not only study chemistry theory but also develop an appreciation for the values of their community's culture (Andayani, Anwar, & Hadisaputra, 2021). Other research findings indicate that ethnochemistry learning can improve students' scientific literacy through the integration of local knowledge with modern chemistry concepts, thereby demonstrating that local culture holds great potential as a contextual learning resource in chemistry education (Wulandari et al., 2025).

The Role of Ethnochemistry in Facilitating Understanding of Atomic Structure and Its Contribution to Scientific Literacy

Ethnochemistry plays an important role in helping students understand atomic structure and the role of atoms through learning that is connected to local culture and everyday life. Atomic material that is abstract becomes much easier to understand when students approach it through real phenomena in their environment such as the process of traditional food fermentation, the use of natural materials, or changes in substances encountered daily. Culture-based learning makes it easier for students to connect science concepts with direct experience, making learning more meaningful and contextual (Maharani, Juddin, & Sophian, 2026).

In the learning process, ethnochemistry can also improve students' science process skills. Through activities involving observation of local culture, students are trained to observe, gather information, analyse data, and draw conclusions based on discovered facts. These activities make students more active during the learning process and help improve their critical thinking and problem-solving abilities. Ethnoscience learning has also been found capable of improving students' scientific reasoning through inquiry and contextual approaches (Maharani, Juddin, & Sophian, 2026).

Beyond improving science process skills, ethnochemistry also helps students understand atomic concepts more concretely, thereby reducing misconceptions. Many students perceive atomic material as theory that is difficult to understand because it cannot be observed directly. By linking chemistry concepts to local culture and the surrounding environment, students can understand that changes in substances and particle interactions actually occur frequently in everyday life. The use of local learning resources such as traditional foods, traditional games, and the immediate environment makes chemistry concepts easier to understand and more relevant for students (Oktavian, Pranoto, & Sholihah, 2024).

The ethnochemistry approach also makes learning more student-centred because students are directly involved in the process of discovering scientific concepts through authentic experience. This type of learning can increase students' creativity, activity, and ability to connect culture with modern scientific knowledge. Ethnochemistry therefore constitutes an effective approach for comprehensively improving students' atomic concept understanding, science process skills, and scientific literacy (Oktavian, Pranoto, & Sholihah, 2024).

3. Contribution of Ethnochemistry-Based Atomic Learning to Students' Cultural and Civic Literacy

Cultural and civic literacy is an essential competency that needs to be cultivated in students from an early age. According to Nurkhalisa et al. (2023), cultural literacy is the ability of individuals to understand and take positions toward Indonesian culture as the identity of the nation, while civic literacy is the ability to understand rights and obligations as a citizen. These two competencies do not develop in isolation; they mutually support each other in forming a generation with a strong sense of identity that is simultaneously responsible toward national life. In this context, ethnochemistry-based atomic learning emerges as an approach capable of activating both literacies simultaneously within the chemistry classroom.

Ethnochemistry as a learning approach that integrates chemistry concepts with local cultural practices makes a tangible contribution to strengthening students' cultural identity. When the concepts of atomic structure and chemical bonding are connected with cultural practices such as batik-making, the processing of traditional metals in keris and gamelan, and the fermentation processes involved in producing tempe and tape, students not only understand chemistry more contextually but also construct a sense of pride in the cultural heritage of their nation (Wahyudiati & Fitriani, 2021). This is consistent with the view of Aikenhead and Ogawa (as cited in Zaid & Ahmad, 2026), who assert that modern scientific knowledge and indigenous knowledge can be placed side by side harmoniously in the educational process to enrich students' understanding rather than negate one another. Through this perspective, local culture is no longer regarded as something separate from science but as a source of knowledge that carries dignity and is acknowledged scientifically.

The contribution to civic literacy is no less significant. The various cultural practices used as contexts in atomic learning are laden with civic values such as mutual cooperation, harmony with nature, and responsibility toward environmental sustainability. As Widiastuti et al. (2024) note, civic literacy is not solely about knowledge of law and politics; it encompasses the values, skills, and dispositions required to participate effectively in community and national life. These values are implicitly present in the ethnochemistry context in the wisdom of using environmentally friendly natural dyes in batik, the collective management of materials in the production of earthenware, and the ancestral wisdom of using medicinal plants without harming the ecosystem.

When students understand the chemical basis of these practices, they simultaneously absorb the civic values embedded within them.

Furthermore, ethnochemistry-based atomic learning also contributes to building students' multicultural awareness an important component of civic literacy in a pluralistic nation like Indonesia. By presenting cultural contexts from various ethnic groups from Batak ulos to Palembang songket and Kasongan earthenware side by side in a single learning narrative, students are invited to appreciate cultural diversity as a national strength rather than a source of division. Banks (as cited in Purwasari et al., 2023) asserts that effective multicultural education helps students develop positive attitudes toward their own culture while simultaneously fostering openness toward the cultures of others. In the perspective of ethnochemistry-based atomic learning, every culture receives equal recognition as a contributor to chemical wisdom, so that no single culture appears superior to any other.

The contribution of ethnochemistry-based atomic learning to cultural and civic literacy aligns with the vision of the Pancasila Student Profile as formulated by the Ministry of Education and Culture (2020), particularly in the dimensions of global diversity, mutual cooperation, and critical reasoning. Ladson-Billings (as cited in Yetti & Sumadi, 2025), in her theory of culturally relevant pedagogy, affirms that culturally relevant instruction not only improves academic achievement but also helps students develop critical awareness of their social and cultural conditions an essential foundation for the formation of active and responsible citizens. Ethnochemistry-based atomic learning is therefore not merely a strategy for making chemistry more engaging; it is a transformative approach that simultaneously builds students' science competence, cultural identity, and citizenship character in a holistic manner.

4. Implications of Ethnochemistry-Based Atomic Concept Learning for Scientific Literacy and Cultural–Civic Literacy

Ethnochemistry-based atomic concept learning has positive implications for the advancement of students' scientific literacy and cultural and civic literacy because it connects scientific concepts with the cultural realities of students' everyday lives. This approach not only supports students in understanding atomic concepts in a more concrete and contextual manner but also enhances awareness of local cultural values as part of their civic identity. Learning about atomic concepts based on ethnochemistry can integrate scientific principles with students' cultural experiences, making the learning process more relevant and meaningful. Through the use of interactive simulations, online laboratories, and demonstration videos, students can develop understanding of atomic concepts and their cultural connections for example, in the production of iron, ceramics, and the combustion of local materials (Djarwo et al., 2025). Suanda and Wahyudiati (2023) also revealed that the Ngejot tradition contains scientific principles closely related to atomic structure material. In line with this, Seprianto and Hasibuan (2021) and Asda et al. (2023) argued that the ethnochemistry and ethnoscience approaches are highly effective in improving students' scientific literacy, science process skills, and critical thinking abilities.

In addition to improving science understanding, teaching atomic concepts through an ethnochemistry focus also strengthens students' understanding of cultural and civic literacy. Anastasya et al. (2024) state that cultural and civic understanding is essential for maintaining cultural identity in the era of globalisation. Ethnochemistry learning makes culture a source of learning that allows students not only to understand chemistry more deeply but also to appreciate local traditions. Anggreni et al. (2023) emphasise that the ethnochemistry approach can increase students' sense of responsibility, creativity, self-confidence, patriotism, and social care. In the context of atomic instruction, these affective dimensions are manifested when students realise that their ancestors had already applied atomistic principles in cultural traditions long before modern science formally articulated them. Research by Wati et al. (2024) also shows that the Merdeka Curriculum grounded in local wisdom contributes to the formation of students' character and cultural pride.

Learning about atomic concepts through the ethnochemistry approach aligns with the principle of deep learning because it connects these concepts with students' authentic experiences.

Syafi'i (2025) notes that deep learning helps students understand how concepts are applied in everyday life. The ethnochemistry approach supports this principle because the culture explored in learning is an element of students' daily lives. Research by Wijaya et al. (2023) reveals that integrating local culture into the learning process can improve students' critical thinking abilities, character formation, and social skills. In the context of atomic learning through ethnochemistry, the concept of the atom becomes more meaningful because it is connected to cultural practices familiar to students, while simultaneously stimulating reflection on the relationship between traditional knowledge and modern science through authentic and enriching cultural exploration. This aligns with the Merdeka Curriculum's emphasis on meaningful, relevant, and student-centred learning (Haq & Prasetiyo, 2025).

To optimise the understanding of atomic concepts through the ethnochemistry approach, innovations in media, digital technology, and culture-focused curriculum reinforcement are required. Djarwo et al. (2025) recommend the development of modules that prioritise digital literacy and ethnoscience, while Nareswari et al. (2023) developed an 'Etnochem' e-flipbook that leverages local wisdom through a STEAM approach. In addition, Augmented Reality (AR) and Virtual Reality (VR) technologies can play a role in demonstrating atomic concepts using cultural objects such as gamelan and keris (Laila & Atun, 2026). Reinforcing a culturally grounded curriculum is also of paramount importance to ensure that ethnochemistry learning proceeds in an orderly manner within the Merdeka Curriculum. Annisha (2024) notes that integrating local wisdom can cultivate students' sense of cultural pride and identity.

Overall, the mastery of atomic concepts grounded in ethnochemistry is not merely about methodological innovation; it represents a new paradigm in chemistry education that positions culture as both the medium and the means of learning. When cognitive and affective elements converge within a strong cultural context supported by innovative media, digital technology, and a responsive curriculum chemistry instruction can produce a generation that not only understands science but also possesses cultural awareness and strong civic consciousness as the foundation for national development in the face of 21st-century challenges.

CONCLUSION

The findings of this study demonstrate that the ethnochemistry approach successfully reconstructs the learning of atomic concepts previously considered abstract, submicroscopic, and prone to misconceptions into a concrete, contextual, and meaningful learning process. Through the integration of various cultural practices and local wisdom, such as batik-making, traditional food fermentation (tape and tempe), the processing of metals in keris and gamelan, and the Ngejot tradition, students can visualise matter interactions and atomic structure through real phenomena in their surrounding environment. This interdisciplinary approach has been proven to not only enhance comprehensive chemistry conceptual understanding and reduce students' scientific misconceptions, but also to significantly sharpen science process skills (scientific reasoning) through activities involving observation, data analysis, critical thinking, and problem-solving.

In addition to strengthening the cognitive dimension and scientific literacy, ethnochemistry-based atomic learning makes a substantive contribution to the revitalisation of students' cultural and civic literacy. When students are able to explore and understand the scientific basis behind the traditional technologies of their ancestors, this process simultaneously cultivates pride, patriotism, multicultural awareness, and a strengthened sense of national identity amid the currents of globalisation. The civic values embedded in local cultural practices such as mutual cooperation and responsibility toward environmental sustainability are also implicitly absorbed by students, which is entirely consistent with the vision of the Pancasila Student Profile in the Merdeka Curriculum. The future implications of these findings underscore the importance of sustained innovation through the integration of digital technologies (such as e-flipbooks and Augmented Reality) and the reinforcement of local-wisdom-based curricula, with the aim of producing 21st-century generations that are not only scientifically excellent but also possessed of existential awareness and a strong national character.

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