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Digital Ethnoscience: AR/VR Media Shaping Chemistry Learning in Indonesia

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ABSTRACT

Chemistry learning still faces challenges due to the abstract nature of its concepts, particularly at the submicroscopic level, as well as the limited connection between subject matter and students' everyday life contexts. Augmented reality (AR) and virtual reality (VR), on the other hand, offer interactive visualizations that can help students understand chemical concepts more concretely, while ethnoscience provides cultural context and local wisdom that make learning more meaningful. This article aims to analyze the trends, characteristics, and future directions of ethnoscience-based AR/VR media in chemistry learning in Indonesia through a systematic literature review. The findings indicate that AR is more widely used than VR, especially for topics that require spatial visualization such as atomic structure, chemical bonding, molecular shapes, and virtual laboratories. Research on ethnoscience in chemistry education has also grown rapidly, particularly in improving chemical literacy and promoting contextual learning. However, the direct integration of ethnoscience-based AR/VR remains limited. These findings highlight that the future development of chemistry learning media needs to balance technological aspects, conceptual accuracy, cultural relevance, and readiness for classroom implementation.

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1. INTRODUCTION

Chemistry instruction has a distinctive character compared to other school subjects because it requires students to understand phenomena at three levels of representation simultaneously: macroscopic, submicroscopic, and symbolic (Johnstone, 1991; Ismail, 2020). This condition creates learning difficulties when students try to integrate their understanding of real phenomena, abstract particle models, and theoretical symbolic language (Rahmawati et al., 2022). As a result, they often become trapped in rote memorization and are unable to develop a deep and coherent understanding of chemical concepts. Therefore, instructional media play a crucial role in helping to visualize complex theories that are impossible to capture directly with the human senses (Marbun et al., 2025).

The rapid advancement of technology in recent years has paved the way for transforming chemistry education through the use of augmented reality (AR) and virtual reality (VR) as innovative instructional media. AR enriches physical reality with interactive visual overlays, whereas VR creates digital environments that bring learning experiences into more immersive three-dimensional spaces (Joronavalona et al., 2025; Laila & Atun, 2026). Both technologies are regarded as potential solutions in chemistry learning because they can animate visualizations of molecular structures and particle interactions, as well as provide virtual laboratory simulations for various processes that cannot be directly observed. A growing body of research has demonstrated that integrating AR/VR can enhance students’ engagement and enthusiasm and sharpen their visuospatial abilities, ultimately strengthening conceptual understanding, particularly when combined with appropriate instructional design (Fransiska & Fitriyani, 2024; Wijayanti et al., 2024).

However, technological sophistication alone is not sufficient to ensure the success of innovative instructional media; it must also be relevant to students’ social, cultural, and lived contexts. Indonesia’s rich cultural diversity holds tremendous potential as meaningful and contextual learning material for students. Through the lens of ethnoscience, various local cultural practices from the use of natural materials to traditional processing techniques are viewed as valuable local wisdom that deserves to be brought into real-life contexts in science learning, including chemistry (Munawwarah & Alqadri, 2025; Nuraini & Aznam, 2026).

Through an ethnoscience approach, students can explore chemical theories more concretely by engaging with local wisdom in their surroundings, such as salt production techniques, fermentation processes, the use of natural dyes, and the processing of local food ingredients (Fadhilah et al., 2024; Pratiwi et al., 2024; Yuendita & Rohaeti, 2025). In this way, the implementation of ethnoscience not only deepens subject matter content but also plays a vital role in fostering pride in cultural identity while creating a much more memorable form of chemical literacy for students. The research trend on integrating ethnoscience into chemistry education appears to be rapidly accelerating, in line with the growing number of academics who are exploring the potential of local wisdom. Recent reviews indicate that, over the past three years, more and more researchers have published work on ethnoscience in chemistry education, which has been shown to greatly support the learning process and generate new ideas for school curricula (Yuendita & Rohaeti, 2025).

Despite this promising development, research on ethnoscience and technology-enhanced learning has largely evolved along separate trajectories. Although research on ethnoscience continues to grow, studies that specifically combine the potential of AR/VR technology with local wisdom in chemistry education are still rarely explored in depth. Research on the use of AR in chemistry has mostly focused on molecular visualization or virtual laboratory simulations; however, only a few studies have attempted to connect these technologies with the rich local cultural heritage found in Indonesia (Fransiska & Fitriyani, 2024; Laila & Atun, 2026). On the other hand, studies on ethnoscience have so far tended to rely on the use of printed modules (Pratiwi et al., 2024) or student worksheets (Suparwati et al., 2023) and have not yet extensively addressed the use of more modern immersive media.

The integration of AR/VR technology and ethnoscience concepts actually has a very strong foundation for further development (Pusparani & Selamat, 2021). The use of 3D visualization technologies has been shown to help students simplify and organize complex information so that it becomes easier to understand, while ethnoscience serves as a conceptual bridge that helps students grasp new subject matter by connecting it to cultural experiences that are already familiar in their daily lives. In other words, AR/VR functions to clarify the visualization of content, whereas ethnoscience ensures that this content feels authentic and relevant to students’ lives. The combination of these two elements has the potential to make chemistry learning much easier to understand because the material is presented in a way that is both concrete and closely aligned with students lived experiences (Hadisaputra et al., 2025).

The potential of AR/VR technology and ethnoscience-based approaches has often been investigated separately as means of simplifying complex chemistry content, yet efforts to integrate the two within a single learning design remain very limited and warrant further exploration. Drawing on a review of various scientific publications, this article seeks to map out new directions for future chemistry learning media that can balance technological sophistication with cultural values as a foundation for making the learning process more meaningful.

2. METHODS

This study employs a Systematic Literature Review (SLR) method guided by the PRISMA 2020 protocol (Haddaway et al., 2018; van Dinter et al., 2021) to ensure that the entire analytical process is structured, transparent, and accountable. The use of this method aims to comprehensively and systematically map trends in the integration of AR/VR technology with ethnoscience in chemistry education in Indonesia.

The research data consist of journal articles and scientific conference proceedings published between 2016 and 2025, retrieved from Google Scholar and Scopus. The search was conducted using specific combinations of keywords covering AR/VR technology, chemistry education, and ethnoscience in the Indonesian context to obtain relevant literature. This ten-year time span was deliberately set so that the analysis would accurately capture current trends and recent innovations in the development of chemistry learning media.

Data selection was carried out by applying several criteria: selected articles had to focus on chemistry education, employ AR/VR media or ethnoscience, present empirical data or development results, and be relevant to the Indonesian context. Conversely, articles were excluded if they discussed technology only in general terms without any connection to chemistry, lacked a clear methodological description, or were not available in full-text form. The selection procedure consisted of four stages: (1) identification (initial data collection), (2) screening (verifying the relevance of titles and abstracts), (3) eligibility (assessing the full text based on the criteria), and (4) inclusion (determining the final set of articles). The entire selection process was documented in a PRISMA flow diagram to maintain transparency. Data extracted from the selected articles included year of publication, type of media, chemistry topic, cultural context, and key findings. These data were then synthesized using a thematic–descriptive approach to identify trend patterns, research contributions, and directions for the future development of chemistry learning media.

3. FINDINGS AND DISCUSSION

General Trends in the Literature

The literature review shows that research combining AR, VR, and ethnoscience in chemistry learning is still at a very early stage. Studies on AR are currently far more numerous than those on VR, while work on ethnoscience in education has actually expanded rapidly over the past few years. Even so, articles that directly and explicitly fuse AR/VR technology with ethnoscience in a single instructional design remain difficult to find. As a result, this study largely concentrates on two closely related strands: the use of AR/VR in chemistry and the implementation of ethnoscience in chemistry learning (Yuendita & Rohaeti, 2025; Laila & Atun, 2026; Fillah et al., 2026).

This situation suggests that, although technological innovation and culture-based approaches are both advancing quickly, they are still rarely brought together in a coherent learning framework. Thus, this study argues that future research should move beyond simply producing sophisticated digital media and instead prioritize how these technologies can be meaningfully interwoven with local wisdom, so that learning chemistry feels more concrete, contextual, and personally relevant for students.

Table 1. Summary of Literature Pattern Findings.

Focus of Review	Trend of Findings	Implications
AR in Chemistry Learning	Widely used for visualizing abstract concepts, molecular structures, and as interactive media (Hoai et al., 2024; Kenneally & Bentley, 2024; Ripsam & Nerdel, 2024).	Suitable for content that is difficult to imagine directly.
VR in Chemistry Learning	Research frequency is relatively lower, but it has proven superior in facilitating 3D simulation and exploration (Novianty et al., 2020; Pereshvikina et al., 2021).	Suitable for immersive learning experiences and virtual laboratories.
Ethnoscience	Growing rapidly, especially for local context and chemical literacy (Faista et al., 2023; Prasetyo et al., 2023; Wardani et al., 2023).	Makes learning more contextual and relevant.
Integration of AR/VR and Ethnoscience	Still limited and tends to appear in early-stage development studies (Pusparani & Selamat, 2021; Kurniawan & Sumari, 2024; Hadisaputra et al., 2025; Fillah et al., 2026).	Becomes a promising direction for future research.

Table 1 shows that AR and VR excel at providing vivid, immersive visualizations, while ethnoscience adds a cultural layer that makes learning more meaningful. Bringing these two together offers a promising way to tackle two major challenges in chemistry education: content that is hard for students to picture, and the lingering perception that chemistry has little to do with their everyday lives.

Patterns of Use and Chemistry Topics

In studies on AR and VR, the chemistry topics most frequently explored tend to be those that demand strong visual support, such as atomic structure, chemical bonding, molecular geometry, and virtual laboratory simulations. This is unsurprising, since immersive technologies are particularly powerful for clarifying abstract concepts that cannot be directly observed. Typically, AR is employed to project digital objects into the real world, while VR places students inside a fully simulated environment that feels complete and surrounding (Wijayanti et al., 2024; Laila & Atun, 2026).

By contrast, ethnoscience studies more often connect chemistry to local cultural practices, natural materials, and everyday phenomena, such as traditional foods, natural dyes, salt production, fermentation, or processes grounded in local wisdom. This highlights the role of ethnoscience as a bridge between scientific concepts and students lived experiences. When these two tendencies are brought together, the most promising targets are topics that are abstract yet closely tied to local practices—for example, molecular structures in natural products, chemical changes in traditional foods, or crystallization processes in salt production (Fadhilah et al., 2024; Pratiwi et al., 2024).

Table 2. Chemistry Topics and Integration Potentials

Chemistry Topics	AR/VR Potential	Ethnoscience Potential
Atomic structure and chemical bonding	Visualization of 3D models and particle interactions (Aris et al., 2020; Hoai et al., 2024).	Can be linked to minerals or local products (Faista et al., 2023; Wardani et al., 2023).
Molecular shape and stereochemistry	Spatial exploration and rotation of objects (Chiu et al., 2019; Kenmeally & Bentley, 2024).	Can be linked to natural compounds and traditional

		foods (Nazar et al., 2024; Olim et al., 2024).
Chemical equilibrium and reaction rate	Simulation of dynamic processes (Pereshvikina et al., 2021; Fitria, 2023).	Can be contextualized through fermentation and changes in food materials (Faista et al., 2023; Rizky & Andromeda, 2024).
Crystals and solutions	Virtual laboratories and visual simulations (Novianty et al., 2020; Rusdi et al., 2023).	Can be connected to salt, crystallization, and local materials (Wardani et al., 2023; Rizky & Andromeda, 2024).

Table 2 illustrates that integrating AR/VR with ethnoscience is especially well suited to chemistry topics that are abstract yet closely tied to local community life. It serves as a reminder that media selection should not be driven solely by technological sophistication, but must align with sound pedagogy and remain relevant to students' immediate environments.

Implications for Learning Outcomes and Chemical Literacy

Most studies indicate that AR and VR are highly effective in boosting students' motivation, conceptual understanding, and participation, because they make it possible to visualize chemistry content that is usually hard to imagine. At the same time, ethnoscience-based approaches have been shown to strengthen scientific literacy and help students recognize that chemistry is deeply intertwined with their own cultural traditions. In simple terms, if AR/VR serves as the engine for engaging visuals and interactive experiences, ethnoscience provides the meaning and real-world context behind what students are learning.

Several studies that have begun to combine these two approaches report that AR/VR media infused with local wisdom can make students more engaged and help them grasp the material more easily. Although the number of such studies is still limited, these early results send a strong signal that blending advanced technology with local culture is not just a novelty, but a highly promising direction for education. Taken together, these findings reinforce the idea that chemistry learning becomes far more effective when students are not only exposed to theory but are also invited to understand the context and practical value of that knowledge in their everyday lives.

Critical Analysis and Directions for Future Research

Unlike AR/VR studies in education more broadly, the main bottleneck in chemistry learning does not lie in how sophisticated the devices are, but in how well learning activities are designed to balance visualization, interaction, and scientific theory. Many AR/VR products are technically impressive, yet still fall short when it comes to targeting specific learning objectives in chemistry. Conversely, ethnoscience-based approaches are rich in cultural values, but they have not always taken full advantage of immersive technologies to help students grasp abstract chemical concepts.

For this reason, developing learning media that treats local culture not as decorative "background," but as the core of chemical explanation becomes a promising way forward. For example, VR can be used to simulate chemical processes involved in producing traditional goods, while AR can visualize the molecular structures of the local materials used in those products. Through such designs, the integration of AR/VR and ethnoscience is no longer just a technological upgrade, but a learning strategy that weaves together science, cultural values, and powerful visual representation into a coherent whole.

Table 3. Development Directions Based on Review Findings

Aspect	Literature Findings	Development Directions
AR	Dominant in the visualization of abstract concepts (Hoai et al., 2024; Kenneally & Bentley, 2024; Ripsam & Nerdel, 2024).	Needs to be extended to local contexts and ethnoscience.
VR	Has strong potential for 3D simulation and exploration (Novianty et al., 2020; Pereshvikina et al., 2021).	To be developed for culture-based learning experiences.
Ethnoscience	Strong in local contexts and chemical literacy (Faista et al., 2023; Prasetyo et al., 2023; Wardani et al., 2023).	To be connected with interactive digital media
Integration of AR/VR and ethnoscience	Still limited (Pusparani & Selamat, 2021; Kurniawan & Sumari, 2024; Hadisaputra et al., 2025; Fillah et al., 2026).	Becomes a priority focus for future research and development.

Conceptual Contributions of the Review

This study shows that the development of chemistry learning media in Indonesia is gradually shifting toward formats that are more visual, interactive, and concrete for students. The key contribution is not simply the introduction of yet another type of digital tool, but the opening of a pathway for integrating immersive technologies with local wisdom. Indirectly, the article argues that the most meaningful innovations for chemistry education in Indonesia are those that can connect complex theoretical ideas with the cultural experiences that are already familiar in students' everyday lives.

4. CONCLUSION

This review shows that although AR, VR, and ethnoscience in Indonesian chemistry education are still mostly applied separately, they each hold strong potential to complement one another. AR and VR excel at visualizing abstract concepts and enabling simulations, while ethnoscience adds depth by situating learning in local cultural contexts. Even though integrated implementations are still limited, existing attempts indicate that combining these approaches can effectively enhance students' understanding and engagement with difficult content. Future media development should therefore prioritize designs that are not only technologically sophisticated, but also scientifically sound and closely aligned with Indonesia's cultural realities.

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