



ETHNO-VIRTUAL REALITY MEDIA ON WEDHANG UWUH AS A TRADITIONAL INDONESIAN HERBAL BEVERAGE TO SUPPORT SCIENCE AND TECHNOLOGY LITERACY

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ABSTRACT

Indonesian higher-education science learning requires environments that connect scientific concepts, digital technologies, and culturally meaningful contexts. This study investigated an Ethno-Virtual Reality (Ethno-VR) learning environment centered on Wedhang Uwuh, a traditional Indonesian herbal beverage. The investigation focused on its pedagogical characteristics, scientific content, validity, and reported student responses. A mixed-methods research and development design was employed with 29 chemistry education students enrolled in a Mini Research Practicum and three experts in science education, ethnoscience, and educational technology. Data came from expert validation, student-response questionnaires, observations, interviews, documentation, and contextual laboratory activities involving organoleptic and gas-sensor observations. The Ethno-VR environment was organized as an interactive virtual museum containing cultural history, health and social perspectives, preparation processes, scientific explanations, experimental evidence, and multimedia resources. Expert validation supported the revised media's applicability. The ratings indicate positive perceptions of the learning experience, cultural relevance, inquiry activities, and perceived support for science and technology literacy. The findings support media quality and perceived learning affordances rather than causal claims about literacy gains.

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Keywords: ethno-virtual reality; wedhang uwuh; culturally responsive; scientific literacy; technological literacy; immersive learning

INTRODUCTION

Science and technology literacy is increasingly important in higher education. Students need to understand scientific concepts, interpret evidence, evaluate claims, use digital technologies appropriately, and communicate reasoned conclusions. Contemporary science education

emphasizes scientific practices, inquiry, and socially relevant questions as important contexts for scientific literacy (Holbrook & Rannikmae, 2007; Bossér, 2024; Eymur & Çetin, 2024). Expanding digital learning environments also increases the need for pedagogically purposeful, sustainable technologies connected to authentic contexts (Dziubaniuk et al., 2023; Moro et al., 2023). The present study responds to this need by linking dis-

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ciplinary science, digital technology, inquiry, and culturally meaningful learning.

Virtual Reality (VR) provides immersive environments for exploring places, processes, and representations that may be difficult to access directly. Systematic reviews indicate that its educational value depends on learning-task design, instructional guidance, and alignment between technological features and pedagogical purposes (Radianti et al., 2020; Won et al., 2023; Lui et al., 2023; Oje et al., 2025). Meta-analytic evidence also indicates benefits of VR in STEM learning, particularly when activities involve active learning rather than passive viewing (Cromley et al., 2023). Here, VR functions as an instructional environment rather than a presentation technology.

Ethnoscience provides a complementary foundation by positioning community knowledge and local practices as meaningful contexts for reconstructing scientific concepts. Examining local knowledge enables students to compare experiential explanations with disciplinary concepts. Socio-scientific issues (SSI) extend this process by engaging students with evidence, benefits, risks, social interests, and environmental consequences associated with familiar practices. Research on functional scientific literacy likewise emphasizes SSI, discussion, evidence, and inquiry (Zidny & Eilks, 2018; Rahmawati et al., 2020; Bossér, 2024).

Wedhang Uwuh is a traditional Indonesian hot beverage made from herbal and spice-based plant ingredients and is significant in local cultural practices (Estiasih et al., 2025; Fauziyyah et al., 2025). Its preparation provides observable contexts for discussing extraction, diffusion, color and aroma changes, secondary metabolites, sensory properties, and relationships between traditional knowledge and scientific interpretation (Nugraheni et al., 2025). While it can be compared to other global hot beverages, such as Germany's Glühwein and China's ginger tea, each remains distinct in cultural context and preparation methods. Glühwein is wine-based, specific to the Advent season and Christmas traditions (Germany Travel, 2026), whereas ginger tea in China often incorporates brown sugar and serves various traditional purposes (Chao et al., 2011; Shanghai Municipal Government, 2025). Japan's tea culture, exemplified by *chanoyu* (the tea ceremony), emphasizes careful preparation and hospitality (Japan National Tourism Organization, 2022), contrasting with the spice-centric nature of Wedhang Uwuh. These comparisons aim to contextualize Wedhang Uwuh for international audiences, highlighting its unique Indone-

sian origins and sensory qualities. In education, particularly science education, gaps remain in integrating immersive technologies with culturally relevant scientific inquiry. The emphasis has often been on the immersive experience rather than its connection to local knowledge.

Research highlights three gaps in the study of ethnoscience, SSI, and immersive technologies in science education. While many VR studies focus on immersion, fewer link immersive learning to culturally relevant scientific inquiry (Won et al., 2023; Oje et al., 2025). Ethnoscience often centers on local knowledge, yet interactive virtual representations based on empirical evidence remain underexplored. In addition, current research on digital learning and sustainable development typically addresses institutional impacts, highlighting the need for contextualized learning environments to enhance culturally responsive science education and promote science and technology literacy (Chung et al., 2024; Zou et al., 2024). This study's novelty lies in its pedagogical design and empirical evaluation. *Wedhang Uwuh* is integrated as a culturally authentic anchor with ethnoscience, SSI-oriented inquiry, contextual laboratory evidence, and an immersive virtual museum. Empirically, the study evaluates the revised Ethno-VR environment through expert validation and reported student responses. The study makes no claim that VR alone produces measurable literacy gains. This position aligns with evidence that immersive technologies provide greater educational value when their affordances align with learning activities and evidence-based pedagogy (Cromley et al., 2023; Lui et al., 2023; Oje et al., 2025).

The study presents a transferable pedagogical architecture for immersive science learning, exemplified through the Indonesian case of Wedhang Uwuh. This approach allows for adaptation across various cultures by substituting local narratives and empirical activities while maintaining a structured sequence of cultural exploration, questioning, evidence generation, digital interpretation, and communication. The architecture can be applied to traditional foods, beverages, and community knowledge in regions such as Asia, South America, and Africa, provided it honors local meanings and ethical perspectives (Barbara, 2022; Hou et al., 2022; Nemcova et al., 2023; Sun & Ch'ng, 2024; Li et al., 2025). Significantly, the study underscores how Ethno-VR merges culturally situated knowledge with contemporary science and technology literacy, enabling students to derive scientific questions from familiar practices and engage with evidence

through digital tools. Past research supports the notion that integrating Indigenous knowledge into science education offers meaningful contexts for STEM engagement, while immersive technologies foster active, inquiry-based learning (Conrad et al., 2024; Matindike & Ramdhany, 2025; Wan Razab et al., 2026). Related studies also indicate that VR-integrated learning can support dimensions of scientific literacy when students are engaged in inquiry, evidence interpretation, and communication rather than simply experiencing immersion (Winarni et al., 2024). However, the study interprets learning outcomes as affordances rather than literacy gains because it lacked a validated pre-test–post-test measure.

The broader contribution of the Ethno-VR approach lies in its adaptability beyond specific cultures. For instance, traditional herbal drinks in Asia, traditional foods in South America, and Indigenous knowledge in Africa (Zidny et al., 2021) can serve as authentic entry points for scientific inquiry and empirical investigation, provided local stakeholders are actively involved. Knowledge has been integrated into science learning through project-based learning, technology-supported activities, field research, cultural practices, and reflective learning, suggesting that the pedagogical structure can be adapted while the cultural content remains locally grounded (Rasmawan et al., 2025; Wan Razab et al., 2026). By linking local cultural knowledge with scientific practices, this study promotes a pedagogical design principle that emphasizes cultural contextualization in developing science and technology literacy through immersive experiences. Ultimately, the Ethno-VR design principle connects local knowledge with scientific inquiry and digital representation, representing a significant advancement in education tailored to diverse cultural audiences.

The conceptual framework positions ethnoscience and SSI as contextual and interpretive resources, inquiry as the mechanism for engaging with evidence, and VR as the immersive environment connecting these elements. Research indicates that immersive VR is most educationally useful when students receive purposeful guidance, engage in active learning tasks, and connect digital representations with disciplinary reasoning (Parong & Mayer, 2021; Won et al., 2023; Oje et al., 2025). *Wedhang Uwuh* serves as the starting point for scientific questions, empirical evidence, technological interpretation, and communication. Science learning is also connected with sustainability and community contexts. SDG 4 is treated only as a broader educational alignment framework, not as a directly measured

outcome. The learning environment has relevance to SDG 4, particularly its emphasis on quality tertiary education, relevant technical and digital skills, and education for sustainable development and cultural diversity (United Nations, 2026). The primary empirical outcomes in this study are media quality, applicability, and perceived learning affordances related to science and technology literacy. Thus, SDG 4 provides a broader educational context for interpreting the learning environment's potential significance rather than a study outcome. Causal evidence of improvement in science and technology literacy would require a stronger comparative or pre-test/post-test design (Chung et al., 2024).

Three research questions guided the study: (1) What pedagogical and scientific characteristics define the revised Ethno-VR learning environment for *Wedhang Uwuh*? (2) To what extent do expert reviewers consider the revised media valid and applicable? (3) How do students respond to the Ethno-VR-supported learning activities in relation to cultural understanding, inquiry participation, and science and technology literacy? The questions focus on media quality and educational use. Accordingly, the objectives were to characterize the revised Ethno-VR environment, determine its validity and applicability through expert assessment, and examine student responses during implementation.

METHODS

This study employed a mixed-methods research and development design to evaluate a revised Ethno-VR learning environment for science education. Development followed four adapted stages: preliminary study, product design, development and validation, and testing and revision. The evaluation combined expert assessment, student-response data, and qualitative observations of learning activities. The design focused on media quality and educational use rather than causal effects from a controlled experiment. Participants were 29 chemistry education students enrolled in a Mini Research Practicum at Universitas Negeri Semarang. Three experts in science education, ethnoscience, and educational technology served as media reviewers. Students used the revised Ethno-VR environment during inquiry-oriented activities involving cultural exploration, discussion, laboratory work, and presentation of findings.

Three instrument components were used: (1) an expert validation sheet covering visual presentation, audio, text, and instructions, content

relevance, information accuracy, conceptual clarity, appeal, supporting media, alignment with science and technology literacy and quality science education, usability, and experiential learning; (2) a student-response questionnaire addressing learning objectives, cultural interest, benefits and risks of *Wedhang Uwuh*, inquiry and laboratory participation, and perceived support for science and technology literacy; and (3) observation and interview guides for documenting student engagement and interpretation. Laboratory documentation included organoleptic observations and gas-sensor response patterns. These observations served as contextual evidence of learning.

Expert-validation data were summarized using criterion-level means and an overall mean. Student-response data were summarized from the reported five-point Likert ratings. The team interpreted qualitative observations and interviews thematically, focusing on cultural contextualization, inquiry participation, and students' interpretations of science-related issues. The analysis therefore avoids causal claims about literacy improvement that the reported numerical evidence does not support.

Development Procedure of Ethno-VR *Wedhang Uwuh* Media

The team developed the revised Ethno-VR media in four stages. The preliminary stage identified learning needs and selected the scientific and cultural content of *Wedhang Uwuh*. The design stage translated these requirements into a virtual museum structure and learning sequence. Development and validation involved constructing the virtual environment with spatial/3D authoring tools and reviewing its scientific, cultural, and pedagogical content. Testing and revision incorporated student feedback and expert recommendations to refine the learning environment.

Preliminary study – The research team identified the learning outcomes, cultural narratives, scientific concepts, and potential inquiry questions associated with *Wedhang Uwuh*. The stage emphasized relationships between traditional knowledge and scientific explanations.

Product design – The team prepared a storyboard and content map. These materials connected cultural history, preparation practices, health and social perspectives, scientific explanations, experimental evidence, and multimedia resources within the virtual museum.

Development and validation – Three experts constructed and reviewed the interactive environment. Revision priorities included text and instruction clarity, audio quality, visual or-

ganization, scientific accuracy, and alignment of the learning content with science and technology literacy and quality science education.

Testing and revision – 29 chemistry education students used the revised media in inquiry-oriented activities. Student responses and observations identified usability and learning-experience issues. The main suggestions concerned audio volume and selected visual and decorative elements.

The resulting learning environment comprised four complementary content dimensions: scientific understanding, health and socio-cultural context, structural and chemical representation, and cultural-artistic representation. *Wedhang Uwuh* connected these dimensions within the virtual museum. The design provided a route from cultural experience to scientific inquiry and digital interpretation.

Portable Arduino-Based Gas-Sensor Measurement Procedure

The volatile-related aroma response of the *Wedhang Uwuh* spice mixture was examined using a portable Arduino-based gas-sensor system equipped with an MQ-type semiconductor sensor array. The measurement procedure consisted of sample placement, volatile release, sensor exposure, signal acquisition, and computer-based visualization. First, the prepared *Wedhang Uwuh* sample was placed in the sampling chamber and heated to release volatile substances from the spice mixture. The released volatiles interacted with the gas-sensor array, changing the electrical resistance of the sensing elements. The Arduino microcontroller acquired and processed these electrical responses and transferred them to the computer for visualization as sensor-response profiles. The response patterns were then recorded and compared across the sensor channels to examine relative differences in volatile-related aroma responses. In the learning activities, students used the sensor output to observe and interpret empirical response patterns, compare samples, relate sensor responses to sensory aroma observations, and discuss how preparation conditions may affect volatile release. This procedure supported science literacy by engaging students in observation, evidence interpretation, comparison, and evidence-based explanation, while supporting technology literacy through Arduino-based sensing, digital data acquisition, processing, and visualization. The sensor outputs were treated as comparative response patterns rather than definitive identification or quantification of individual volatile compounds because semicon-

ductor gas sensors are cross-sensitive; confirmatory identification would require an established analytical technique such as GC-MS.

RESULTS AND DISCUSSION

Pedagogical and Scientific Design of the Ethno-VR Learning Environment

The revised Ethno-VR environment functions as a learning space in which *Wedhang Uwuh* provides an authentic context for scientific inquiry. Familiar cultural materials and practices introduce the topic, followed by scientific explanations and empirical evidence. Guided activities address health, social, and environmental dimensions. Figure 1 presents the pedagogical architecture.

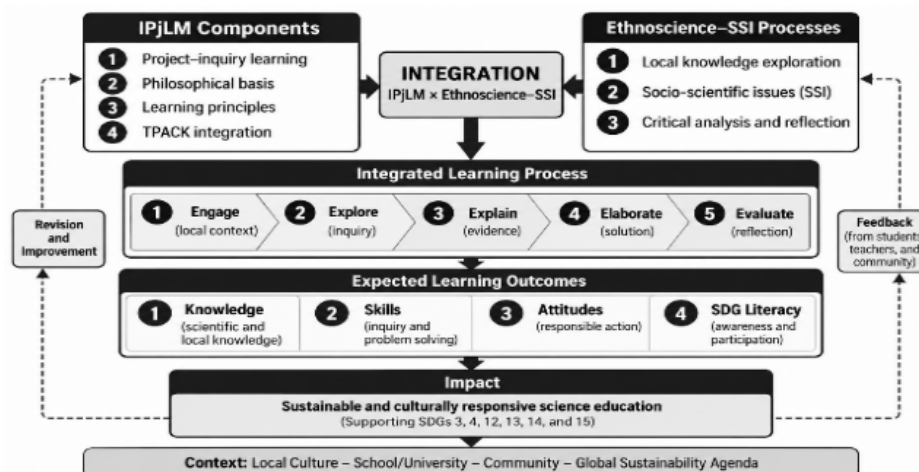


Figure 1. Pedagogical Architecture of the Revised Ethno-VR Learning Environment

Four dimensions structure the environment: local cultural context, scientific inquiry, digital immersion, and literacy-oriented activity. *Wedhang Uwuh* provides the cultural anchor, while organoleptic, phytochemical, and gas-sensor activities provide empirical evidence. The Ethno-VR museum organizes these resources in an immersive environment. Guided inquiry directs students to interpret information and communicate conclusions, making the media an instructional environment rather than a virtual display. SSI prompts address the benefits and limitations of traditional herbal beverages, responsible con-

sumption, cultural preservation, and relationships between traditional practices and scientific evidence. These prompts support interpretation and discussion. Integration represents a design feature of the learning environment; the empirical focus remains on media quality and implementation. The design is consistent with evidence that immersive VR benefits from active learning, explicit task design, and pedagogical guidance (Cromley et al., 2023; Won et al., 2023; Oje et al., 2025). Table 1 summarizes the integrated learning architecture.

Table 1. Integrated Learning Architecture of IPjLM, Ethno-SSI, and VR for Contextualized Science and Technology Literacy

Design dimension	Role in the Ethno-VR learning environment
Cultural context	Wedhang Uwuh ingredients, preparation, history, community meanings, and cultural heritage provide the authentic starting point for learning.
Scientific inquiry	Students examine organoleptic properties and gas-sensor response patterns to connect observations with chemistry concepts.
Digital immersion	The virtual museum organizes cultural, scientific, health, multimedia, and reference resources in an interactive environment.
Literacy-oriented activity	Students observe, question, interpret evidence, discuss socio-scientific perspectives, and communicate conclusions using digital and scientific information.

Implementation began with a culturally meaningful problem or question related to *Wedhang Uwuh*. Students explored its history, ing-

redients, preparation, benefits, limitations, and social meanings. Students formulated questions, then identified evidence to examine through la-

laboratory or observational activities. The sequence provided a concrete context for inquiry and interpretation of scientific information. Laboratory activities involved tool and material preparation, observation of the physical and sensory characteristics of *Wedhang Uwuh*, phytochemical screening, and examination of gas-sensor respon-

se patterns. Connections with the Ethno-VR environment linked empirical evidence to cultural knowledge and digital representation. The low-cost sensor served as a learning and visualization tool rather than a replacement for analytical instrumentation. The authentic *Wedhang Uwuh* prepared for this study is displayed in Figure 2.



Figure 2. Authentic *Wedhang Uwuh* Prepared for the Study

Students communicated findings from organoleptic observations, phytochemical screening, and gas-sensor activities. Students selected and interpreted relevant information, explained relationships between traditional practices and scientific concepts, and communicated evidence-

based conclusions. The activities provided opportunities to apply science and technology literacy in a contextual learning setting. Table 2 presents the observable characteristics of *Wedhang Uwuh* before and after reflux.

Table 2. Organoleptic characteristics of *Wedhang Uwuh* Before and After Reflux

Observation	Before reflux (dry)	After Reflux (wet/liquid)
Color	Brown	Orange
Shape	Fine powder	Liquid
Aroma	Pungent, with mixed herbal aromas	Pungent, with an alcohol-like note
Taste	Spicy and sweet	Bitter and spicy

According to Table 2, the dry sample was a fine brown powder with a pungent herbal aroma and a spicy-sweet taste. After reflux, it became an orange liquid with a mixed, alcohol-like aroma and a bitter-spicy taste. The observations provide a context for discussing extraction, solubility, thermal processing, and changes in sensory properties. Response intensities differed across the sensor/software categories, allowing comparison of aroma-related responses and discussion of how spice composition and preparation condi-

tions may influence volatile emissions. Low-cost semiconductor sensors are cross-sensitive; the displayed categories therefore represent sensor responses rather than definitive identification or quantification of individual volatile compounds (Ijaz et al., 2025). Confirmatory compound identification requires an established analytical method such as GC-MS. Figure 3 presents the complementary mean sensory evaluation of the prepared beverage.

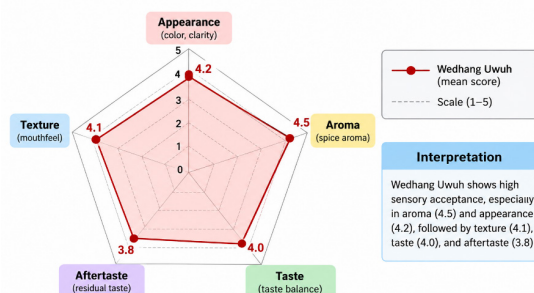
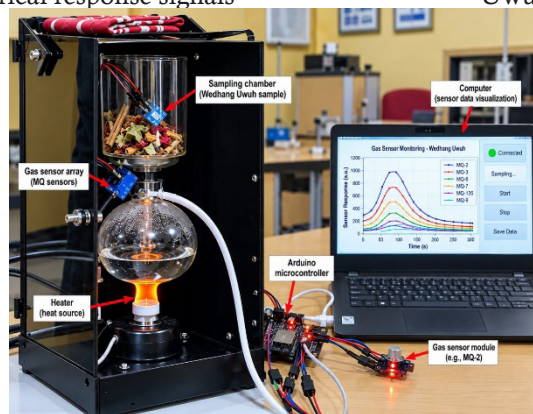


Figure 3. Organoleptic Evaluation of *Wedhang Uwuh* based on Mean Sensory Scores

In addition to the organoleptic analysis, the volatile-related response profile of *Wedhang Uwuh* was examined using a portable **Arduino-based gas-sensor device**. The device operates by exposing semiconductor gas sensors to volatile substances released from the sample, which induces changes in the electrical resistance of the sensing elements. The sensor software converts these changes into electrical response signals

and visualizes them, allowing observation of relative differences in gas-response patterns among *Wedhang Uwuh* samples. This portable Arduino-based system provides a low-cost approach to introducing students to measuring and visualizing volatile-related chemical information. Figure 4 presents the comparative gas-sensor response profiles from the *Wedhang Uwuh* samples.



(a)



(b)

Figure 4. (a) Portable Arduino-Based Gas-Sensor System for Measuring and Visualizing Volatile-Related Responses of *Wedhang Uwuh* Samples; (b) Comparative response profiles of the Portable Gas Sensors for *Wedhang Uwuh* Samples

Figure 4 shows the portable Arduino-based gas-sensor system and sensor array used to examine volatile-related responses from *Wedhang Uwuh* samples. The prepared *Wedhang Uwuh* sample was placed in the sampling chamber, allowing volatile substances to interact with the semiconductor sensor array. The Arduino microcontroller detected and processed changes in

sensor resistance, and the resulting signals were displayed as response profiles on the computer. Differences in response intensity among the samples provide comparative empirical evidence of their volatile-related characteristics. In the learning activities, students interpreted the sensor-response patterns, compared the data among samples, related the responses to sensory aroma,

and discussed how preparation conditions could influence volatile or gas-response behavior. This process supported science literacy by engaging students in observing, interpreting empirical evidence, and constructing explanations from experimental data, while supporting technology literacy through an Arduino-based sensing system to acquire, process, and visualize chemical information. Because the semiconductor sensors are cross-sensitive, labels such as alcohol, CH₄, CO, LPG, benzene, and hexane represent sensor/software response categories rather than confirmed molecular identities or concentrations; identifying individual compounds would require confirmatory analysis such as GC-MS. Thus, the Arduino-based gas-sensor activity provided a low-cost technological bridge between the traditional Wedhang Uwuh context, scientific evidence, and science and technology literacy, while helping students recognize both the applications and limitations of gas-sensing technology.

Qualitative Evidence of Students' Interpretation of *Wedhang Uwuh*

Interviews provided qualitative evidence of how students interpreted the cultural and scientific issues presented in the learning environment. The reported responses are illustrative rather than representative because only a small number were included. They demonstrate the types of reasoning elicited by the Ethno-VR-supported activities and are not used to generalize students' health knowledge. Students were asked whether *Wedhang Uwuh* could contribute to health and why they held that view. One student connected

the beverage with bioactive compounds and antioxidant activity and noted that *Wedhang Uwuh* should not replace a healthy lifestyle or medical treatment. The response illustrates an attempt to connect a traditional practice with a scientific explanation while distinguishing educational information from medical advice.

Questions about possible risks of excessive consumption elicited responses concerning adverse effects when ingredients are consumed in inappropriate amounts. The responses provided material for discussing dose, evidence, uncertainty, and responsible interpretation of health claims. Qualitative evidence supports the Ethno-VR environment's role in initiating science-related discussion but does not provide quantitative evidence of improved scientific literacy. The interview responses indicate opportunities to consider both the potential benefits and limitations of a culturally familiar beverage. This balance aligns with SSI-oriented learning. Students were encouraged to examine traditional claims through evidence and recognize that cultural value and scientific evaluation can coexist.

Characteristics and Validation of the Ethno-VR Learning Environment

The revised Ethno-VR environment was organized as a virtual museum comprising an introductory area, a first-floor gallery, a second-floor gallery, and a closing resource area. Content progressed from cultural orientation to scientific and health information, technological processes, multimedia evidence, and further learning resources. Table 3 summarizes this content structure.

Table 3. Content Structure of the Ethno-VR *Wedhang Uwuh* Virtual Museum

Virtual gallery space	Description of content and learning assets
Introductory gallery	Provides an overview of the virtual museum, its identity, orientation, and introductory information on <i>Wedhang Uwuh</i> .
First-floor gallery	Presents the history, diversity, cultural context, preparation, health-related perspectives, and community and expert views on the benefits and limitations of <i>Wedhang Uwuh</i> .
Second-floor gallery	Presents technological aspects of preparation and production, health-related information, films, music, documentaries, and study findings.
Closing gallery	Provides videos, posters, learning materials, journal articles, and reference resources related to <i>Wedhang Uwuh</i> .

The virtual museum reconstructs selected cultural and scientific aspects of *Wedhang Uwuh* in an immersive environment. The introductory and gallery areas provide cultural orientation, while the scientific and health sections provide explanatory content. Multimedia resources add

further representations, and the closing library provides supporting learning materials. The structure supports navigation, contextual learning, and student inquiry rather than simply reproducing a physical museum. Figure 5 shows the first-floor gallery.



Figure 5. Virtual Gallery on the First Floor (Source: <https://www.youtube.com/watch?v=8mM8pHpULI>)

Three experts evaluated the revised Ethno-VR media Assessment covered visual and audio quality, clarity, content relevance and accuracy, conceptual clarity, supporting media, relevance to

science and technology literacy and quality science education, usability, and experiential learning opportunities. Table 4 reports detailed results.

Table 4. Expert Validation Results for the Revised Ethno-VR Wedhang Uwuh Media

Component	Score from			Average score
	Reviewer 1	Reviewer 2	Reviewer 3	
Visual Display	3	3	4	3.33
Audio quality (Sound, effects, clarity)	4	3	4	3.67
Clarity of text and instructions	4	3	3	3.33
The relevance of the material to science and technology literacy and quality science education	3	3	3	3.00
The truth and accuracy of the information presented	4	4	3	3.67
Clarity of concept delivery	4	4	3	3.67
Media appeal	4	3	3	3.33
Ease of understanding the material	4	4	3	3.67
Supporting media	3	4	4	3.67
The media provides contextual insights relevant to quality science education and sustainability	4	4	4	4
Media can be used flexibly	4	4	4	4
Media can provide experiences	4	3	4	3.33

Implementation and Student Responses

Student engagement with the revised Ethno-VR environment was examined during an inquiry-oriented learning sequence. Activities included virtual museum exploration, question formulation, examination of empirical evidence, discussion of socio-scientific perspectives, con-

textual laboratory activities, and communication of findings. The sequence moved from the cultural context of *Wedhang Uwuh* toward evidence-based scientific interpretation. Responses were considered across scientific, technological, cultural, and sustainability-related dimensions. Figure 6 presents the response profile.

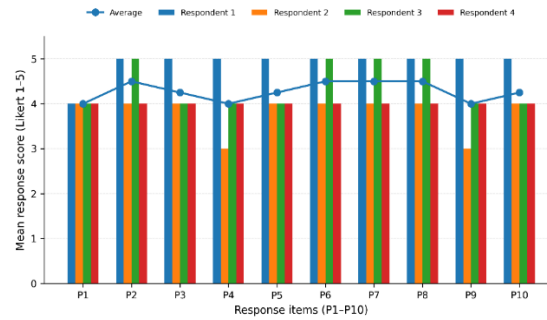


Figure 6. Respondent Ratings for the Ethno-VR-Supported *Wedhang Uwuh* Learning Experience

Figure 6 presents ratings from four reported respondents for ten indicators (P1–P10) on a five-point Likert scale. Ratings ranged from 3 to 5, and item-level averages across the four displayed respondents ranged from 4.00 to 4.50. The highest averages occurred for P2, P6, P7, and

P8, each at 4.50; P1, P4, and P9 averaged 4.00. These values describe the four reported respondent profiles and should not be interpreted as aggregate estimates for all 29 participants. Table 5 lists the corresponding response statements.

Table 5. Statements Used to Assess Responses to the Ethno-VR-Supported Learning Experience

Aspect	Statement
P1	The learning outcomes and course objectives were clear and easy to understand.
P2	The learning activities supported my interest in and understanding of Indonesian spices.
P3	The learning activities helped me understand the potential benefits and risks associated with consuming spices.
P4	The learning activities helped me understand the relevance of science and technology literacy to everyday and societal contexts.
P5	I was able to assemble the equipment used for the <i>Wedhang Uwuh</i> experiment.
P6	I was able to conduct chemical laboratory tests on the spices.
P7	I was able to discuss community issues related to <i>Wedhang Uwuh</i> using evidence and guided inquiry.
P8	I developed greater appreciation for the cultural heritage of <i>Wedhang Uwuh</i> and Indonesian spices.
P9	I understood how VR supports learning about <i>Wedhang Uwuh</i> and related science concepts.
P10	I perceived that the learning activities supported my science and technology literacy.

Qualitative comments in Table 6 described the narration and gallery content as clear and useful. Students suggested increasing audio volume and improving selected visual and decorative elements. The comments indicate specific refinements in audio delivery, visual communication, and spatial presentation. The response pattern represents the reported ratings rather than a general measure of VR enjoyment. P1–P2 address learning orientation and engagement. The ratings indicate that learning objectives were understandable and that the activities supported

interest in Indonesian spices. *Wedhang Uwuh* provided a familiar cultural context for connecting everyday knowledge with formal science-learning objectives. P3–P4 address scientific interpretation and contextual learning. The ratings indicate attention to the potential benefits and risks of consuming spices and to the relevance of science and technology literacy to everyday and societal contexts. P5–P7 address practical and inquiry-oriented activities. The responses indicate perceived participation in equipment assembly, chemical laboratory testing, and evidence-based

discussion of community issues. Such responses describe perceived participation and competence rather than independently measured practical skills. Laboratory activities involving organoleptic observations, phytochemical screening, and gas-sensor response patterns were connected with the Ethno-VR environment. The sequence linked cultural observation with empirical evidence, interpretation, and communication, consistent with inquiry-oriented science education in which students engage with evidence and construct explanations (Dah et al., 2024).

P8–P9 address the relationship between cultural and technological dimensions of the learning environment. P8 concerns appreciation of *Wedhang Uwuh* and Indonesian spice heritage, whereas P9 concerns the perceived contribution of VR to learning about the cultural object and related science concepts. The ratings suggest that the technology was meaningful within a recognizable cultural context. The cultural object provided authenticity and relevance, while VR provided immersion, spatial visualization, and access to contextualized resources. This interpretation aligns with culturally responsive learning and prior research on immersive and technology-supported learning (Brown et al., 2020; Radiani et al., 2020; Reeves et al., 2021; Brown et al., 2021; Petersen et al., 2022). P10 concerns perceived support for science and technology literacy. The rating indicates that the learning activities were perceived to connect scientific information, practical evidence, cultural knowledge, and digital technology. Such perception is not evidence of objectively measured improvement in science and technology literacy. P10 is therefore treated as a perceived learning affordance rather than a measured learning gain. Evidence of actual improvement would require a validated literacy instrument administered before and after the intervention, preferably with a comparison group and an appropriate analysis of change.

The reported response profile shows perceived connections among cultural context, scientific inquiry, laboratory practice, digital technology, and literacy-oriented learning. The strongest item-level averages occurred for P2, P6, P7, and P8. The findings support the perceived relevance and usability of the revised Ethno-VR environment and indicate pedagogical affordances for connecting culturally situated knowledge with formal science learning. Because the evidence comes from reported respondent ratings, the findings should not be generalized to all 29 par-

ticipants. The study does not establish a causal effect on science and technology literacy. Future studies should involve participants from more diverse age groups to examine the applicability of the Ethno-VR approach across different learners. Further development could also adapt the framework to other culturally significant traditional herbal beverages, such as comparable drinks from Southeast Asia and India, to explore its broader cross-cultural and international relevance.

CONCLUSION

The study developed and evaluated a revised Ethno-Virtual Reality learning environment centered on *Wedhang Uwuh* as a culturally meaningful context for science learning. The environment combined cultural narratives, scientific explanations, contextual experimental evidence, inquiry-oriented activities, and immersive digital resources. Expert assessment yielded an overall mean of 3.58 on a four-point scale, supporting the revised media's applicability. Reported respondent ratings were positive, with item-level averages of 4.00–4.50 across the four displayed respondent profiles. Qualitative feedback identified specific usability improvements, particularly audio volume and selected visual elements. The study contributes a culturally responsive Ethno-VR environment that supports inquiry and provides perceived learning affordances for connecting cultural knowledge, scientific evidence, digital technology, and science and technology literacy. The response data are perceptual and insufficient to establish causal improvement in science and technology literacy. In the broader educational context, the approach aligns with the aims of SDG 4 by emphasizing contextual, inclusive, and technology-supported science learning, but SDG 4 is not treated as a measured outcome in this study. Future research should evaluate learning gains using validated pre-test/post-test measures and an appropriate comparison design.

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