Enhancing Scientific Literacy through Augmented Reality in Ethnochemistry: Exploring Students' Perceptions in Sasambo Cultural Context

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***Abstract*—Enhancing students' scientific literacy is essential to help them develop critical thinking and problem-solving skills in science learning. This study aims to develop an AR application that can visualize the molecular structure of chemical compounds from the perspective of the Sasambo ethnic group. The Sasambo ethnic group's rich cultural heritage and traditional practices contribute significantly to the cultural mosaic of Indonesia. This research employed a mixed-method approach involving development, implementation, and evaluation stages. The Augmented Reality (AR) application was developed using Unity 3D and Vuforia SDK, and validated by media and content experts. Data were collected through questionnaires and scientific literacy tests. The study involved a sample group of eighty-five students taking basic chemistry courses to ensure the reliability and relevance of the findings. The results indicated that students found the AR application practical and effective for learning chemistry, with 60.0% agreeing on its efficiency and 46.7% strongly agreeing that it aided in understanding ethnochemical concepts. Additionally, 40.7% reported improved scientific literacy, and 56.7% emphasized integrating cultural elements. Scientific literacy outcomes also showed high proficiency, particularly in interpreting data (77.24%), explaining data scientifically (75.25%), and designing investigations (58.75%). This research contributes to integrating local wisdom into science education through immersive technology, providing an innovative approach that bridges cultural context with abstract scientific content and supports the development of culturally responsive and engaging chemistry learning.**

***Keywords*—augmented reality, ethnochemistry, traditional practices, scientific literacy**

I. Introduction

Chemistry learning in the modern era demands innovation to increase students' understanding and involvement more deeply [1, 2]. One increasingly relevant approach is integrating technology and local culture into learning, which allows the association of chemical concepts with students' daily experiences [3]. This integration enriches students' learning experiences and increases the relevance of the subject matter to their daily lives, making learning more applicable and easier to understand [4, 5]. Combining modern technology and local wisdom makes chemistry learning more contextual and meaningful, encouraging increased student science literacy [6, 7]. This approach also facilitates understanding complex chemical concepts through higher visualization and interactivity, strengthening students' cultural identity [8, 9]. Thus, integrating technology and local wisdom in chemistry learning can increase students' engagement, understanding, and appreciation of science and culture [10, 11].

However, one of the main problems in chemistry education is students' difficulty understanding abstract concepts such as molecular structure, bonding, and chemical interactions [12]. These concepts are often presented in a decontextualized manner, far from students' everyday experiences. As a result, students struggle to see the relevance of their learning, leading to a lack of interest, low engagement, and superficial understanding. This issue is particularly evident when learning relies heavily on textual or two-dimensional representations, which fail to convey chemical phenomena' spatial and interactive nature. Moreover, conventional learning often overlooks the cultural context that could otherwise serve as a bridge between scientific knowledge and students' lived realities.

The integration of Augmented Reality (AR) technology in the visualization of chemical molecules has become an essential innovation in science education, allowing students to understand the structure and interactions of molecules in a more in-depth and interactive way. With AR, students can manipulate three-dimensional molecular models, significantly enhancing their understanding of molecular geometry and chemical bond types [7]. In addition, AR facilitates the understanding of spatial concepts that are often difficult to grasp through conventional learning methods, such as two-dimensional modelling on paper or static visualization on a screen [13]. Suh and Propper [5] showed that using AR in chemistry education significantly increased student engagement and learning outcomes, as this approach allows for a more dynamic and interactive exploration of concepts. In addition, AR also provides the advantage of improving students' molecular visualization skills, which are important in understanding chemical reactions and interactions between molecules [10].

Furthermore, the implementation of AR in the chemistry curriculum has been proven effective in reducing the gap between theory and practice and facilitating knowledge transfer from abstract concepts to real applications [11]. In collaborative learning, AR allows students to interact simultaneously with molecular models, enriching discussions and understanding of concepts [4]. Therefore, AR technology enriches the learning experience and improves students' long-term knowledge retention in the visualization of chemical molecules [6].

AR technology in chemistry learning has great potential to

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facilitate students' scientific literacy by integrating local cultural elements into teaching materials. AR allows students to experience interactive simulations of chemical processes relevant to local wisdom, such as traditional salt-making techniques or fermentation processes in making local foods. In this way, students can understand abstract chemistry concepts through a cultural context close to their lives, enhancing their engagement and understanding of science [14, 15]. The use of AR in education not only enriches students' learning experiences, facilitates deeper conceptual understanding, and improves overall scientific literacy [16]. In addition, AR can strengthen the connection between scientific knowledge and local culture, making learning more relevant and meaningful for students [1].

Despite its promise, current research and applications of AR in chemistry learning have yet to fully explore its potential in integrating local cultural wisdom. There is a significant gap in studies that contextualize AR-based chemistry education within specific ethnic traditions or indigenous knowledge systems, especially those rooted in Indonesia's rich cultural heritage. This lack of contextualized innovation limits the cultural relevance and identity-based engagement in science learning.

Combining ethnochemistry and AR technology can be an innovative solution to overcome the challenges of learning chemistry that is abstract and difficult for students to understand. When ethnochemistry is combined with AR, students not only learn chemistry concepts in an abstract form but also see how these concepts are applied in everyday life through their cultural traditions. It increases student engagement and helps them relate new knowledge to their everyday experiences, thus deepening their understanding and improving their scientific literacy. AR technology has been widely applied to facilitate chemistry learning, such as in the visualization of molecular structures and simulation of chemical reactions [17, 18]. Although AR shows excellent potential in chemistry education, to our knowledge, no study explicitly applies AR in the context of local cultural wisdom related to aspects of chemistry topics. This research was therefore conducted to address that gap by developing and implementing an AR-based learning tool rooted in the local wisdom of the Sasak, Samawa, and Mbojo Sasambo ethnic groups in West Nusa Tenggara (NTB). Some aspects of local wisdom that are the focus of this study include traditional medicine, the use of natural dyes, traditional foods, salt making, coconut sugar making, and traditional coconut oil processing.

The Sasambo ethnic group has a rich cultural heritage incorporating various traditional practices closely related to chemical processes. One notable example is traditional fabric dyeing using natural colourants such as indigo leaves, Sumba seeds, areca nut, and mangosteen rind. These natural dyes contain anthocyanin pigments, a group of flavonoid compounds responsible for plants' red, purple, and blue colouration. Anthocyanins, including cyanidin, delphinidin, and pelargonidin, have been widely used in traditional textiles due to their vibrant colour profiles and chemical stability [19–21]. Fig. 1 illustrates examples of anthocyanin sources used in Sasambo traditional batik dyeing.

In addition to textile dyeing, coconut-based products such as palm sugar and coconut oil play a crucial role in Sasambo cultural practices. The production of palm sugar involves the thermal degradation of glucose ($C_6H_{12}O_6$), which under acidic heating conditions forms 5-Hydroxymethyl-2-Furaldehyde (HMF)—a key marker of sugar breakdown in food chemistry [22–24]. Meanwhile, traditional coconut oil processing utilizes coconut milk as a base, where proteins such as albumin and globulin contribute to the colloidal stability of the emulsion during extraction. These proteins are responsible for maintaining the dispersion of fat and water, making them essential components in the formation and stability of natural coconut oil [25, 26].

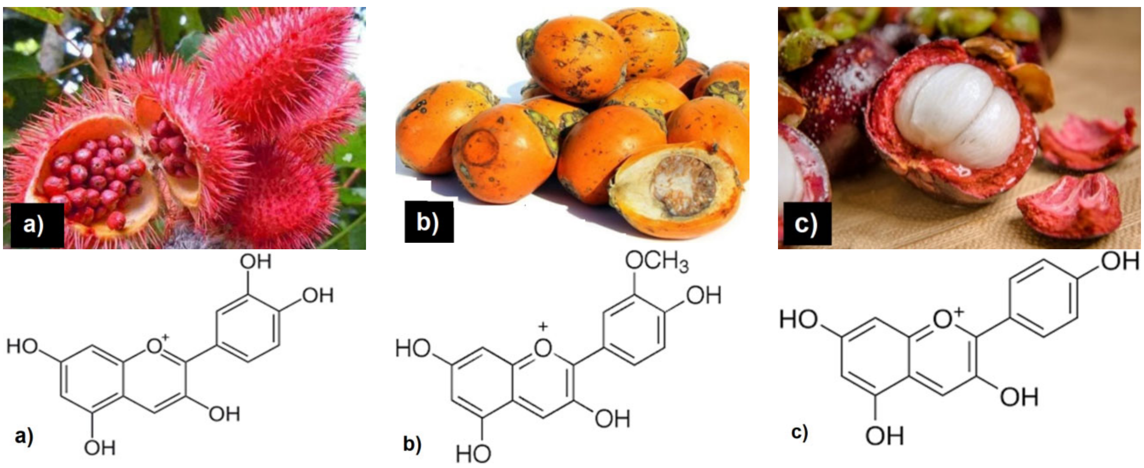

Fig. 1. Natural dyes for traditional fabrics. a) Safari seeds contain Cyanidin pigment. b) Areca nut contains Peonidin pigment. c) Mangosteen contains pelargonidin as a natural color pigment.

Another culturally significant process is traditional salt production along coastal regions such as Bima. Salt is obtained by sun-drying seawater in shallow pans, resulting in sodium chloride (NaCl) crystallization. This practice reflects basic crystallization and ionic bonding principles, as the arrangement of Na^+ and Cl^- ions into a cubic lattice can be observed and studied to understand fundamental chemical structures [4].

II. Methodology

A. Development Process

This study adopts the 4D development model—Define, Design, Develop, Disseminate—by Thiagarajan *et al.* [27] to guide the creation of AR-based chemistry learning media integrated with local wisdom. In the define stage, researchers identified educational needs and the potential of incorporating Sasambo cultural elements to ensure the content is scientifically accurate and culturally relevant, thereby enhancing student engagement and understanding [3].

AR media was developed in the design stage to connect abstract chemical concepts with ethnochemical practices rooted in Sasambo traditions. Chemical structures were modelled using ChemDraw 12.0 and Chem3D to produce accurate 2D and 3D representations [28, 29], enabling interactive visualization in AR environments [30]. The development process used Unity 2021.3 LTS with AR Foundation and Vuforia Engine SDK 10×. At the same time, models were optimized in Blender 3.1 and enhanced with interactive features like rotation, zoom, and on-tap information display [31–34]. Testing was conducted on a laptop (Intel Core i5, 8GB RAM, and the NVIDIA GTX 1050 Ti. For mobile deployment, Xiaomi Redmi Note 8 running Android 10+ with 4GB RAM, an octa-core processor, and GPU support for OpenGL ES 3.0

Implementation in classrooms followed three phases: preparation (media finalization and teacher training), implementation (student interaction), and evaluation (scientific literacy tests and perception questionnaires). In the dissemination stage, the AR media was introduced to broader educational settings to assess its cultural and pedagogical relevance [4, 35]. This approach highlights integrating immersive technology and local wisdom to promote culturally responsive and engaging science education.

B. Obtaining Chemical Information

The first step of this research involved gathering chemical information related to ethnochemical practices within the Sasambo ethnic group—comprising the Sasak, Samawa, and Mbojo communities in West Nusa Tenggara, Indonesia. Their local wisdom is rich in ethnochemical applications, including traditional medicine, natural dyeing, food fermentation, and salt and coconut oil production. This stage focused on identifying active compounds in medicinal plants, pigments in dyes, and chemical processes in traditional practices, serving as the foundation for integrating cultural context into chemistry learning.

C. Visualization of Ethnochemical Concepts through AR

The development of AR media successfully transformed abstract ethnochemical concepts into immersive visual experiences, as shown in Figs. 2–4. Fig. 2 presents the AR interface designed to visualize anthocyanin pigment molecules found in traditional fabric dyes. Students can interact with detailed 3D molecular structures such as cyanidin, peonidin, and pelargonidin, which are key components in natural dyes used by the Sasambo community. These visualizations allow users to observe the aromatic ring systems and glycosidic linkages that define anthocyanins, fostering a better understanding of their role as flavonoid pigments and their chemical variability based on plant sources.

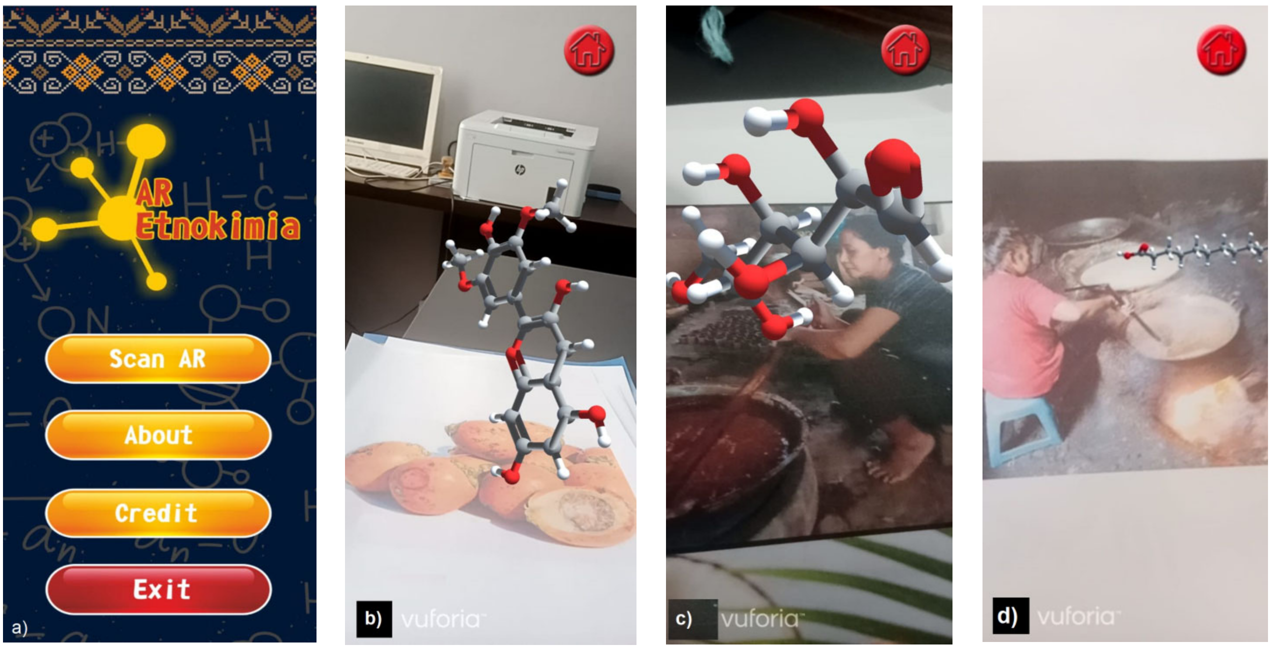

Fig. 2. a) Augmented Reality Cover for visualization of molecules related to ethnochemical aspects. b) Visualization of anthocyanin pigment molecules using AR c) The process of making coconut oil d) Traditional coconut oil making through heating.

Fig. 3 expands the AR experience to include visualization of glucose degradation in coconut sugar production and protein structures in coconut oil processing. Learners can view the molecular form of 5-Hydroxymethyl-2-Furaldehyde (HMF), a compound produced through the heating of glucose, directly linked to the traditional method of palm sugar making. Additionally, AR visualizations depict the globular structure of globulin, a protein that stabilizes coconut milk during oil extraction, making protein interaction and folding patterns tangible for students. In Fig. 4, AR showcases the ionic lattice structure of NaCl, simulating the crystallization process of traditional salt making. Students can explore the three-dimensional cubic arrangement through interactive manipulation of Na^+ and Cl^- ions and comprehend ionic bonding and symmetry in crystal systems.

D. Student Grouping and Questionnaire Design

To ensure contextual relevance, students were grouped according to their cultural backgrounds—Sasak, Samawa, and Mbojo—within the Sasambo ethnic group. It allowed the study to assess how each subgroup responded to AR-based chemistry learning integrated with local wisdom, ensuring scientific understanding and cultural authenticity.

Student perceptions were measured using a validated 5-point Likert scale questionnaire covering five aspects: ease and practicality of the AR application (A), conceptual understanding in ethnochemistry (B), enhancement of scientific literacy (C), academic benefits (D), and the importance of cultural integration in learning (E).

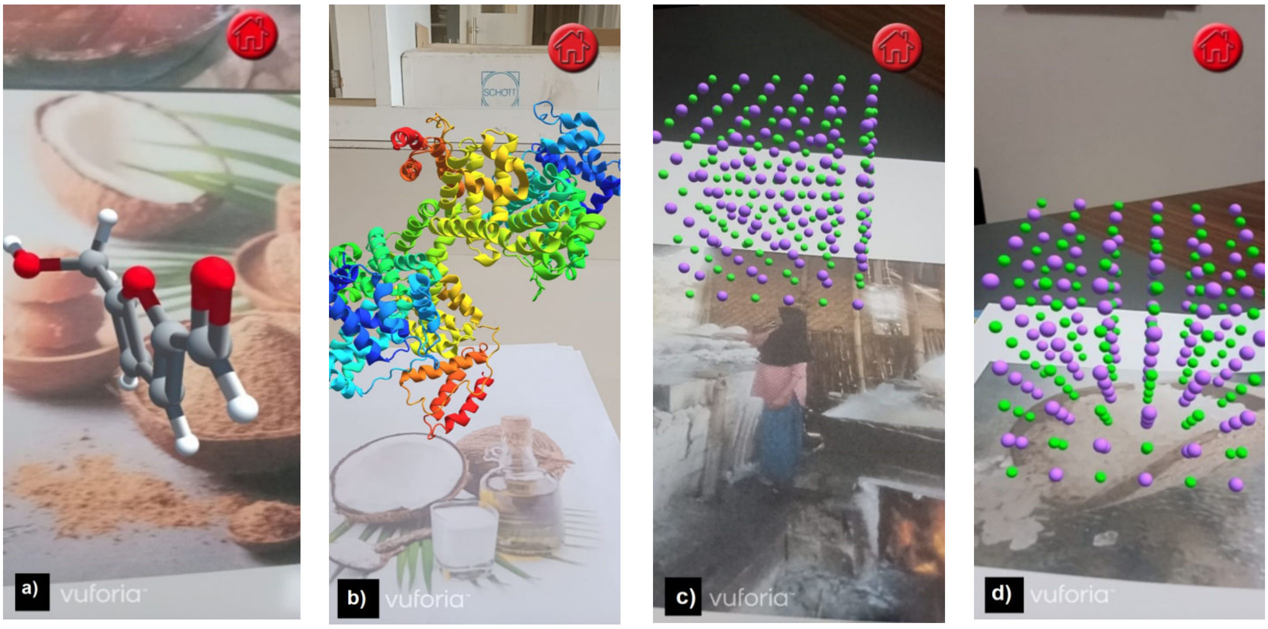

Fig. 3. a). Visualization of 5-hydroxymethyl-2-furaldehyde in coconut sugar; b) visualization of globulin protein as the main compound in coconut milk; c) Traditional salt making through a heating process. d) Visualization of the NaCl structure from table salt.

III. Results and Discussion

A. Implementation and Student Engagement with AR-Based Ethnochemistry Learning

The implementation of the developed AR application was carried out in a basic chemistry class consisting of 85 students, of whom approximately 95% identified with the Sasambo ethnic groups—namely Sasak (Lombok), Samawa (Sumbawa), and Mbojo (Bima)—in West Nusa Tenggara, Indonesia. These ethnic groups were purposefully selected as the ethnochemical content embedded within the AR application directly aligned with their local practices and traditional knowledge. During classroom implementation, students were organized into small collaborative groups and assigned tasks to explore molecular structures associated with cultural activities such as natural dyeing, salt crystallization, and coconut-based product processing. Students navigated interactive three-dimensional models using their smartphones, allowing them to manipulate and visualize chemical structures derived from their daily cultural context (Fig. 4).

Evaluation of the AR media's effectiveness was conducted through a structured questionnaire assessing student perception and perceived improvement in scientific literacy. The results revealed a positive reception, with a large proportion of students agreeing that the AR learning experience was interactive, culturally meaningful, and conceptually accessible. Students reported that the ability to visualize abstract chemical concepts in AR helped them better understand scientific ideas and relate them to their traditional practices. This not only enhanced comprehension but also reinforced the relevance of chemistry in everyday life. Notably, many students exhibited increased confidence in explaining molecular structures and their functions, suggesting a deeper conceptual grasp fostered through contextual learning. These findings confirm that integrating AR with ethnochemistry supports scientific understanding and enhances student engagement by validating and connecting with their cultural identity—an outcome consistent with contemporary approaches to culturally responsive science education.

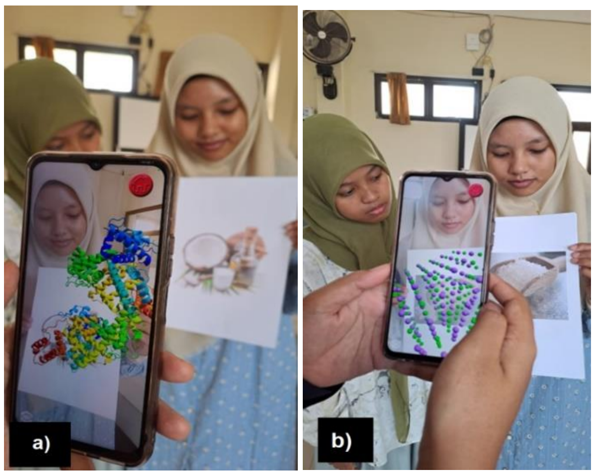

Fig. 4. Learning activities using AR related to ethnochemistry in class. a). Students visualize globulin protein as the main compound in coconut milk; b) Students visualize the NaCl structure from table salt.

B. Students' Perceptions Regarding AR

Further analysis of the student's perceptions regarding AR confirmed that 48% of students either agreed or strongly agreed that the AR-based media enhanced their ability to visualize and understand chemical structures, particularly those related to local cultural practices (Fig. 5). Specifically, 28% agreed, and 20% strongly agreed that the AR helped them understand and visualize chemical principles in ethnochemistry (Item B). This finding suggests that the AR application did not merely serve as a digital visualization tool, but also functioned as a meaningful bridge between abstract chemical concepts and students' lived cultural experiences [36–38]. By embedding chemical content within familiar ethnochemical contexts, the AR media appeared to foster deeper conceptual engagement and improve the contextual relevance of chemistry learning.

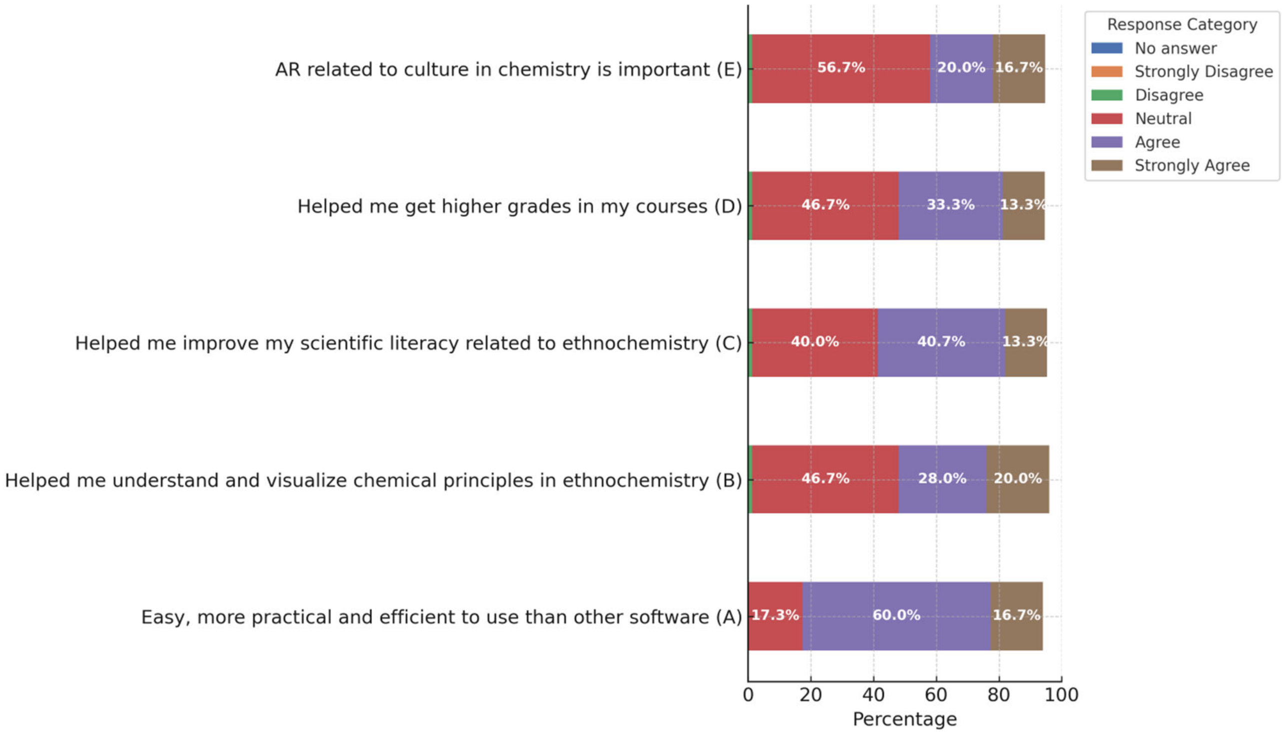

Fig. 5. Student perceptions of AR-based ethnochemistry.

Although the instrument did not require students to rank specific chemical structures, classroom observations and informal interviews revealed that students were especially engaged when interacting with AR models related to traditional fabric dyeing—an important cultural practice among Sasambo communities. These dyeing techniques use natural colourants derived from Sumba seeds, areca nut, and mangosteen, rich in anthocyanin pigments. The anthocyanin molecular structures, when visualized in AR, appeared particularly impactful due to their direct connection to students' daily life experiences. Students showed increased enthusiasm and comprehension when learning through these culturally familiar materials, underscoring the importance of aligning instructional design with cultural context to improve science education outcomes.

Regarding overall educational benefits, 53.3% of students (40.0% agreed and 13.3% strongly agreed) indicated that the AR application improved their scientific literacy related to ethnochemistry (Item C). It supports the idea that combining immersive technology with culturally relevant content can significantly enhance students' conceptual comprehension. Furthermore, 46.7% of students (33.3% agreed and 13.3% strongly agreed) believed that the AR helped them achieve better academic outcomes (Item D), even though only a third explicitly stated that it improved their grades. Notably, 56.7% of students strongly agreed that integrating AR with cultural content is important in chemistry learning (Item E), highlighting strong support for culturally responsive educational approaches. These perceptions were also reflected in classroom dynamics, where increased student motivation, curiosity, and confidence were consistently observed during AR-enhanced learning activities.

A particularly significant learning outcome was students' improved comprehension of chemical structures associated with natural pigments, especially anthocyanins, in traditional dyeing practices. These molecular visualizations were easier for students to grasp and more engaging due to their cultural familiarity. The convergence of immersive technology with local wisdom rendered scientific content more accessible, tangible, and personally meaningful, illustrating how AR can be effectively leveraged to bridge the gap between abstract molecular science and real-world cultural applications in diverse educational settings.

C. Student Science Literacy after Using AR

The improvement of students' science literacy skills can also be viewed from the aspect of science literacy competency, which consists of 3 indicators of science literacy, namely indicators of explaining phenomena scientifically, interpreting data and scientific facts and evaluating and designing scientific investigations [39–43]. The improvement in each indicator of science literacy is shown in Fig. 6.

Students' ability to interpret scientific data and facts reached 77.24%, which is indicated by their ability to recognize issues and key characteristics of phenomena contained in scientifically investigated literacy question instruments. This mastery shows that students can identify scientific issues directly related to their scientific knowledge, especially in ethnochemistry. In the learning process, analysis questions on scientific literacy connect students' cognitive aspects with phenomena they often encounter in everyday life. These questions encourage students to apply scientific knowledge in real-world contexts, which helps them develop critical thinking and problem-solving skills [44]. Based on cognitive learning theory, students use their prior knowledge to process new information by linking it to previously acquired knowledge. This process, known as cognitive schemata, allows students to strengthen their understanding by integrating new concepts into existing knowledge frameworks [41]. Scientific literacy questions that require in-depth analysis test students' conceptual understanding and promote more meaningful learning [45].

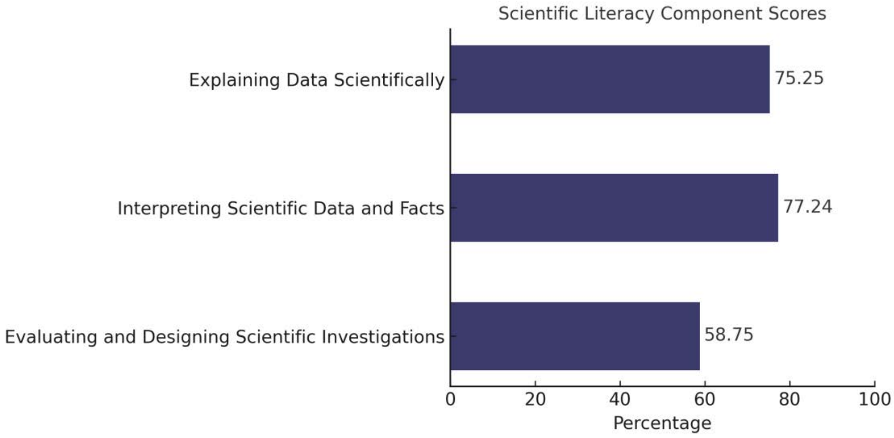

Fig. 6. Aspects of students' scientific literacy after using augmented reality.

The scientific literacy competency aspect in the indicator explaining phenomena scientifically achieved by students was 75.02% with good criteria. It is shown through students' ability to apply the scientific knowledge they have understood, especially related to local culture. Students' ability to explain phenomena scientifically shows that their understanding of scientific concepts significantly impacts their ability to respond to phenomena they encounter in everyday life.

On the other hand, the scientific literacy aspect in the evaluation and design of scientific investigation indicators achieved by students was 58.2% with sufficient criteria. This value shows that students' ability to evaluate and design scientific investigations still needs improvement. It may be due to students' limitations in evaluating the things needed to understand aspects of scientific literacy, especially in the context of local culture. For example, students may need help designing experiments involving traditional materials or evaluating the scientific processes in that context.

IV. Conclusion

AR technology developed for visualizing the structure of chemical compounds in the context of local cultural traditions has proven effective in improving students' scientific literacy. By utilizing AR to visualize ethnochemical processes such as dyeing batik cloth, making coconut sugar, coconut oil, and traditional table salt, students can more easily, practically, and effectively understand the structure of chemical molecules. In conclusion, students considered AR an important and useful tool for supporting chemistry learning. Significantly, students' scientific literacy towards local customs and traditions increased by an average of 70% after using AR in class. This study confirms that integrating AR technology in chemistry learning improves understanding of chemical materials and strengthens appreciation for local cultural traditions.

Despite these promising results, this study has several areas warrant further exploration. The current research primarily focused on students' perceptions and conceptual understanding but did not include in-depth cognitive assessments or long-term learning retention. Future studies are recommended to include pre-and post-test designs that quantitatively measure learning gains in different cognitive domains, as well as comparative studies between AR-based and traditional learning methods. In addition, expanding the scope of cultural representation beyond the Sasambo ethnic group could provide insights into how AR supports cross-cultural science education. It is also suggested that future development integrates more interactive elements, such as simulation of chemical reactions, voice-over explanations, or gamification features, to engage learners further. Lastly, further research is needed to explore how AR can be adapted for inclusive education, ensuring accessibility for students with diverse learning needs and technological limitations.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization, S.H.; methodology, S.H..; data curation, J.I. S.H; writing—original draft preparation, S.H., Y.A., and B.B; writing—review and editing, S. H. Y. A. A. L. and J.I; authors have read and agreed to the published version of the manuscript. All authors had approved the final version.

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