



Developing STEM-Ethnoscience-Based IPAS Learning through *Gendang Loke Nggerang* to Improve Elementary Students' Scientific Literacy

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Abstract

Integrating indigenous cultural knowledge into science education offers opportunities to develop scientific literacy through culturally meaningful learning experiences. This study aimed to develop and evaluate STEM-ethnoscience-based IPAS learning tools incorporating *Gendang Loke Nggerang*, a traditional Manggarai drum, as a contextual resource for teaching sound and its properties. An exploratory sequential mixed-methods design was employed, combining ethnoscience exploration, instructional product development, expert validation, preliminary trials, and quasi-experimental effectiveness testing. Qualitative data were collected through observations, interviews with five customary elders, and cultural documentation. These findings informed the development of teaching modules, learning materials, instructional videos, student worksheets, and scientific literacy assessments. The learning tools underwent expert validation and preliminary testing before implementation in a nonequivalent pretest-posttest control group design involving 343 fifth-grade students (experimental: $n = 174$; control: $n = 169$) in Manggarai Regency. Scientific literacy was examined across four dimensions: scientific context, knowledge, competence, and attitude. Expert validation supported the validity of the developed learning tools, while the experimental group demonstrated higher scientific literacy outcomes than the conventional learning group. Statistical analysis revealed a significant between-group difference ($F = 11.891$, $p = .001$), with a mean difference of 2.314 and a modest effect size ($Es = 0.32$). These findings suggest that integrating *Gendang Loke Nggerang* into STEM-ethnoscience-based IPAS learning can support elementary students' scientific literacy while providing an educational pathway for preserving and revitalizing Manggarai cultural knowledge.

Keywords: STEM-ethnoscience; IPAS learning; *Gendang Loke Nggerang*; Scientific literacy; Indigenous knowledge.

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INTRODUCTION

Science education has an important role in developing students' scientific literacy because it enables learners to understand natural phenomena, use evidence, solve problems, and make responsible decisions in personal, social, environmental, and technological contexts. Scientific literacy is not limited to the mastery of scientific concepts, facts, or formulas, but also includes the ability to think scientifically, interpret data, evaluate evidence, and apply scientific knowledge critically in real-life situations (Vieira & Tenreiro-Vieira, 2016). Wahyu et al. (2020) explain that scientific literacy includes the dimensions of scientific context, scientific content or knowledge, and scientific competence as part of twenty-first-century learning skills. In the current development of science education, scientific literacy is also increasingly associated with students' scientific identity, environmental awareness, agency,

and willingness to engage with science-related issues using scientific knowledge and values (OECD, 2023). At the elementary school level, scientific literacy is particularly important because early science learning shapes students' habits of observing, questioning, reasoning, investigating, and connecting scientific ideas with everyday experiences.

The urgency of strengthening scientific literacy in Indonesia is supported by international assessment data. The Programme for International Student Assessment (PISA) has consistently shown that Indonesian students' scientific literacy remains a serious concern. Historical data indicate that Indonesia ranked 38 out of 41 participating countries in 2000, 38 out of 40 countries in 2003, 50 out of 57 countries in 2006, 60 out of 65 countries in 2009, 64 out of 65 countries in 2012, and 63 out of 70 countries in 2015 (Afriana et al., 2016). This trend indicates that the problem of scientific literacy is persistent rather than incidental. The situation remains challenging in the most recent PISA cycle. In PISA 2022, Indonesia's science score decreased by 13 points compared with PISA 2018 (OECD, 2023). Although PISA assesses 15-year-old students, the results are relevant for elementary education because scientific reasoning, inquiry habits, and the ability to relate science to real-life contexts are built from earlier levels of schooling. If elementary science learning does not provide opportunities for students to observe phenomena, ask questions, analyze evidence, conduct simple investigations, and connect scientific concepts with familiar contexts, students may continue to experience difficulties in applying science in more complex learning situations.

One factor contributing to the low development of scientific literacy is the tendency of science learning to be conducted in an abstract, textbook-centered, and decontextualized manner. In many classrooms, science is still taught through explanation and memorization, while students' local environments, cultural experiences, and community knowledge are not sufficiently used as learning resources. Such learning may help students remember definitions, but it does not always help them understand why scientific concepts are meaningful in their daily lives. This condition creates a gap between formal scientific knowledge and students' lived experiences. In elementary schools, the implementation of IPAS learning provides an important opportunity to overcome this problem. IPAS, as an integration of natural and social sciences in the elementary curriculum, is designed to help students understand the relationship between themselves, society, nature, and the environment. The Merdeka Curriculum emphasizes essential learning materials, flexibility, student-centered learning, and contextual learning that supports students' competencies and character development (Kemendikbudristek et al., 2024). Therefore, IPAS learning needs to be designed not only as conceptual learning, but also as contextual, inquiry-based, interdisciplinary, and culturally meaningful learning.

One approach that can bridge formal science and students' sociocultural experiences is ethnoscience. Ethnoscience refers to local knowledge systems, practices, classifications, and explanations developed by communities in understanding natural and social phenomena. Ethnoscience does not position local knowledge as the opposite of modern science. Rather, it provides a bridge for reconstructing community knowledge into scientific concepts that can be discussed, tested, and reflected upon in the classroom. Adam et al. (2024) state that ethnoscience-based instruction can support students' critical thinking because it connects scientific principles with community-based knowledge. The integration of culture into science learning is also consistent with culturally responsive pedagogy, which emphasizes the importance of using students' cultural knowledge, prior experiences, and frames of reference to make learning more meaningful and effective (Gay, 2018). Similarly, culturally relevant pedagogy emphasizes that learning should support academic success, cultural competence, and critical awareness (Ladson-billings et al., 1995). In this perspective, local culture is not merely an illustration in learning, but a meaningful resource for constructing scientific understanding.

The integration of ethnoscience with Science, Technology, Engineering, and Mathematics (STEM) provides a stronger pedagogical framework for developing scientific literacy. STEM learning encourages students to understand concepts through inquiry, design,

experimentation, measurement, problem solving, and communication. Science provides conceptual understanding of natural phenomena; technology provides tools, media, and practical applications; engineering provides design and problem-solving processes; while mathematics provides measurement, comparison, pattern recognition, and quantitative reasoning (Bybee, 2013). Sahin (2015) emphasize that STEM learning involves minds-on and hands-on activities that allow students to think, design, test, and communicate ideas. Dede (2022) also argues that STEM learning can strengthen students' engagement when it is organized around meaningful problems and active participation. Furthermore, STEM contributes to students' understanding of science materials, interest in science, and development of science process skills (Sahin, 2015). When combined with ethnoscience, STEM learning can help students explore local cultural objects and practices using scientific reasoning, technological tools, engineering design, and mathematical analysis. Studies have shown that ethnoscience-oriented STEM learning can improve creative thinking, innovation, problem-solving abilities, and scientific literacy (Babalola & Keku, 2024; Sudarmin et al., 2024).

Manggarai culture in East Nusa Tenggara offers rich potential for STEM-ethnoscience-based IPAS learning. Manggarai communities possess cultural artifacts, traditional houses, musical instruments, ecological knowledge, ritual practices, agricultural systems, environmental values, and local technological practices that can be reconstructed as science learning resources. One important cultural site is Todo Village in Manggarai Regency, which has historical and cultural significance. Todo cultural heritage includes Mbaru Niang, traditional ceremonies, and *Gendang Loke Nggerang*. Previous studies have discussed the structural uniqueness of Mbaru Niang and the cultural potential of traditional villages in Manggarai (Pradipto & Tristanto, 2021; Sangkak & Ikmal, 2022). Traditional practices in Todo Village also contain ethnoscientific elements that can provide concrete examples of how local wisdom reflects scientific concepts in everyday life. This is relevant to science learning because local wisdom-based science learning has been shown to increase the relevance of science material and support students' science learning outcomes (Safutri, et al. 2024).

One cultural object that has strong potential as an ethnoscience learning resource is *Gendang Loke Nggerang*. In Manggarai culture, the drum is not merely a musical instrument, but also a cultural symbol embedded in historical narratives, customary ceremonies, ancestral heritage, community identity, and social communication. From an educational perspective, *Gendang Loke Nggerang* is highly relevant for the IPAS topic of sound and its properties because it can be connected with concepts such as vibration, sound source, sound propagation, resonance, frequency, amplitude, sound intensity, and material properties. The drum produces sound when its membrane vibrates after being struck. The membrane material and its tension influence pitch, loudness, and sound quality. The body of the drum functions as a resonating chamber that amplifies sound. The sound propagates through air as a medium, while the size, shape, diameter, and length of the drum can be connected to mathematical reasoning through measurement, comparison, proportion, and pattern. The making and use of the drum can also be related to traditional technology and engineering because it involves material selection, structural design, acoustic function, and durability. Thus, *Gendang Loke Nggerang* provides a concrete, culturally familiar, and scientifically meaningful context for learning sound and its properties.

To make the integration of *Gendang Loke Nggerang* into STEM-ethnoscience-based IPAS learning more explicit and scientifically traceable, the cultural elements identified from Todo Village were reconstructed into IPAS concepts, STEM components, and scientific literacy dimensions. This mapping is necessary because the use of local culture in science learning should not only introduce cultural heritage as a learning context, but also show how cultural objects contain scientific, technological, engineering, and mathematical meanings that can be transformed into learning activities. The mapping is presented in Table 1.

Table 1. Mapping of Manggarai Ethnoscience, STEM Components, IPAS Concepts, and Scientific Literacy Dimensions

Cultural Element	Ethnoscience Meaning in Manggarai Culture	Science Concept in IPAS	Technology Component	Engineering Component	Mathematics Component	Scientific Literacy Dimension
Gendang Loke Nggerang	A sacred traditional drum preserved in Todo cultural tradition and used in customary ceremonies as a symbol of ancestral heritage, identity, and communication.	Sound as a result of vibration; sound source; sound waves; sound intensity.	Traditional technology for producing sound using natural materials and manual construction techniques.	Design of a drum structure that enables sound production and amplification.	Measurement of drum diameter, membrane area, and comparison of sound intensity.	Scientific context; students connect sound concepts with cultural ceremonies and local heritage.
Drum membrane	The surface of the drum that is struck to produce sound during cultural events.	Vibration; relationship between membrane tension and sound quality; frequency and amplitude.	Selection and preparation of membrane material based on local knowledge.	Tensioning and fixing the membrane to produce stable sound.	Comparison of tension, surface area, and pitch differences.	Scientific knowledge; students explain that sound is produced by vibrating objects.
Drum body or resonating chamber	The wooden body of the drum functions as a container that shapes and strengthens the sound.	Resonance; amplification of sound; propagation of sound waves.	Use of wood and traditional construction techniques to create a resonating chamber.	Structural design that supports resonance and sound projection.	Measurement of length, diameter, volume, and proportion of the drum body.	Scientific competence; students analyze how structure affects sound quality.
The act of striking the drum	A cultural practice performed in ceremonies to produce symbolic and communicative sound.	Force, vibration, amplitude, and sound intensity.	Human use of a traditional instrument as a sound-producing tool.	Technique of striking to produce different sound strengths.	Comparison between weak and strong strikes; simple data recording of sound differences.	Scientific competence; students observe, compare, and interpret sound phenomena.
Sound propagation from the drum	Drum sound spreads and can be heard by people in the surrounding area during customary activities.	Sound propagation through air; sound requires a medium; distance and sound intensity.	Use of sound as a traditional medium of communication in community life.	Positioning and use of the drum to allow sound to spread effectively.	Estimation of distance and comparison of sound loudness at different positions.	Scientific context and competence; students relate sound propagation to real cultural situations.
Materials used in	Local materials are selected	Properties of materials;	Traditional material	Selection of suitable	Classification and	Scientific knowledge

Cultural Element	Ethnoscience Meaning in Manggarai Culture	Science Concept in IPAS	Technology Component	Engineering Component	Mathematics Component	Scientific Literacy Dimension
drum construction	based on durability, availability, and sound quality.	relationship between material characteristics and sound.	processing based on local knowledge.	materials for strength, durability, and acoustic function.	comparison of material characteristics.	; students identify how material properties influence sound production.
Mbaru Niang Todo	A traditional conical house that stores cultural objects and represents Manggarai identity and social order.	Shape, structure, balance, force distribution, and environmental adaptation.	Traditional architectural technology using local materials.	Structural design of a conical house that supports stability and protection.	Geometry of conical forms, angles, symmetry, and proportion.	Scientific context; students connect traditional architecture with science and mathematics.
Customary ceremony involving the drum	Cultural rituals in which the drum has symbolic, communicative, and social functions.	Sound in social life; human use of sound; interaction between science, culture, and society.	Use of traditional instruments in social communication and cultural preservation.	Organization of tools, space, and sound in ceremonial settings.	Sequencing, rhythm, pattern, and repetition in drum sounds.	Scientific attitude; students develop appreciation, curiosity, and responsibility toward local culture and science.
Learning video of Gendang Loke Nggerang	Documentation of cultural heritage used as learning media in IPAS classrooms.	Observation of sound phenomena, vibration, and cultural context.	Digital media used to represent local culture in learning.	Instructional design that transforms cultural documentation into learning activities.	Interpretation of visual and numerical information from video-based tasks.	Scientific competence and attitude; students observe, question, discuss, and reflect on cultural-scientific phenomena.
Student project or simple sound instrument	Students reconstruct the working principle of the drum through a simple STEM activity.	Sound source, vibration, resonance, frequency, amplitude, and material properties.	Use of simple tools and available materials to create a sound-producing model.	Engineering design process: planning, making, testing, revising, and presenting a sound instrument.	Measuring size, comparing results, recording data, and presenting findings.	Scientific competence and attitude; students conduct inquiry, solve problems, and communicate

Cultural Element	Ethnoscience Meaning in Manggarai Culture	Science Concept in IPAS	Technology Component	Engineering Component	Mathematics Component	Scientific Literacy Dimension
						evidence-based conclusions.

Table 1 shows that *Gendang Loke Nggerang* can be reconstructed as a STEM-ethnoscience learning resource because it contains scientific concepts related to sound, technological knowledge related to traditional material processing, engineering principles related to structure and acoustic function, and mathematical reasoning related to measurement, proportion, rhythm, and comparison. The cultural meaning of *Gendang Loke Nggerang* also provides a meaningful context for developing students' scientific literacy, especially in the dimensions of scientific context, scientific knowledge, scientific competence, and scientific attitude. Therefore, the use of *Gendang Loke Nggerang* in IPAS learning is not merely intended to introduce local culture, but to transform cultural heritage into a structured learning resource that supports scientific inquiry, contextual understanding, and cultural revitalization.

Previous studies have demonstrated the contributions of STEM-based learning, ethnoscience-oriented instruction, and local wisdom-based science education to students' scientific literacy and learning outcomes (Afriana et al., 2016; Babalola & Keku, 2024; Jihannita et al., 2024; Sudarmin et al., 2023; Wahyu et al., 2023). Specifically, STEM-based project learning integrating Manggarai indigenous science has been investigated as an approach to improving students' scientific literacy (Wahyu et al., 2023). However, several research gaps remain. First, although previous studies have integrated STEM and ethnoscience into science education, limited attention has been given to systematically reconstructing a specific Manggarai cultural artifact into interconnected STEM components and scientific literacy dimensions. Second, existing research on Manggarai indigenous science has not specifically examined *Gendang Loke Nggerang* as a contextual learning resource for teaching sound and its properties within elementary IPAS education. Third, while previous studies have highlighted the educational potential of local cultural knowledge, the processes through which ethnoscientific findings are translated into integrated instructional products, including teaching modules, learning videos, student worksheets, assessment instruments, and measurable scientific literacy indicators, remain insufficiently documented. Fourth, empirical evidence regarding the development, validation, and effectiveness of STEM-ethnoscience-based IPAS learning tools grounded in Todo cultural practices remains limited. Addressing these gaps requires an approach that extends beyond describing cultural values to systematically reconstructing indigenous knowledge into structured IPAS learning tools and empirically evaluating their contribution to elementary students' scientific literacy.

The novelty of this study lies in the specific and systematic integration of *Gendang Loke Nggerang* into STEM-ethnoscience-based IPAS learning for elementary school students in Manggarai Regency. Unlike previous studies that discuss local wisdom or ethnoscience in general, this study focuses on one specific cultural object and reconstructs it into learning tools for the topic of sound and its properties. Unlike conventional STEM learning, which often uses general scientific problems or modern technological contexts, this study uses a cultural artifact that is meaningful to students' local identity. Unlike ethnoscience learning that only describes cultural practices, this study maps *Gendang Loke Nggerang* into STEM components, scientific literacy dimensions, learning activities, learning videos, teaching modules, student worksheets, and assessment indicators. In addition, this study uses a mixed-method exploratory sequential design, allowing qualitative exploration of Todo cultural practices to become the basis for product development and quantitative testing (Martawijaya et al., 2023; Creswell & Creswell, 2018). This design differs from direct experimental studies because it begins with the

reconstruction of authentic cultural data before testing the effectiveness of the developed learning tools.

In this study, cultural revitalization is operationally understood as the process of documenting local cultural knowledge, identifying its scientific meanings, reconstructing it into learning content, integrating it into IPAS learning tools, and using it to strengthen students' scientific literacy and cultural awareness. Thus, revitalization does not mean reducing culture to scientific explanation, but placing Manggarai cultural heritage in an educational space where students can appreciate cultural values while understanding the scientific principles embedded in cultural artifacts and practices. The learning tools developed in this study include teaching modules, textbooks, learning videos, student worksheets, and assessment instruments. These tools are designed to guide students to observe Gendang Loke Nggerang, identify scientific concepts related to sound, conduct STEM-based activities, interpret findings, and reflect on the relationship between science and Manggarai culture.

Based on the background, gap, and novelty above, this study has two main objectives. First, it aims to identify and reconstruct the ethnoscientific values contained in *Gendang Loke Nggerang* and Todo cultural practices as the basis for developing STEM-ethnoscience-based IPAS learning tools. Second, it aims to examine the effectiveness of the developed learning tools in improving elementary students' scientific literacy in Manggarai Regency. The scientific literacy measured in this study includes scientific context, scientific knowledge, scientific competence, and scientific attitude. Through these objectives, the study is expected to contribute to the development of contextual IPAS learning that strengthens scientific literacy while preserving and revitalizing Manggarai cultural heritage through formal education.

METHOD

This study employed an exploratory sequential mixed-methods design, beginning with a qualitative exploration of Manggarai ethnoscience in Todo Village, followed by the development, validation, and quantitative evaluation of STEM-ethnoscience-based IPAS learning tools. This design was selected because the qualitative findings provided the conceptual and cultural foundation for developing instructional materials, while the quantitative phase examined the effectiveness of the developed learning tools in improving elementary students' scientific literacy (Creswell & Creswell, 2018). The research was conducted in five sequential phases: ethnoscience exploration, product development, expert validation, small-group trial, and quasi-experimental effectiveness testing. The overall research design and sequence of qualitative and quantitative procedures are illustrated in Figure 1.

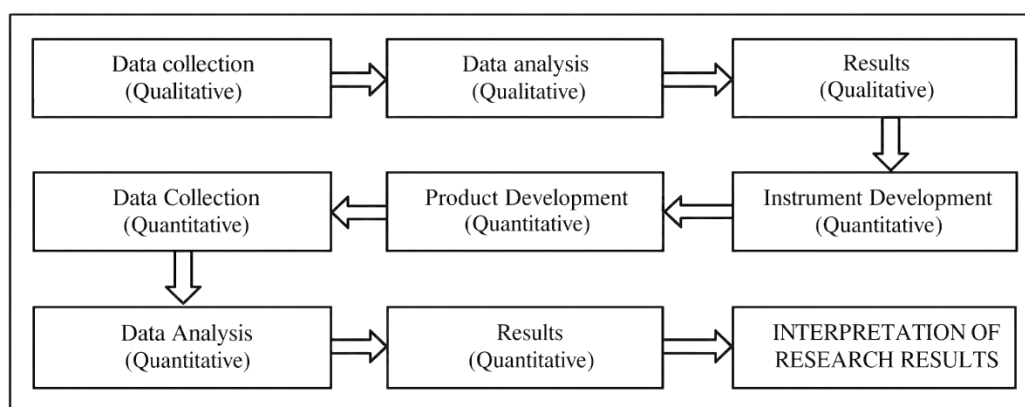


Figure 1. Research Flow of the Exploratory Sequential Mixed-Methods Design.

The qualitative phase involved five Manggarai customary leaders, identified by the initials HM, YU, KL, AL, and EJ, who were purposively selected as key informants based on their cultural knowledge, experience, and direct involvement in customary practices and the preservation of Manggarai cultural heritage. These informants provided in-depth information regarding the historical, cultural, and ethnoscientific meanings of *Gendang Loke Nggerang* and

related cultural practices in Todo Village. Interview data were complemented by field observations and cultural documentation to identify indigenous knowledge relevant to elementary IPAS learning, particularly scientific concepts related to sound and its properties. The qualitative findings subsequently informed the development of culturally contextualized STEM-ethnoscience-based instructional materials and scientific literacy assessment instruments.

Research Design and Procedure

The research procedure consisted of five sequential phases. The first phase was qualitative ethnoscience exploration, which aimed to identify the cultural meanings and scientific values embedded in *Gendang Loke Nggerang* and Todo cultural practices. The second phase was product development, in which the qualitative findings were reconstructed into STEM-ethnoscience-based IPAS learning tools. The third phase was expert validation, which assessed the validity of the learning tools and instruments. The fourth phase was a small-group trial conducted to examine the readability, practicality, and initial implementation of the learning tools. The fifth phase was a main field test using a quasi-experimental nonequivalent pretest-posttest control group design to examine the effectiveness of the developed learning tools. The research procedure is presented in Table 2.

Table 2. Research Phases, Objectives, Data Sources, Instruments, and Data Analysis

Phase	Objective	Data Sources/ Participants	Instruments	Data Analysis
Phase 1: Ethnoscience exploration	To identify the cultural meanings and scientific values of <i>Gendang Loke Nggerang</i> and Todo cultural practices.	Traditional leader/customary elder, cultural practitioners, documentation of Todo cultural heritage, and field observations.	Observation sheet, interview guide, documentation checklist, field notes.	Data reduction, data display, conclusion drawing, and ethnoscience reconstruction.
Phase 2: Product development	To develop STEM-ethnoscience-based IPAS learning tools based on the qualitative findings.	Results of ethnoscience exploration and IPAS curriculum documents.	Product development guide, IPAS curriculum analysis sheet, STEM-ethnoscience mapping matrix.	Descriptive analysis and instructional design analysis.
Phase 3: Expert validation	To examine the content, construct, language, media, cultural relevance, and assessment validity of the learning tools.	Experts in science education, learning technology, culture, language, and media.	Expert validation sheets.	Content Validity Ratio (CVR), Content Validity Index (CVI), and qualitative analysis of expert suggestions.
Phase 4: Small-group trial	To examine the readability, practicality, and initial implementation of the learning tools.	220 fifth-grade students from five elementary schools in Manggarai Regency.	Student response questionnaire, teacher response questionnaire, observation sheet, and scientific literacy test.	Descriptive statistics and qualitative analysis of implementation notes.
Phase 5: Main field test	To examine the effectiveness of STEM-	174 students in the experimental group and 169 students in	Scientific literacy test, scientific attitude	Descriptive statistics, statistical assumption testing,

Phase	Objective	Data Sources/ Participants	Instruments	Data Analysis
	ethnoscience-based IPAS learning in improving students' scientific literacy.	the control group from five elementary schools in Manggarai Regency.	observation sheet, student worksheet, and implementation observation sheet.	between-group inferential analysis, pairwise comparisons, and effect size estimation.

Phase 1: Ethnoscience Exploration

The qualitative phase was conducted in Todo Village, Manggarai Regency, East Nusa Tenggara. This phase aimed to explore the ethnoscientific values of *Gendang Loke Nggerang* and related Todo cultural practices. Data were collected through observation, interviews, and documentation. Observations were conducted to identify cultural objects, the physical form of *Gendang Loke Nggerang*, its location within the traditional house, and the cultural context in which it is used. Interviews were conducted with customary elders and cultural informants who had knowledge of the history, meaning, and function of *Gendang Loke Nggerang* in Todo cultural tradition. Documentation was used to collect visual and textual data related to *Gendang Loke Nggerang*, Mbaru Niang, and Todo cultural practices.

The qualitative data were analyzed using data reduction, data display, and conclusion drawing. The data were then reconstructed into ethnoscience categories by identifying the relationship between cultural meanings and scientific concepts. For example, the membrane of *Gendang Loke Nggerang* was reconstructed into the concept of vibration, the drum body into resonance and sound amplification, and the sound produced by the drum into sound propagation and sound intensity. To improve the trustworthiness of qualitative findings, data were triangulated through observation, interviews, and documentation.

Phase 2: Product Development

The results of the ethnoscience exploration were used as the basis for developing STEM-ethnoscience-based IPAS learning tools for the topic of sound and its properties. The product development procedure was adapted from Borg and Gall's development model, consisting of research and information collecting, planning, preliminary product development, expert validation, product revision, small-group trial, main field testing, and operational product revision.

The products developed in this study consisted of: (1) teaching modules, (2) textbooks or student learning materials, (3) learning videos of *Gendang Loke Nggerang*, (4) student worksheets, and (5) scientific literacy assessment instruments. The teaching module was designed to guide teachers in implementing STEM-ethnoscience-based IPAS learning. The textbook presented cultural narratives and scientific explanations related to sound and its properties. The learning video was used to provide students with visual access to *Gendang Loke Nggerang* and its cultural context. Student worksheets were designed to guide inquiry, observation, measurement, discussion, and reflection activities. The assessment instruments were developed to measure students' scientific literacy in four dimensions: scientific context, scientific knowledge, scientific competence, and scientific attitude.

The STEM-ethnoscience integration was developed through a mapping process. The science component focused on vibration, sound sources, sound waves, resonance, frequency, amplitude, and sound propagation. The technology component focused on traditional material processing and the use of learning videos. The engineering component focused on the structure, design, acoustic function, and durability of the drum. The mathematics component focused on measurement, comparison, proportion, rhythm, and simple data interpretation. This mapping became the basis for designing the learning syntax, student activities, and assessment indicators.

Phase 3: Expert Validation

The developed STEM-ethnoscience-based IPAS learning tools and assessment instruments underwent expert validation to examine their content accuracy, cultural relevance, pedagogical appropriateness, and technical feasibility for elementary science education. The validation involved five experts, comprising three learning design experts and two elementary IPAS subject-matter experts. The evaluation covered the alignment of instructional content with IPAS learning outcomes, integration of STEM components and Manggarai ethnoscience, appropriateness of learning activities, clarity of instructional language, quality of learning media, design of student worksheets, and suitability of assessment indicators. Particular attention was given to ensuring that the scientific concepts reconstructed from *Gendang Loke Nggerang* were accurate, culturally meaningful, and appropriate for fifth-grade elementary students.

Content validity was evaluated using Lawshe's Content Validity Ratio (CVR) and the Content Validity Index (CVI) to assess expert agreement regarding the relevance and appropriateness of the developed products and assessment items. Expert ratings were complemented by qualitative comments and recommendations, which informed revisions to instructional content, learning activities, media presentation, and assessment instruments. Following expert validation, the scientific literacy assessment underwent item-level analysis using corrected item-total correlations to examine item discrimination and internal consistency. Cronbach's alpha was employed to assess the internal consistency reliability of the scientific literacy test and questionnaire instruments. The scientific literacy assessment included polytomously scored items designed to measure scientific context, scientific knowledge, and scientific competence, while scientific attitude was assessed through structured observation. The expert validation and instrument evaluation procedures provided the basis for refining the learning tools and assessment instruments before their implementation in the small-group trial.

Phase 4: Small-Group Trial

The small-group trial was conducted to evaluate the readability, practicality, and preliminary implementation of the developed STEM-ethnoscience-based IPAS learning tools before the main field test. This phase involved 220 fifth-grade students from five elementary schools in Manggarai Regency: SDI Lao, SDK Ruteng 1, SDK Kumba 1, SDK Ruteng 2, and SDI Iteng 1. During the trial, students participated in learning activities addressing sound and its properties through the integration of *Gendang Loke Nggerang* as a culturally contextualized learning resource. The developed teaching modules, instructional videos, student worksheets, and assessment instruments were implemented to examine their suitability for elementary students and their capacity to facilitate science learning through ethnoscience-oriented STEM activities.

Data were collected using student and teacher response questionnaires, classroom observation sheets, student worksheets, and scientific literacy assessments. Student and teacher responses were used to evaluate the clarity, accessibility, and practicality of the instructional materials, while classroom observations provided information regarding their initial implementation. Scientific literacy assessments and student worksheets provided preliminary evidence of students' learning performance across the targeted scientific literacy dimensions. The collected data were analyzed descriptively to identify strengths and aspects requiring improvement. Findings from this trial informed revisions to the teaching modules, instructional videos, worksheets, and assessment instruments, particularly regarding instructional clarity, cultural-scientific connections, and alignment with scientific literacy indicators, before proceeding to the main field test.

Phase 5: Main Field Test and Quasi-Experimental Design

The main field test employed a quasi-experimental nonequivalent pretest-posttest control group design to evaluate the effectiveness of STEM-ethnoscience-based IPAS learning in

improving elementary students' scientific literacy. The study involved 343 fifth-grade students from five elementary schools in Manggarai Regency, comprising 174 students in the experimental group and 169 students in the control group. The experimental group received STEM-ethnoscience-based IPAS instruction, whereas the control group participated in conventional IPAS learning covering the same topic of sound and its properties. Because students were assigned through existing school or classroom arrangements rather than individual randomization, the study adopted a nonequivalent group design. The instructional intervention was implemented over four learning meetings, with pretest and posttest assessments administered before and after the intervention, respectively.

The experimental group engaged in STEM-ethnoscience-based learning activities integrating *Gendang Loke Nggerang* as a contextual resource for investigating scientific concepts related to sound. Students observed instructional videos documenting the traditional drum and its cultural significance, identified scientific phenomena involving vibration, sound production, resonance, and sound propagation, and discussed connections between Manggarai cultural practices and scientific explanations. Learning activities also involved guided inquiry, simple observations and investigations, worksheet-based tasks, and reflection on the scientific and cultural meanings of the learning experience. In contrast, the control group received conventional IPAS instruction through teacher explanations, textbook-based discussions, and standard learning exercises without explicit integration of *Gendang Loke Nggerang* or structured STEM-ethnoscience activities. Scientific literacy was assessed through the dimensions of scientific context, scientific knowledge, scientific competence, and scientific attitude to examine differences in learning outcomes between the two instructional conditions.

Research Participants and Sampling Technique

The study involved four main categories of participants: qualitative informants, expert validators, students participating in the preliminary trial, and students participating in the main field test. Five Manggarai customary elders were purposively selected as qualitative informants based on their knowledge of *Gendang Loke Nggerang*, experience with Todo cultural practices, and involvement in preserving local cultural heritage. Expert validation involved five specialists, comprising three learning design experts and two elementary IPAS subject-matter experts, selected based on their expertise and relevance to the developed instructional products. The preliminary trial involved 220 fifth-grade students from five elementary schools in Manggarai Regency, selected through school- and class-based sampling to evaluate the initial implementation of the learning tools.

The main field test involved 343 fifth-grade students from elementary schools in Manggarai Regency, comprising 174 students in the experimental group and 169 students in the control group. A nonequivalent group design was employed because individual random assignment was not feasible within the participating schools. The experimental group received STEM-ethnoscience-based IPAS learning, whereas the control group received conventional IPAS instruction. Five elementary school teachers were also involved in implementing the instructional activities. The distribution of participants, data sources, and selection procedures is summarized in Table 3.

Table 3. Participants and Data Sources

Component	Participants/Data Sources	Number	Selection Technique
– Ethnoscience exploration	Manggarai customary elders knowledgeable about <i>Gendang Loke Nggerang</i> and Todo cultural heritage	5 customary elders	Purposive sampling
– Expert validation	Learning design experts and elementary IPAS subject-matter experts	5 experts (3 learning design; 2 subject-matter)	Expertise-based purposive selection

Component	Participants/Data Sources	Number	Selection Technique
– Small-group trial	Fifth-grade students from SDI Lao, SDK Ruteng 1, SDK Kumba 1, SDK Ruteng 2, and SDI Iteng 1	220 students	School/class-based sampling
– Main field test: Experimental group	Fifth-grade students receiving STEM-ethnoscience-based IPAS learning	174 students	Nonequivalent group assignment
– Main field test: Control group	Fifth-grade students receiving conventional IPAS learning	169 students	Nonequivalent group assignment
– Teachers	Elementary school teachers implementing IPAS instruction in participating classes	10 teachers	Purposive/school-based selection

Table 3 summarizes the participants involved in each research phase. The study combined purposively selected cultural informants and expert validators with school-based student participants. The main field test included 343 students distributed across experimental and control conditions, allowing the developed instructional tools to be evaluated under existing elementary school classroom arrangements.

Research Instruments

Data were collected using instruments designed to support the qualitative exploration, instructional product validation, preliminary trial, and quasi-experimental effectiveness testing. The qualitative phase employed semi-structured interview guides, observation sheets, field notes, and documentation checklists to investigate the cultural meanings and ethnoscientific characteristics of Gendang Loke Nggerang. Expert validation sheets were used to evaluate the scientific accuracy, cultural relevance, pedagogical appropriateness, and technical quality of the developed instructional materials. During the preliminary trial, student and teacher response questionnaires, classroom observation sheets, and student worksheets were used to examine readability, practicality, and initial implementation. The main field test employed scientific literacy assessments and structured observation instruments to evaluate students' learning outcomes following the instructional intervention.

Scientific literacy was operationalized through four dimensions: scientific context, scientific knowledge, scientific competence, and scientific attitude. Scientific context concerned students' ability to connect scientific concepts with everyday situations and Manggarai cultural practices. Scientific knowledge addressed conceptual understanding of sound and its properties, while scientific competence focused on explaining phenomena, interpreting observations, and drawing evidence-based conclusions. Scientific attitude reflected students' interest in science, engagement in inquiry activities, and responsibility toward cultural and environmental contexts. The scientific literacy test and supporting worksheets were used to assess the cognitive dimensions, whereas scientific attitude was evaluated through structured classroom observation. The dimensions, indicators, and corresponding instruments are presented in Table 4.

Table 4. Dimensions and Indicators of Scientific Literacy

Dimension	Indicator	Instrument
– Scientific context	Identifying connections between sound-related concepts, cultural ceremonies, everyday experiences, and Manggarai cultural heritage.	Scientific literacy test and student worksheet.
– Scientific knowledge	Explaining vibration, sound sources, sound propagation, resonance, frequency, amplitude, and material properties.	Scientific literacy test.
– Scientific competence	Explaining scientific phenomena, interpreting observations and data, comparing findings, and drawing evidence-based conclusions.	Scientific literacy test, student worksheet, and observation sheet.

Dimension	Indicator	Instrument
– Scientific attitude	Demonstrating interest in science, willingness to engage in scientific inquiry, sensitivity to cultural and environmental contexts, and responsibility during learning activities.	Scientific attitude observation sheet.

Table 4 presents the operational indicators used to evaluate scientific literacy in the context of STEM-ethnoscience-based IPAS learning. The indicators were aligned with instructional activities addressing sound and its properties through Gendang Loke Nggerang, allowing students' conceptual understanding, scientific reasoning, contextual application, and scientific attitudes to be examined using complementary assessment instruments.

Data Analysis

Qualitative data obtained through interviews, observations, and cultural documentation were analyzed using data reduction, data display, and conclusion drawing. The analysis began with identifying recurring cultural meanings, traditional practices, and ethnoscientific characteristics associated with Gendang Loke Nggerang and Todo cultural heritage. The identified findings were subsequently reconstructed into scientific concepts and mapped onto STEM components, elementary IPAS learning outcomes, and scientific literacy dimensions. Triangulation of interview, observation, and documentation data was used to strengthen the credibility of the qualitative interpretations. These findings provided the empirical foundation for instructional product development and informed the interpretation of the quantitative outcomes.

Quantitative data from expert validation and the preliminary trial were analyzed descriptively to evaluate product quality, instructional practicality, and initial implementation. Expert ratings were examined using the Content Validity Ratio (CVR) and Content Validity Index (CVI), while instrument reliability was assessed using Cronbach's alpha. Student and teacher responses, classroom observations, and preliminary scientific literacy outcomes were summarized to identify aspects requiring revision before the main field test. For the quasi-experimental phase, descriptive statistics, including means, standard deviations, minimum scores, and maximum scores, were used to summarize scientific literacy outcomes across the experimental and control groups. Statistical assumptions, including normality and homogeneity of variance, were examined before inferential testing. Between-group differences were evaluated using the reported test of between-subjects effects, followed by pairwise comparisons to identify differences in scientific literacy outcomes between instructional conditions. The magnitude of the observed difference was examined using an effect size estimate.

Effect size interpretation followed the criteria adopted in the study: values of $Es \leq 0.20$ indicated a low effect, $0.20 < Es \leq 0.80$ indicated a modest or moderate effect, and $Es > 0.80$ indicated a high effect. Accordingly, the reported effect size of $Es = 0.32$ was interpreted as modest. Quantitative findings were considered alongside the qualitative ethnoscience reconstruction to explain how culturally contextualized STEM learning was associated with students' scientific literacy outcomes.

RESULTS AND DISCUSSION

The results of this study are presented according to the research phases: ethnoscience exploration, product development and expert validation, small-group trial, main field testing, and statistical effectiveness testing. This structure is used to show the relationship between the cultural exploration of Gendang Loke Nggerang, the development of STEM-ethnoscience-based IPAS learning tools, and the empirical testing of students' scientific literacy.

Ethnoscience Exploration of *Gendang Loke Nggerang* and *Todo Cultural Practices*

The qualitative exploration conducted in Todo Village showed that *Gendang Loke Nggerang* is not only a traditional musical instrument, but also a cultural symbol that represents

ancestral heritage, customary authority, social identity, and community communication in Manggarai culture. Based on interviews with customary elders and field observations, *Gendang Loke Nggerang* is kept in the traditional house, locally known as *Mbaru Niang* or *Niang Todo*, and is associated with traditional ceremonies and historical narratives of the Todo community.



Figure 2. Documentation of *Gendang Loke Nggerang* and cultural objects inside *Mbaru Niang Todo*

The cultural narrative of *Gendang Loke Nggerang* contains symbolic meanings related to inheritance, continuity of life, social responsibility, and communal prosperity. The traditional house in Todo Village, which has a conical structure and symbolic spatial organization, also reflects local knowledge related to structure, balance, material use, and environmental adaptation. These findings indicate that Todo cultural practices contain ethnoscientific values that can be reconstructed into elementary IPAS learning.

From the perspective of IPAS learning, *Gendang Loke Nggerang* is particularly relevant to the topic of sound and its properties. The drum produces sound when its membrane vibrates after being struck. The membrane material and tension influence the quality, pitch, and loudness of the sound. The wooden body of the drum functions as a resonating chamber that amplifies the sound, while the sound produced by the drum propagates through air as a medium. These characteristics provide a concrete context for learning vibration, sound source, sound propagation, resonance, frequency, amplitude, sound intensity, and material properties. The reconstruction of cultural meanings into scientific concepts is summarized in Table 5.

Table 5. Reconstruction of *Gendang Loke Nggerang* into IPAS Scientific Concepts

Cultural Finding	Ethnoscience Interpretation	IPAS Concept	Learning Implication
– <i>Gendang Loke Nggerang</i> is struck during customary ceremonies.	Sound is produced by physical interaction between the beater and the drum membrane.	Sound source, vibration, amplitude.	Students observe that sound is produced by vibrating objects.
– The drum membrane produces different sound qualities depending on its condition and tension.	Material type and membrane tension influence sound characteristics.	Frequency, pitch, loudness, material properties.	Students compare how membrane tension and material affect sound.
– The wooden body of the drum strengthens the sound.	The drum body functions as a resonating chamber.	Resonance and sound amplification.	Students analyze how structure influences sound quality.
– The drum sound can be heard by people around the ceremonial area.	Sound propagates through air as a medium.	Sound propagation and sound intensity.	Students relate sound propagation to distance and medium.
– The drum is made using local materials and traditional techniques.	Local technology involves material selection, design, and acoustic function.	Technology, engineering design, material properties.	Students design or simulate a simple sound-producing instrument.

Cultural Finding	Ethnoscience Interpretation	IPAS Concept	Learning Implication
– <i>Gendang Loke Nggerang</i> is preserved as cultural heritage.	Cultural objects can become sources of scientific inquiry and cultural awareness.	Science in cultural and social contexts.	Students connect scientific concepts with Manggarai cultural heritage.

These findings became the basis for developing STEM-ethnoscience-based IPAS learning tools. The cultural exploration did not merely document cultural narratives, but reconstructed cultural objects and practices into scientific concepts, STEM components, learning activities, and scientific literacy indicators.

Product Development and Expert Validation

The ethnoscience findings were used to develop STEM-ethnoscience-based IPAS learning tools for fifth-grade elementary students on the topic of sound and its properties. The products developed consisted of teaching modules, student learning materials, learning videos, student worksheets, and scientific literacy assessment instruments. The learning video documented *Gendang Loke Nggerang* and *Todo* cultural practices as contextual media for introducing the concepts of sound, vibration, resonance, and sound propagation.

The learning tools were designed by integrating four STEM components. The science component focused on sound sources, vibration, sound waves, resonance, frequency, amplitude, and sound propagation. The technology component involved the use of traditional sound-producing technology and digital learning videos. The engineering component focused on the structure and acoustic function of the drum. The mathematics component involved measurement, comparison, proportion, rhythm, and interpretation of simple data.

The products were validated by experts in science education, learning technology, culture, language, and learning media. The validation assessed content accuracy, cultural relevance, STEM integration, suitability with IPAS learning outcomes, media quality, language clarity, learning syntax, student worksheet design, and assessment alignment. The results of expert validation indicated that the developed learning tools were valid and feasible for small-group testing.

Table 6. Summary of Expert Validation Results

Product/ Instrument	Validation Aspect	CVI Result	Interpretation	Revision Based on Expert Suggestions
– Teaching module	IPAS content, learning objectives, STEM syntax, cultural integration	0.91	Valid	Learning steps were clarified and cultural context was strengthened.
– Student learning material/textbook	Concept accuracy, readability, cultural narrative, scientific explanation	0.89	Valid	Scientific explanation of sound and resonance was made more explicit.
– Learning video	Media quality, cultural accuracy, visualization, relevance to sound concepts	0.87	Valid	Video narration and guiding questions were revised.
– Student worksheet	Inquiry activities, STEM tasks, measurement activities, reflection	0.90	Valid	Worksheet instructions and observation tasks were simplified.
– Scientific literacy test	Item relevance, construct validity,	0.88	Valid	Test items were revised based on expert feedback.

Product/ Instrument	Validation Aspect	CVI Result	Interpretation	Revision Based on Expert Suggestions
– Scientific attitude observation sheet	language clarity, scoring guide Indicator clarity, observer guidance, scoring rubric	0.86	Valid	Observation indicators and scoring criteria were clarified.

The expert validation results were followed by product revision. The revisions included improving the clarity of learning instructions, strengthening the connection between *Gendang Loke Nggerang* and scientific concepts, simplifying student worksheet tasks, and aligning assessment items with the four dimensions of scientific literacy.

Small-Group Trial Results

The small-group trial was conducted with 220 fifth-grade students from five elementary schools in Manggarai Regency: SDI Lao, SDK Ruteng 1, SDK Kumba 1, SDK Ruteng 2, and SDI Iteng 1. This trial aimed to examine the readability, practicality, and initial implementation of the STEM-ethnoscience-based IPAS learning tools before the main field test.

The descriptive results of the small-group trial showed that students who learned through STEM-ethnoscience-based IPAS learning obtained higher average scores than students who learned through conventional learning in the dimensions of scientific context, scientific knowledge, and scientific competence. The results are presented in Figure 3.

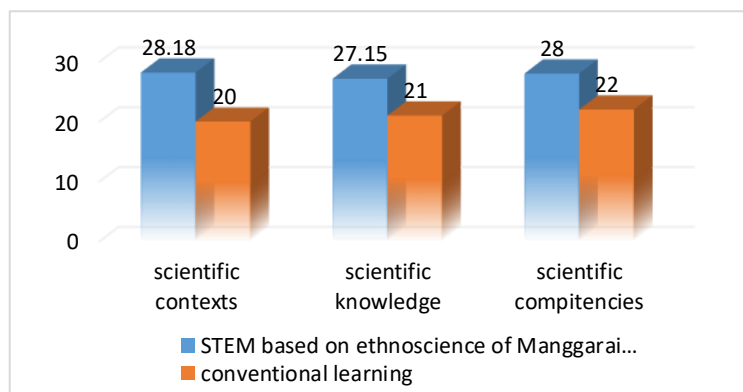


Figure 3. Small-Group Trial Results for Scientific Context, Scientific Knowledge, and Scientific Competence

Figure 3 indicates that the STEM-ethnoscience-based IPAS learning group achieved higher scores across all three dimensions. The largest difference was found in the scientific context dimension, suggesting that the use of *Gendang Loke Nggerang* as a culturally familiar learning context helped students connect the concept of sound with everyday cultural experiences. The scientific attitude dimension was measured through student performance observation during learning activities using student worksheets and the learning video. The results are presented in Figure 4.

Figure 4 shows that students in the STEM-ethnoscience-based IPAS learning group demonstrated higher scientific attitude scores than students in the conventional learning group. The highest difference was found in the indicator of sensitivity and responsibility, indicating that culturally contextual learning encouraged students to show greater awareness of the relationship between science, culture, and local heritage.

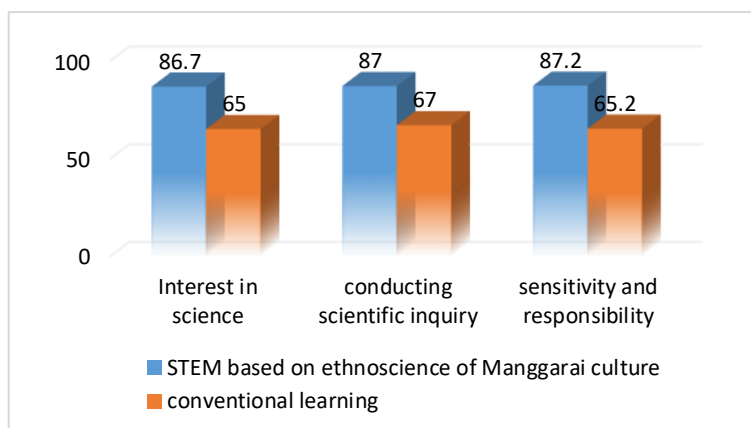


Figure 4. Small-Group Trial Results for Scientific Attitude

The results of the small-group trial were used to revise the learning tools before the main field test. The revisions focused on improving the clarity of instructions in the worksheets, strengthening guiding questions in the learning video, and aligning student activities with the indicators of scientific literacy.

Main Field Test Results

The main field test was conducted in five elementary schools in Manggarai Regency. The experimental group consisted of 174 fifth-grade students who learned through STEM-ethnoscience-based IPAS learning, while the control group consisted of 169 fifth-grade students who learned through conventional IPAS learning. The learning topic was sound and its properties.

The descriptive results of the main field test showed that the experimental group obtained higher average scores than the control group in the dimensions of scientific context, scientific knowledge, and scientific competence. The results are shown in Figure 5.

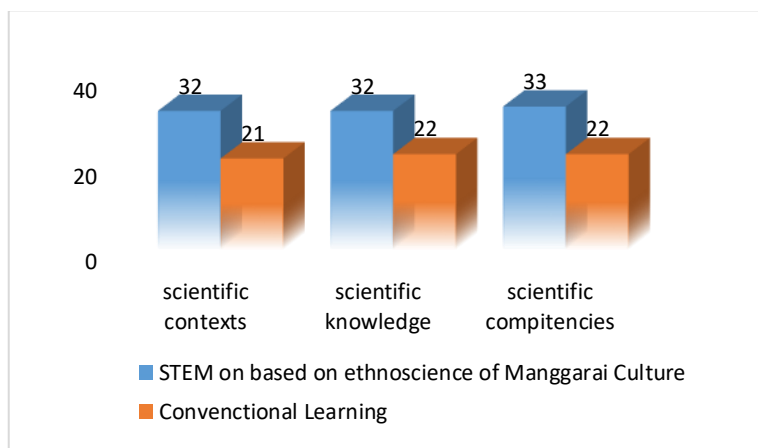


Figure 5. Main Field Test Results for Scientific Context, Scientific Knowledge, and Scientific Competence

Figure 5 shows that the experimental group obtained higher average scores in all dimensions. The highest score was found in scientific competence, suggesting that STEM-ethnoscience activities supported students' ability to explain sound phenomena, interpret observations, and draw conclusions from learning activities. The scientific attitude results in the main field test are presented in Figure 6.

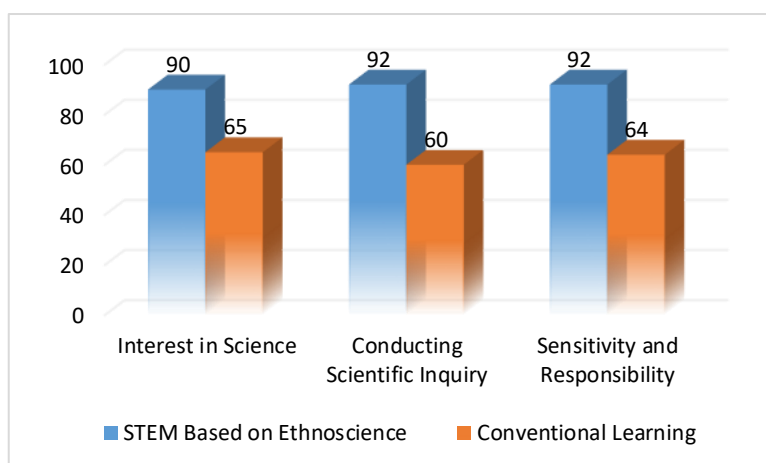


Figure 6. Main Field Test Results for Scientific Attitude

Figure 6 indicates that students in the experimental group showed higher scientific attitude scores than those in the control group. The largest difference was found in the indicator of conducting scientific inquiry. This result suggests that learning activities involving observation, discussion, worksheet completion, and STEM-based exploration of *Gendang Loke Nggerang* encouraged students to participate more actively in inquiry-based learning.

Statistical Test of Effectiveness

The effectiveness of STEM-ethnoscience-based IPAS learning was examined by comparing students' scientific literacy scores between the experimental and control groups. The test of between-subjects effects showed a significant difference in scientific literacy between students who learned through STEM-ethnoscience-based IPAS learning and those who learned through conventional learning, $F = 11.891$, $p = 0.001$, with a mean difference of 2.314. Since the significance value was lower than 0.05, the null hypothesis was rejected. This indicates that STEM-ethnoscience-based IPAS learning had a statistically significant effect on students' scientific literacy.

The pairwise comparison also showed that the mean difference in scientific literacy between the experimental and control groups was 2.314, with $p = 0.001$. This means that the scientific literacy score of students who learned through STEM-ethnoscience-based IPAS learning was significantly higher than that of students who learned through conventional IPAS learning.

The effect size analysis showed $Es = 0.32$. Based on the criteria used in this study, $Es = 0.32$ is categorized as a modest effect, not a very high effect. Therefore, the findings indicate that STEM-ethnoscience-based IPAS learning significantly improved students' scientific literacy with a modest effect size. The statistical results are summarized in Table 7.

Table 7. Statistical Test of the Effectiveness of STEM-Ethnoscience-Based IPAS Learning

Statistical Component	Result	Interpretation
Test of between-subjects effects	$F = 11.891$	There was a significant difference between groups.
Significance value	$p = 0.001$	Significant at $\alpha = 0.05$.
Mean difference	2.314	The experimental group obtained a higher scientific literacy score than the control group.
Effect size	$Es = 0.32$	Modest effect.
Decision	H_0 rejected	STEM-ethnoscience-based IPAS learning had a significant effect on students' scientific literacy.

Overall, the results show that the developed STEM-ethnoscience-based IPAS learning tools were valid for implementation, improved students' scientific literacy scores in both small-group and main field tests, and produced a statistically significant difference between the

experimental and control groups. The strongest descriptive improvements were found in scientific context and scientific attitude, indicating that the integration of *Gendang Loke Nggerang* helped students connect science learning with cultural experience and encouraged more active participation in inquiry-based learning.

DISCUSSION

The findings of this study indicate that STEM-ethnoscience-based IPAS learning integrating *Gendang Loke Nggerang* was associated with better scientific literacy outcomes among fifth-grade elementary students than conventional IPAS instruction. Students in the experimental group demonstrated higher scores in scientific context, scientific knowledge, scientific competence, and scientific attitude. The between-group analysis revealed a statistically significant difference ($F = 11.891, p = .001$), with a mean difference of 2.314 and a modest effect size ($Es = 0.32$). These findings suggest that integrating culturally meaningful resources with interdisciplinary STEM activities can contribute to scientific literacy development, although the magnitude of the observed difference should be interpreted proportionally. Previous research has demonstrated the potential of STEM education to support students' learning outcomes across different instructional settings (Wahono et al., 2020). Similarly, meta-analytic evidence suggests that STEM-oriented instruction can contribute positively to science achievement, although effects vary according to instructional characteristics, educational contexts, and implementation conditions (Karaşah Çakıcı et al., 2021). The present findings extend this literature by examining the integration of a specific Manggarai cultural artifact into elementary IPAS learning rather than implementing STEM activities independently of students' sociocultural experiences.

The positive outcomes observed in the experimental group can be understood through the contextual relevance of *Gendang Loke Nggerang* as an instructional resource connecting students' cultural experiences with scientific concepts. Rather than introducing sound solely through textbook explanations, the developed learning tools provided opportunities to investigate scientific phenomena embedded in a traditional musical instrument associated with Manggarai cultural heritage. Context-based science education has been shown to support more positive attitudes toward science while maintaining conceptual learning outcomes comparable to those achieved through conventional instruction (Bennett et al., 2007). Furthermore, learning activities that help students recognize connections between scientific content and their everyday experiences can strengthen perceived relevance and interest in science (Hulleman & Harackiewicz, 2009). From a cross-cultural science education perspective, learners may encounter differences between knowledge developed through cultural experiences and explanations presented in formal science classrooms. Aikenhead and Jegede (1999) conceptualized this relationship through cultural border crossing and collateral learning, emphasizing the importance of supporting students as they move between everyday cultural understanding and scientific ways of knowing. In the present study, *Gendang Loke Nggerang* provided a culturally meaningful context through which students could connect familiar practices with scientific explanations of vibration, resonance, sound propagation, and material properties. However, cultural familiarity should be regarded as a plausible contributing factor rather than an independently verified mechanism because the study did not directly isolate its influence on learning outcomes.

The reconstruction of Manggarai ethnoscience into structured instructional materials represents another important contribution of this study. Indigenous cultural knowledge was not treated merely as supplementary information or a motivational introduction to science lessons. Instead, cultural narratives, traditional material selection, drum construction, and customary practices were systematically examined and mapped onto scientific concepts, technological applications, engineering considerations, mathematical reasoning, and scientific literacy indicators. Zidny et al. (2020) argue that indigenous knowledge can contribute to more inclusive and contextually meaningful science education when relationships between different

knowledge systems are critically examined. Similarly, Meyer and Crawford (2011) emphasize that authentic scientific inquiry becomes more educationally inclusive when instructional practices acknowledge culturally situated ways of knowing. Research involving science teachers has also highlighted the importance of culturally responsive instructional knowledge and the challenges involved in incorporating indigenous knowledge into formal science curricula (Brown & Crippen, 2017; Photo & McKnight, 2024). These perspectives are relevant to the present study because the development of STEM-ethnoscience-based IPAS learning required cultural information obtained from customary elders to be translated into scientifically appropriate, pedagogically accessible, and assessable learning activities. This reconstruction provides a potential model for integrating indigenous knowledge into elementary science education while respecting the cultural meanings associated with traditional artifacts.

The improvement in scientific knowledge can be interpreted in relation to students' opportunities to observe and explain sound-related phenomena through concrete examples. *Gendang Loke Nggerang* illustrates the relationship between mechanical vibration and sound production because its membrane vibrates when struck, while the drum body contributes to the resonance and acoustic characteristics of the resulting sound. These properties provided contextual examples for discussing sound sources, frequency, amplitude, resonance, sound propagation, and material characteristics. The learning video, student worksheets, and guided investigations enabled scientific concepts to be presented through observable situations rather than relying exclusively on abstract explanations. This interpretation is consistent with previous studies suggesting that ethnoscience-oriented instructional materials can connect scientific knowledge with local cultural contexts and strengthen students' scientific understanding (Jihannita et al., 2024; Sudarmin et al., 2024). Previous research on science literacy has also emphasized the importance of connecting conceptual knowledge with the interpretation and application of scientific information (Jufrida et al., 2019). Nevertheless, the present findings do not establish which specific instructional component contributed most strongly to students' conceptual development, as the intervention combined cultural context, learning videos, worksheets, and STEM-oriented activities within a single instructional condition.

The higher scientific competence scores observed in the experimental group may also be associated with opportunities for guided scientific inquiry. Students engaged in activities involving observation, identification of scientific phenomena, interpretation of information, comparison of sound-related characteristics, and evidence-based conclusion drawing. These activities correspond to central processes of scientific inquiry and provide opportunities to develop competencies beyond factual recall. Furtak et al. (2012), in a meta-analysis of experimental and quasi-experimental studies, demonstrated that inquiry-based science teaching can support student learning, with differences in instructional guidance influencing outcomes. Similarly, Lazonder and Harmsen (2016) found that guidance plays an important role in the effectiveness of inquiry-based learning. More recent research has also indicated that appropriately structured inquiry activities can support scientific literacy development, particularly when students are encouraged to engage with scientific evidence and explanations (Eymur & Çetin, 2024). In this study, guided worksheets and teacher-supported learning activities provided opportunities for students to investigate sound-related concepts through *Gendang Loke Nggerang*. The findings are therefore consistent with the wider literature on guided scientific inquiry, although the relative contributions of inquiry guidance and cultural contextualization were not separately examined.

The integration of the four STEM components further distinguishes the developed learning tools from conventional IPAS instruction. Science was represented through the investigation of vibration, sound sources, resonance, frequency, amplitude, and propagation. Technology was incorporated through digital instructional videos and traditional methods of constructing and using sound-producing instruments. Engineering was addressed through the

structural and acoustic functions of the drum, including material selection, membrane tension, and instrument design. Mathematics was integrated through measurement, comparison, proportional reasoning, and interpretation of simple observational data. This interdisciplinary organization enabled students to examine a culturally familiar object from several complementary perspectives. Research on STEM-oriented project learning has demonstrated the potential of interdisciplinary activities to support scientific literacy, problem-solving, and higher-order thinking (Afriana et al., 2016; Martawijaya et al., 2023; Wahyu et al., 2023). Halawa et al. (2024), through a systematic review of instructional design in K–12 STEM education, also highlight the importance of coherent instructional design in supporting integrated STEM learning. In the present study, the mapping of ethnoscientific findings onto STEM components and scientific literacy indicators provided a coherent basis for developing teaching modules, instructional videos, student worksheets, and assessment instruments. Nevertheless, the study evaluated the combined instructional approach and therefore cannot determine the independent contribution of each STEM component to the observed outcomes.

The scientific attitude findings provide further evidence of the potential educational relevance of culturally contextualized learning. Students in the experimental group demonstrated higher descriptive scores in interest in science, participation in scientific inquiry, and sensitivity and responsibility toward cultural and environmental contexts. These findings suggest that the integration of familiar cultural resources may have created opportunities for students to engage with science in ways connected to their everyday experiences and local identities. Hulleman and Harackiewicz (2009) demonstrated that linking scientific learning materials to students' lives can support interest and academic performance. Culturally responsive science education also emphasizes the role of learners' experiences, identities, and cultural resources in making classroom activities more meaningful (Brown & Crippen, 2017; Meyer & Crawford, 2011). Furthermore, culturally relevant scientific communication activities can provide opportunities for students to connect scientific participation with meaningful purposes (Sedlacek & Lomeli, 2024). These perspectives help explain why *Gendang Loke Nggerang* may have supported student interest and engagement during IPAS instruction. However, because scientific attitude was assessed through structured classroom observation, the observed differences should be interpreted as differences in assessed classroom behaviors rather than direct evidence of enduring changes in students' motivation, identity, or cultural commitment.

The comparison between the experimental and control groups also underscores the importance of the learning opportunities provided through different instructional approaches. Conventional IPAS instruction in the comparison condition emphasized teacher explanations, textbook-based discussions, and standard exercises. In contrast, STEM-ethnoscience-based learning incorporated cultural observation, guided inquiry, interdisciplinary interpretation, worksheet-based investigations, and reflection on relationships between scientific concepts and cultural practices. These differences provide a plausible explanation for the higher scientific literacy scores observed in the experimental group. However, the literature indicates that inquiry-based instruction does not automatically produce superior outcomes merely because students participate in exploratory activities. Oliver et al. (2021), using comparative PISA data, highlighted the complexity of relationships between inquiry-oriented instruction and scientific achievement. Kang (2022) further demonstrated the importance of considering instructional quality when examining associations between inquiry-based learning and science literacy. Accordingly, the present findings should not be interpreted as evidence that conventional instruction is universally ineffective or that ethnoscience-based STEM activities will consistently outperform other approaches. Rather, they suggest that a structured combination of contextualized content, guided investigation, and interdisciplinary activities may provide additional learning opportunities within the participating classrooms.

The modest effect size observed in this study also requires attention when interpreting

instructional effectiveness. Although the between-group difference was statistically significant, $Es = 0.32$ indicates a limited-to-moderate magnitude under the classification adopted in the study. This distinction is important because statistical significance and educational magnitude represent different aspects of intervention outcomes. Research on inquiry-based science education suggests that instructional effectiveness depends on the degree of guidance, learning task characteristics, and opportunities for meaningful conceptual engagement (Furtak et al., 2012; Lazonder & Harmsen, 2016). Similarly, evidence on integrated STEM implementation indicates that outcomes vary across educational levels, learning environments, and instructional designs (Wahono et al., 2020; Halawa et al., 2024). The four-meeting intervention implemented in the present study may have provided limited time for extended investigation, iterative engineering activities, and the consolidation of scientific reasoning. Nevertheless, this explanation remains tentative because intervention duration and implementation characteristics were not independently manipulated. The findings therefore support a cautious interpretation of the instructional approach as potentially beneficial rather than establishing its superiority across different conditions.

Teacher preparation and instructional implementation are additional considerations in understanding the applicability of the developed learning tools. Integrating indigenous knowledge with STEM instruction requires teachers to interpret cultural practices accurately, connect them with appropriate scientific explanations, organize inquiry activities, and guide students toward measurable learning outcomes. Margot and Kettler (2019) identified teacher-related challenges and enabling conditions in implementing integrated STEM education, including the importance of instructional support and professional preparation. Research on professional development for primary school teachers also demonstrates the importance of supporting teachers in planning and guiding inquiry-based learning (van Uum et al., 2021). Similarly, investigations of indigenous knowledge integration highlight the need for teachers to understand the educational relevance of cultural knowledge and its relationship with formal science instruction (Photo & McKnight, 2024). These findings suggest that the wider implementation of STEM-ethnoscience-based IPAS learning may depend on teachers' scientific and cultural knowledge, access to appropriate instructional resources, and opportunities to collaborate with local cultural practitioners. The present study did not directly examine these implementation factors as explanatory variables, but they provide relevant considerations for interpreting the transferability of its instructional approach.

The findings also contribute to discussions about the educational role of indigenous cultural heritage. In this study, cultural revitalization was approached through the documentation of *Gendang Loke Nggerang*, reconstruction of its ethnoscientific characteristics, and integration of the resulting knowledge into formal IPAS learning materials. This process demonstrates how cultural artifacts can become resources for investigating scientific phenomena while retaining their historical and communal significance. Zidny et al. (2020) emphasize that meaningful engagement with indigenous knowledge requires attention to the social, cultural, and epistemological dimensions of science education. Likewise, Aikenhead and Jegede (1999) highlight the importance of negotiating relationships between culturally situated knowledge and school science. The present study contributes to this perspective by illustrating how Manggarai cultural knowledge can inform STEM-oriented instructional design for elementary education. However, the development and classroom use of culturally grounded learning tools should not be equated with demonstrated long-term cultural preservation. The study provides evidence of an educational pathway for representing and communicating Manggarai cultural knowledge, whereas broader claims concerning cultural revitalization would require additional longitudinal and community-based evidence.

Taken as a whole, the findings extend previous research on STEM education, ethnoscience, and scientific literacy by demonstrating how a specific Manggarai cultural artifact can be reconstructed into a structured elementary IPAS learning environment and

evaluated empirically. Earlier studies have emphasized the potential of STEM-oriented instruction to support scientific literacy and related learning outcomes (Afriana et al., 2016; Babalola & Keku, 2024; Sudarmin et al., 2023; Wahyu et al., 2023). The present study adds a culturally specific instructional development perspective by linking qualitative ethnoscience exploration with product validation and quasi-experimental evaluation. Its principal contribution lies not only in the statistically significant difference observed between instructional groups, but also in illustrating a systematic process through which indigenous cultural knowledge can be translated into scientific concepts, interdisciplinary learning activities, and measurable scientific literacy indicators. This contribution supports further examination of culturally contextualized STEM education as a potentially useful approach to elementary science learning, while recognizing that instructional effectiveness, cultural relevance, and broader applicability require continued empirical investigation.

CONCLUSION

This study concludes that Gendang Loke Nggerang, as part of Manggarai cultural heritage in Todo Village, contains ethnoscientific values that can be reconstructed into STEM-ethnoscience-based IPAS learning, particularly on the topic of sound and its properties. The reconstruction shows that Gendang Loke Nggerang can be connected to scientific concepts such as vibration, sound source, sound propagation, resonance, frequency, amplitude, sound intensity, and material properties. Through the developed teaching modules, textbooks, learning videos, student worksheets, and assessment instruments, Gendang Loke Nggerang was transformed from a cultural artifact into a contextual learning resource that supports students' understanding of science while strengthening their awareness of Manggarai local wisdom.

The results of the small-group trial and main field test indicate that students who learned through STEM-ethnoscience-based IPAS learning obtained higher scientific literacy scores than those who learned through conventional IPAS learning in the dimensions of scientific context, scientific knowledge, scientific competence, and scientific attitude. The statistical test showed a significant difference between the experimental and control groups, $F = 11.891$, $p = 0.001$, with a mean difference of 2.314. The effect size of $E_s = 0.32$ indicates a modest effect, so the effectiveness of the approach should be interpreted proportionally. These findings suggest that integrating Gendang Loke Nggerang into IPAS learning can support elementary students' scientific literacy while contributing to the revitalization of Manggarai cultural knowledge through formal education. Future studies are recommended to involve longer intervention periods, more complete statistical reporting, and broader cultural contexts to examine the wider applicability of STEM-ethnoscience-based IPAS learning.

LIMITATION

This study has several limitations that should be considered when interpreting its findings. First, the quasi-experimental nonequivalent pretest-posttest control group design did not involve individual random assignment, potentially allowing initial differences between participating classes, teacher characteristics, and school environments to influence the observed outcomes. Second, the intervention was implemented over four instructional meetings, which may have limited opportunities for sustained scientific inquiry, deeper conceptual development, and the assessment of long-term learning retention. Third, the investigation focused on fifth-grade students in Manggarai Regency and used *Gendang Loke Nggerang* as a culturally specific learning resource, limiting the generalizability of the findings to students from different educational and sociocultural contexts. Fourth, scientific attitude was assessed through classroom observation, which may be influenced by observer judgment and requires clear evidence of inter-rater reliability. Finally, the modest effect size and limited reporting of baseline equivalence, confidence intervals, and statistical model specifications

warrant caution when interpreting the magnitude and causal implications of the observed differences in scientific literacy.

RECOMMENDATION

Future research should examine the effectiveness of STEM-ethnoscience-based IPAS learning through longer interventions, more diverse student populations, and more rigorous experimental or quasi-experimental designs that account for baseline differences and school-level influences. Longitudinal studies are recommended to investigate the retention and transfer of scientific literacy across different science topics and learning contexts. Further studies should also explore the integration of other Manggarai cultural artifacts and indigenous knowledge systems to determine the transferability of the instructional approach beyond *Gendang Loke Nggerang*. Greater attention should be given to reporting instrument reliability, including inter-rater agreement for scientific attitude assessments, and providing comprehensive statistical evidence, including adjusted group comparisons, confidence intervals, and clearly defined effect sizes. In educational practice, elementary teachers are encouraged to adapt culturally contextualized STEM activities to local resources while maintaining alignment with IPAS learning objectives and scientific literacy indicators. Collaboration between teachers, cultural practitioners, and curriculum developers is also recommended to support the educational use of indigenous knowledge without overlooking its cultural meanings and community significance.

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AUTHOR CONTRIBUTIONS STATEMENT

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Yuliana Wahyu	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
Zephisius Rudiyanto		✓		✓		✓		✓	✓	✓	✓	✓		
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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known financial or non-financial conflicts of interest that could have influenced the research, interpretation of findings, or preparation of this manuscript.

INFORMED CONSENT

Informed consent was obtained from the participating adult informants and from the parents or legal guardians of the participating elementary school students. Age-appropriate assent was obtained from students, and participation was voluntary. The confidentiality and anonymity of participants were maintained throughout data collection, analysis, and reporting.

DATA AVAILABILITY

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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