Mapping Madurese Cultural Heritage for Secondary Science Education: An Ethnopedagogical Study in Sumenep, Indonesia

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https://doi.org/10.17977/um065.v7.i2.2027.6

Article history
Submitted: 30 July 2026
Revised: 16 August 2026
Accepted: 18 August 2026
Published: 20 August 2026

Keywords
Culturally responsive teaching
Ethnopedagogy
Ethnoscience
Madurese cultural heritage
Science education

Abstract
Science education requires contextual approaches that connect scientific concepts with students' cultural experiences. However, local cultural knowledge remains underutilized as a learning resource, particularly in culturally diverse regions such as Sumenep, Indonesia. This study aims to identify Madurese cultural traditions and analyze their potential contribution to secondary science education through an ethnopedagogical perspective. A qualitative descriptive design was employed involving semi-structured interviews, observations, and document analysis. Ten cultural informants were selected through purposive and snowball sampling. Data were analyzed using thematic analysis to identify cultural meanings, educational values, science-related phenomena, and potential pedagogical connections. The findings identified thirteen Madurese cultural traditions categorized into five domains: ritual and belief systems, environmental and animal-related practices, traditional technology and craftsmanship, performing arts, and social-cultural practices. These traditions contain educational values related to responsibility, cooperation, environmental awareness, and technological knowledge. The analytical mapping revealed potential connections between cultural practices and secondary science concepts, including ecosystems, weather systems, biomechanics, materials science, heat transfer, and sound phenomena. Based on these findings, a preliminary ethnopedagogical mapping framework was developed by connecting cultural traditions, scientific phenomena, and potential learning approaches, including inquiry-based learning, project-based learning, STEAM, and contextual learning. This study highlights the potential of Madurese cultural heritage as a contextual resource for culturally responsive science education while emphasizing the need for further validation through classroom implementation.

1. Introduction

Education is a fundamental process for developing students' knowledge, character, and skills through meaningful learning experiences. In science education, learning is not only expected to develop conceptual understanding but also scientific literacy, critical thinking, problem-solving ability, and students' awareness of their relationship with society and the environment. However, science learning in many educational contexts remains dominated by abstract concepts, textbook-oriented instruction, and limited connections with students' everyday experiences. Such conditions may reduce students' engagement because scientific knowledge is often perceived as detached from their cultural backgrounds and real-life environments (Amri et al., 2021). Therefore, developing contextual science education that connects scientific concepts with students lived experiences has become an important direction in contemporary science education research.

One promising approach to addressing this challenge is culturally responsive education, which emphasizes the importance of incorporating students' cultural backgrounds, experiences, and knowledge systems into learning processes. Culturally Responsive Pedagogy argues that students' cultural identities should not be separated from academic learning but instead should become valuable resources for constructing meaningful knowledge (Gay, 2002; Ladson-Billings, 1995). In science education, this perspective is particularly relevant because indigenous and local knowledge systems often contain empirical observations, environmental understanding, technological practices, and social values that can enrich students' understanding of scientific concepts. Integrating local knowledge into science learning can also strengthen students' cultural identity while promoting more inclusive and relevant educational experiences (Paris, 2012).

ISSN: 2797-3174

In Indonesia, the integration of local wisdom into science education has gained increasing attention due to the country's extensive cultural diversity. Although national curriculum reforms have emphasized contextual and meaningful learning, science instruction in many schools still tends to be separated from local cultural contexts. This disconnection may limit students' opportunities to understand science as knowledge that develops within particular social and environmental settings (Suprapto et al., 2021). Previous studies indicate that local wisdom-based science education has potential to improve scientific literacy and contextual thinking by linking scientific concepts with authentic community practices (Putra & Wahyuni, 2025). However, the utilization of local cultural resources in Indonesian science education remains uneven, particularly in regions where indigenous knowledge has not been systematically documented and transformed into pedagogical frameworks.

Ethnopedagogy and ethnoscience provide theoretical perspectives for bridging local knowledge and formal science education. Ethnopedagogy views culture as an essential foundation for designing meaningful learning experiences, while ethnoscience explores how communities develop knowledge systems through interactions with their surrounding environment. Rather than replacing scientific knowledge with traditional knowledge, these approaches encourage dialogue between indigenous knowledge and modern science to develop deeper scientific understanding (Zidny et al., 2020). Recent studies have demonstrated that culturally grounded science learning can support students' scientific literacy, cultural appreciation, and conceptual understanding when local practices are carefully transformed into appropriate learning contexts (Lubis & Baiduri, 2025; Sakti et al., 2024).

Several previous studies have explored the relationship between local culture and science education, but important limitations remain. First, Govender and Mudzamiri (2022) investigated the incorporation of indigenous artefacts into high school physics education and demonstrated that indigenous materials could support culturally responsive science learning. However, their study focused on a specific indigenous context and did not provide a broader framework for mapping diverse cultural traditions into multiple science disciplines. Second, Rosa et al. (2025) developed culturally responsive science learning resources based on Lampung local wisdom and showed that cultural integration could improve students' physics learning experiences. Nevertheless, the study primarily focused on developing instructional materials rather than systematically identifying cultural values and transforming various traditions into potential science-learning strategies. Third, Rasmawan et al. (2025) reviewed the integration of indigenous knowledge in science education and highlighted various strategies, models, and impacts of incorporating local knowledge into science learning. However, their study primarily synthesized existing research trends and did not specifically examine how diverse cultural traditions within a particular community could be systematically mapped into scientific concepts and pedagogical approaches.

The Madurese community in Sumenep Regency represents an important yet insufficiently mapped cultural context for ethnopedagogical science education. Sumenep possesses diverse cultural traditions, including *Nyadder*, *Ojung*, *Rokat Dhisah*, *Karapan Sapi*, *Sapi Sonok*, *Taneyan Lanjheng*, traditional arts, and keris craftsmanship. These traditions contain various forms of knowledge related to environmental adaptation, material utilization, social organization, technology, and philosophical values. Nevertheless, many of these traditions remain primarily understood as cultural heritage rather than educational resources for science learning. Previous studies have contributed to documenting Madurese cultural practices and exploring their potential relevance to education. For example, Aditya et al. (2025) examined Sandur Madura as a cultural context for science education, demonstrating the potential of Madurese cultural practices to support contextual learning. However, existing studies have generally focused on specific cultural practices rather than systematically examining diverse Madurese traditions as interconnected knowledge systems for secondary science education.

Although recent studies have started to explore the integration of Madurese cultural elements into science education, these investigations have generally focused on specific cultural practices rather than providing a broader mapping of diverse cultural traditions. For instance, Aditya et al. (2025) examined Sandur Madura as a cultural context for science education, demonstrating the potential of Madurese cultural practices to support contextual learning. However, further exploration is needed to identify how various Madurese traditions across different cultural domains contain scientific phenomena, educational values, and possible pedagogical applications. Therefore, a systematic ethnopedagogical analysis is required to develop a more comprehensive understanding of Madurese cultural heritage as a resource for secondary science education.

These limitations indicate a significant research gap. Previous research has established the importance of culturally responsive science education and demonstrated the potential of ethnoscience-based learning, but limited attention has been given to developing a structured mapping between specific Madurese cultural traditions and science-learning strategies at the secondary education level. Furthermore, previous studies have rarely addressed how cultural practices can be analyzed to identify scientific knowledge, educational values, and potential pedagogical applications simultaneously. Therefore, a systematic exploration of Madurese cultural heritage is required to provide a preliminary foundation for developing culturally relevant science education.

ISSN: 2797-3174

Based on this gap, this study addresses two main research questions: (1) What Madurese cultural traditions in Sumenep contain educational values and science-related knowledge that can support secondary science education? and (2) How can these cultural values and knowledge systems be mapped into proposed ethnopedagogical science-learning strategies? By answering these questions, this study aims to identify and analyze the educational potential embedded in Madurese Sumenep cultural traditions and develop a preliminary ethnopedagogical mapping framework for secondary science education. The study is expected to contribute to the growing discussion on culturally responsive science education by demonstrating how local cultural heritage can serve as a meaningful context for connecting scientific concepts, cultural identity, and community knowledge systems.

2. Method

This study employed a qualitative descriptive research design to explore Madurese cultural traditions in Sumenep Regency and analyze their potential contribution to secondary science education through an ethnopedagogical perspective. A qualitative approach was selected because the study aimed to understand cultural meanings, educational values, and science-related knowledge embedded within community practices rather than examine causal relationships or measure the effectiveness of instructional interventions. Qualitative descriptive research is appropriate for studies that seek to provide a comprehensive interpretation of social and cultural phenomena based on participants' experiences and contextual meanings (Nassaji, 2015; Sandelowski & Barroso, 2002).

The study was conducted in Sumenep Regency, Madura, Indonesia, a region characterized by diverse cultural traditions that remain actively practiced within local communities. The research focused on identifying cultural practices that contain educational values and exploring their potential transformation into science-learning contexts. The study adopted an ethnopedagogical perspective, which views local knowledge systems and cultural practices as meaningful resources for developing contextual learning experiences. In this study, cultural traditions were not considered replacements for scientific knowledge but were examined as authentic contexts that may support students' understanding of scientific concepts, scientific literacy, and cultural appreciation. The analytical framework of this study consisted of three interconnected dimensions: (1) identification of cultural practices and their meanings, (2) analysis of educational values embedded within these traditions, and (3) mapping of cultural knowledge into potential secondary science-learning contexts.

The participants of this study consisted of ten cultural informants selected from several communities in Sumenep Regency. The informants represented individuals with direct knowledge and experience regarding Madurese cultural traditions, including cultural leaders, traditional practitioners, performing artists, craftsmen, and community members involved in cultural preservation activities.

Participants were selected using purposive sampling because the research required individuals with specific cultural expertise rather than statistically representative samples. Purposive sampling is appropriate when researchers seek information-rich participants who can provide detailed understanding of a particular phenomenon (Campbell et al., 2020). To identify additional knowledge holders, snowball sampling was subsequently applied. Initial informants recommended other individuals who possessed relevant knowledge about specific traditions, allowing researchers to access cultural expertise embedded within community networks (Parker et al., 2019).

The inclusion criteria were: (1) having direct involvement or knowledge related to at least one Madurese cultural tradition investigated in this study; (2) having experience in cultural practices or preservation activities; and (3) willingness to participate in interviews, observations, and documentation processes. Participant recruitment continued until the researchers obtained sufficient information to answer the research questions. However, because this study was exploratory in nature, the researchers interpreted this condition as thematic sufficiency rather than claiming complete ethnographic saturation. The characteristics of participants are presented in Table 1.

Table 1. Characteristics of Cultural Informants

Informant Code	Gender	Age Category	Cultural Role	Years of Experience	Main Cultural Expertise	Educational Background
I1	Male	>50 years	Cultural leader	>15 years	*Nyadder* tradition	Bachelor degree
I2	Male	>50 years	Traditional practitioner	>15 years	*Ojung* ritual	Senior high school
I3	Male	41–50 years	Cultural practitioner	5–10 years	Traditional ceremonies	Senior high school
I4	Female	41–50 years	Community cultural figure	>15 years	Cultural rituals	Bachelor degree
I5	Male	>50 years	Craftsman	>15 years	*Keris* craftsmanship	Elementary school

ISSN: 2797-3174

Informant Code	Gender	Age Category	Cultural Role	Years of Experience	Main Cultural Expertise	Educational Background
I6	Male	41–50 years	Traditional artist	>15 years	Performing arts	Bachelor degree
I7	Female	31–40 years	Cultural practitioner	5–10 years	Traditional arts	Bachelor degree
I8	Male	>50 years	Community elder	>15 years	*Taneyan Lanjheng*	Senior high school
I9	Male	41–50 years	Traditional practitioner	>15 years	*Karapan Sapi* and *Sapi Sonok*	Senior high school
I10	Male	>50 years	Cultural preservation member	>15 years	Local traditions	Bachelor degree

Data collection was conducted through three complementary techniques: semi-structured interviews, direct observations, and document analysis. The use of multiple data sources enabled methodological triangulation and strengthened the credibility of interpretations. Semi-structured interviews were conducted with ten cultural informants using an interview guide developed based on the research objectives. The interview questions focused on four main areas: (1) historical background and meaning of cultural traditions; (2) knowledge systems embedded within cultural practices; (3) educational values transmitted through traditions; and (4) possible connections between cultural knowledge and science learning. Examples of interview questions included: “What knowledge and values are embedded within this cultural tradition?”, “How is this knowledge transmitted between generations?”, “What natural phenomena, materials, or environmental processes are involved in this practice?” Interviews were conducted with participants’ consent, audio-recorded, and supplemented with field notes.

Observation activities were conducted to document cultural practices, traditional objects, environmental settings, and community interactions associated with selected traditions. The observation protocol focused on physical processes, materials used, environmental relationships, and social values demonstrated through cultural activities. Photographs and field notes were used as supporting evidence. Document analysis was conducted using cultural documents, historical records, local government publications, and previous academic studies related to Madurese traditions. Documentary sources were used to contextualize interview findings and support interpretation through comparison with existing knowledge.

The research process consisted of four stages. The first stage involved preparation and identification of cultural sources. Researchers identified relevant Madurese traditions and established communication with cultural communities and local representatives. The second stage involved field data collection through interviews, observations, and documentation. Data collection was conducted in several locations in Sumenep Regency associated with cultural practices, including communities related to *Nyadder, Ojung, Karapan Sapi, Taneyan Lanjheng*, performing arts, and keris craftsmanship. The third stage involved data organization and interpretation. Interview recordings were transcribed, observation notes were organized, and documentary materials were reviewed. The collected information was categorized based on cultural practices, educational values, and science-related knowledge. The final stage involved ethnopedagogical mapping. Each cultural tradition was analyzed by examining its relationship with scientific phenomena, relevant secondary science concepts, possible inquiry activities, and appropriate pedagogical approaches. The resulting output was positioned as a preliminary ethnopedagogical framework requiring further classroom-based validation.

The collected data were analyzed using thematic analysis following the procedures described by Ahmed et al. (2025). The analysis involved six stages: data familiarization, initial coding, theme development, theme review, theme definition, and reporting. During the coding process, interview transcripts, observation records, and documents were examined to identify recurring patterns related to cultural meanings, knowledge systems, educational values, and scientific relevance. Similar codes were grouped into broader themes representing dimensions of Madurese cultural knowledge.

After cultural themes were identified, an additional analytical process was conducted to map traditions into potential science-learning contexts. Each tradition was examined according to: cultural practice and meaning; scientific phenomena involved; relevant science concepts; possible learning approaches; potential student competencies. For example, keris craftsmanship was analyzed in relation to traditional material processing, heat application, and material properties, while *Ojung* was examined through its relationship with environmental observations and weather-related concepts.

The trustworthiness of this qualitative study was ensured through credibility, dependability, confirmability, and transferability strategies. Credibility was strengthened through triangulation of interviews, observations, and document analysis. Dependability was supported by maintaining systematic documentation of research procedures, data organization, and analytical decisions. Confirmability was maintained by

ISSN: 2797-3174

continuously comparing interpretations with original data sources. Transferability was supported through detailed descriptions of research context, participants, and cultural practices, enabling readers to evaluate the relevance of findings for other educational contexts (Ahmed, 2024; Riazi et al., 2023).

Ethical approval was obtained from Universitas Jember and relevant local authorities. Participants were informed regarding the objectives, procedures, and use of research data before participation. Written consent was obtained before interviews, recordings, and photographic documentation. Participant identities were anonymized to protect confidentiality.

3. Results and Discussion

3.1. Results

The analysis of interview data, observation records, and documentary sources identified thirteen Madurese cultural traditions in Sumenep Regency that contain educational values and potential relevance for secondary science education. The identified traditions represent diverse forms of community knowledge developed through long-term interactions between Madurese society, natural environments, traditional technologies, social structures, and cultural values. The findings indicate that Madurese cultural heritage is not limited to ceremonial activities or symbolic expressions but also represents a complex knowledge system embedded within everyday community practices. These knowledge systems include environmental observations, material processing techniques, animal management practices, architectural knowledge, artistic expressions, and social values transmitted across generations.

Based on thematic analysis, the identified traditions were grouped into five interconnected cultural domains: ritual and belief systems, environmental and animal-related practices, traditional technology and craftsmanship, performing arts and cultural expressions, and social-cultural practices. The classification demonstrates that different cultural traditions contain different forms of knowledge that may provide contextual resources for science education. The classification of identified traditions is presented in Table 2.

Table 2. Classification of Madurese Cultural Traditions Identified in Sumenep Regency

Cultural Domain	Identified Traditions	Characteristics of Cultural Knowledge
Ritual and belief systems	*Nyadder, Ojung, Rokat Dhisah*	Cultural practices related to spirituality, gratitude, collective responsibility, environmental relationships, and community identity
Environmental and animal-related practices	*Karapan Sapi, Sapi Sonok, Sleeping on Sand*	Knowledge related to animal management, environmental adaptation, ecological experiences, and human-nature interaction
Traditional technology and craftsmanship	*Keris craftsmanship, Taneyan Lanjheng*	Knowledge related to material processing, traditional engineering, architecture, spatial organization, and environmental adaptation
Performing arts and cultural expression	*Saronen, Ghedingan, Ludruk, Topeng Dalang*	Knowledge related to sound production, artistic processes, communication, cultural representation, and material utilization
Social and behavioral practices	*Carok*	Social knowledge related to cultural identity, community norms, conflict, and social values

The classification shows that Madurese traditions contain both tangible and intangible knowledge dimensions. Tangible knowledge appears in traditional technologies, artefacts, materials, and environmental practices, whereas intangible knowledge appears in values, beliefs, social relationships, and cultural meanings.

The thematic analysis identified four major educational dimensions embedded within Madurese cultural traditions: spiritual and ethical values, social responsibility, technical knowledge, and environmental awareness. These dimensions represent the educational meanings constructed within cultural practices and transmitted through community participation. The results of thematic analysis are summarized in Table 3.

Table 3. Thematic Analysis of Educational Values and Knowledge Systems Embedded in Madurese Cultural Traditions

Main Theme	Sub-theme	Related Traditions	Evidence Sources	Educational Meaning
Spiritual and ethical values	Gratitude, responsibility, respect toward nature, collective commitment	*Nyadder, Ojung, Rokat Dhisah*	Interviews, observations, cultural documents	Demonstrates relationships between humans, nature, belief systems, and social responsibility
Social and character values	Cooperation, discipline, communication,	*Karapan Sapi, Sapi Sonok, Ludruk, Topeng Dalang*	Interviews and observation of	Represents informal learning processes related to

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Main Theme	Sub-theme	Related Traditions	Evidence Sources	Educational Meaning
	collective participation		cultural practices	responsibility, teamwork, and social interaction
Traditional technological knowledge	Material selection, craftsmanship, processing techniques, adaptation	*Keris craftsmanship, Taneyan Lanjheng*	Observation of artefacts and cultural practices	Shows accumulated experiential knowledge related to technology and environmental adaptation
Environmental knowledge	Human-environment relationships, ecological adaptation, natural resource utilization	*Nyadder, Sleeping on Sand, Rokat Dhisah*	Environmental observations and cultural descriptions	Reflects community knowledge regarding adaptation and interaction with ecosystems
Scientific phenomena embedded in cultural practices	Motion, sound, heat, materials, biological processes	*Karapan Sapi, Saronen, Keris craftsmanship, Sapi Sonok*	Analysis of observable processes	Provides contextual opportunities for connecting cultural experiences with science concepts

The first theme identified from the data concerns the relationship between cultural traditions, moral values, and community perspectives toward nature. Traditions such as *Nyadder, Ojung*, and *Rokat Dhisah* demonstrate how cultural practices function as mechanisms for transmitting values related to gratitude, responsibility, respect, and collective participation.

Nyadder represents a cultural practice associated with gratitude and community commitment. The tradition reflects how communities maintain relationships with their historical identity, environment, and collective responsibilities. *Ojung* demonstrates the relationship between cultural interpretation and environmental phenomena, particularly through community perspectives regarding rainfall and natural conditions. Meanwhile, *Rokat Dhisah* reflects collective efforts to maintain social harmony and relationships between communities and their surrounding environments. These findings indicate that cultural traditions provide educational contexts for discussing ethical relationships between humans, society, and nature.

The second theme relates to social values developed through participation in cultural activities. Traditions such as *Karapan Sapi, Sapi Sonok, Ludruk,* and *Topeng Dalang* demonstrate how cultural practices become spaces for learning cooperation, discipline, communication, and collective responsibility. *Karapan Sapi* involves complex preparation processes involving cattle owners, trainers, and communities. The tradition requires coordination, animal care, and collective effort. Beyond the competition itself, the practice reflects social organization and community participation. *Sapi Sonok* similarly demonstrates relationships between cultural identity and animal management. The practice involves maintaining cattle conditions, training processes, and aesthetic presentation, reflecting responsibility and care toward living organisms. Performing arts such as *Ludruk* and *Topeng Dalang* also represent cultural learning spaces where knowledge, values, and social messages are communicated through performance.

The third theme concerns traditional technological knowledge developed through interaction with materials, tools, and environmental resources. Keris craftsmanship represents one of the strongest examples of traditional technological knowledge identified in this study. The process involves material selection, heating, shaping, and artistic finishing. These practices demonstrate accumulated experiential knowledge regarding material characteristics and transformation processes. *Taneyan Lanjheng* represents another form of traditional knowledge related to spatial organization and environmental adaptation. The arrangement of houses reflects relationships between family structures, social organization, and adaptation to local conditions. These findings show that traditional technologies contain knowledge related to engineering processes, materials, and environmental design.

Environmental knowledge emerged as another important theme. Several traditions demonstrate how Madurese communities develop knowledge through long-term interactions with their environment. Sleeping on Sand represents local adaptation within coastal communities. The practice reflects community experiences regarding environmental conditions and physical comfort. However, the findings position this practice as cultural knowledge rather than scientifically verified medical knowledge. Similarly, *Nyadder* and *Rokat Dhisah* demonstrate how communities construct relationships with natural environments through cultural practices and collective activities.

The analysis further examined the scientific phenomena embedded within identified cultural practices. The purpose of this analysis was not to replace cultural meanings with scientific explanations but to identify possible connections between local practices and secondary science concepts. The findings revealed that

ISSN: 2797-3174

science-related knowledge was primarily associated with four scientific domains: physical processes and material properties; biological systems and animal interactions; environmental systems; sound and technological processes. Table 4 presents the identified relationships between cultural practices and science concepts.

Table 4. Science-Related Knowledge Embedded in Madurese Cultural Traditions

Cultural Tradition	Cultural Practice	Science-Related Phenomena	Relevant Science Concepts
Nyadder	Coastal community tradition and interaction with marine environment	Human interaction with coastal ecosystems	Ecosystem, biodiversity, environmental relationships
Ojung	Community practice related to rainfall expectations	Weather observation and atmospheric phenomena	Water cycle, weather systems, climate
Rokat Dhisah	Village tradition related to community and environment	Human-environment interaction	Sustainability, ecosystems, environmental awareness
Karapan Sapi	Cattle preparation and racing activity	Motion, force, energy, muscle performance	Force and motion, biomechanics, animal physiology
Sapi Sonok	Cattle training and maintenance	Animal growth, health, and behavior	Biology, nutrition, animal welfare
Sleeping on Sand	Human interaction with coastal sand environment	Thermal characteristics of materials	Heat transfer, temperature, material properties
Keris craftsmanship	Traditional metal processing	Heating, shaping, material transformation	Heat transfer, material science, physical changes
Taneyan Lanjheng	Traditional settlement arrangement	Environmental adaptation and spatial design	Architecture, sustainability, environmental science
Saronen	Traditional musical performance	Sound production and vibration	Sound waves, frequency, resonance
Ghedingan	Traditional musical expression	Acoustic characteristics	Vibration, acoustics
Ludruk	Cultural performance and storytelling	Communication and material utilization	Science communication, materials, environment
Topeng Dalang	Mask production and performance	Material selection and artistic technology	Materials science, natural resources
Carok	Social practice and cultural behavior	Human behavior and social interaction	Ethical and interdisciplinary learning

The findings demonstrate that cultural traditions provide diverse contexts for exploring science concepts. Traditions involving physical processes, material transformation, biological interactions, and environmental systems showed the strongest connections with secondary science education.

The final analytical stage involved developing a preliminary ethnopedagogical mapping framework. This framework represents the process of connecting cultural traditions with possible science-learning contexts by considering cultural authenticity, scientific relevance, and pedagogical suitability. The analysis revealed that ethnopedagogical integration requires more than simply attaching scientific concepts to cultural activities. Instead, cultural practices must be interpreted through three analytical stages: identifying meaningful cultural practices, determining scientific phenomena contained within those practices, and designing appropriate learning approaches that maintain both scientific accuracy and cultural meaning.

The findings indicate three main patterns of ethnopedagogical integration. First, cultural traditions can function as contextual entry points for scientific inquiry. Traditions such as *Karapan Sapi* and *Keris* craftsmanship contain observable processes that allow students to investigate force, motion, material properties, and transformation processes. Second, cultural traditions can support environmental and sustainability learning. Traditions such as *Nyadder, Ojung*, Sleeping on Sand, and *Taneyan Lanjheng* provide contexts for discussing ecosystems, environmental adaptation, human relationships with nature, and sustainability issues. Third, cultural traditions can support STEAM and creative science learning. Performing arts such as *Saronen, Ghedingan*, and *Topeng Dalang* provide opportunities to explore sound, vibration, materials, and cultural technology. The preliminary ethnopedagogical mapping is presented in Table 5.

Table 5. Preliminary Ethnopedagogical Mapping of Madurese Cultural Traditions for Secondary Science Education

Cultural Tradition	Proposed Learning Approach	Science Learning Context	Potential Learning Activities	Expected Learning Opportunities
Nyadder	Contextual learning, culturally	Ecosystem and environmental relationships	Investigating coastal ecosystems and community interaction with nature	Understanding environmental awareness and cultural perspectives

ISSN: 2797-3174

Cultural Tradition	Proposed Learning Approach	Science Learning Context	Potential Learning Activities	Expected Learning Opportunities
	responsive teaching			
Ojung	Inquiry-based learning	Weather systems and environmental phenomena	Comparing cultural interpretations of rainfall with scientific explanations	Developing scientific reasoning and environmental understanding
Rokat Dhisah	Problem-based learning	Sustainability and ecosystems	Analyzing community relationships with environmental issues	Developing environmental awareness
Karapan Sapi	Project-based learning, inquiry learning	Force, motion, biomechanics	Investigating movement and physical principles	Connecting scientific concepts with real-life phenomena
Sapi Sonok	Contextual learning	Animal biology and welfare	Exploring animal care and biological processes	Understanding biological systems and ethical relationships
Sleeping on Sand	Inquiry learning	Heat transfer and materials	Investigating thermal characteristics of natural materials	Understanding physical properties through local phenomena
Keris craftsmanship	STEAM learning, project-based learning	Materials science and traditional technology	Examining forging processes and material transformation	Understanding technology and material science
Taneyan Lanjheng	Project-based learning	Architecture and sustainability	Analyzing traditional settlement design	Understanding human-environment adaptation
Saronen and Ghedingan	STEAM learning, inquiry learning	Sound and vibration	Investigating acoustic principles of traditional instruments	Connecting physics concepts with cultural artefacts
Topeng Dalang	Project-based learning	Materials and natural resources	Exploring traditional material selection and processing	Understanding material characteristics and cultural technology

The ethnopedagogical mapping demonstrates that Madurese cultural heritage provides meaningful opportunities for contextual science education. The findings suggest that local traditions can serve as bridges between students' cultural experiences and scientific concepts. However, the framework developed in this study should be considered a preliminary conceptual mapping rather than a validated instructional model. Further empirical studies involving science teachers, curriculum experts, and students are required to evaluate classroom feasibility, learning implementation, and educational outcomes.

3.2. Discussion

3.2.1. Madurese Cultural Heritage as Community-Based Knowledge Systems

The findings of this study demonstrate that Madurese cultural traditions in Sumenep represent more than cultural performances or inherited social practices. They function as community-based knowledge systems containing ecological understanding, technological practices, material knowledge, social values, and interpretations of natural phenomena. These findings reinforce the perspective that local and indigenous knowledge develops through continuous interactions between communities and their surrounding environments, resulting in distinctive ways of understanding, interpreting, and responding to natural and social conditions (Aikenhead & Jegede, 1999; Cobern & Loving, 2001).

The identified traditions illustrate that knowledge within cultural practices is developed through observation, adaptation, experimentation, and intergenerational transmission. For example, keris craftsmanship reflects accumulated experiential knowledge related to material selection, heating processes, shaping techniques, and transformation of materials, while Karapan Sapi demonstrates knowledge associated with animal management, movement, physical performance, and human–animal relationships. Similarly, environmental traditions such as Nyadder, Ojung, and Taneyan Lanjheng represent community experiences regarding relationships between humans, environments, and local ecological conditions.

These findings indicate that cultural heritage can serve as an intellectual resource for science education rather than merely functioning as contextual illustrations added to existing lessons. From an ethnopedagogical perspective, the educational value of cultural traditions lies not only in their connection with scientific concepts but also in their capacity to represent how communities construct and transmit knowledge within particular

ISSN: 2797-3174

environmental and cultural contexts. Therefore, integrating local knowledge into science education may provide opportunities for students to recognize science as a form of knowledge that is connected with human experiences, places, and societies (Bang & Marin, 2015).

3.2.2. Epistemological Boundaries Between Local Knowledge and Scientific Knowledge

Although the findings demonstrate potential relationships between Madurese cultural practices and secondary science concepts, this study emphasizes that ethnopedagogical integration requires careful epistemological consideration. Local cultural knowledge and scientific knowledge represent different knowledge systems with distinct purposes, methods of validation, and ways of explaining phenomena. Therefore, cultural practices should not be interpreted as direct substitutes for scientific explanations, nor should they be valued only when they can be translated into scientific concepts.

For example, *Ojung* provides an important cultural context for discussing community interpretations of rainfall and environmental conditions. However, this tradition should not be interpreted as a scientific mechanism that determines rainfall occurrence. Instead, it can serve as a meaningful starting point for students to explore relationships between cultural perspectives, environmental observations, and scientific explanations of weather phenomena. This approach allows students to understand the coexistence of cultural knowledge and scientific knowledge while maintaining scientific accuracy (Aikenhead, 2001; McKinley & Gan, 2014).

Such epistemological consideration is essential because inappropriate integration may reduce cultural traditions into simplified scientific examples and ignore their historical, social, and symbolic meanings. Ethnopedagogical approaches should therefore facilitate dialogue between knowledge systems rather than replacing one system with another. Through this dialogue, students can develop scientific understanding while also appreciating the cultural contexts in which knowledge is produced and transmitted.

3.2.3. Validity and Limitations of the Ethnopedagogical Mapping Framework

The ethnopedagogical mapping developed in this study provides an analytical framework connecting cultural traditions, science-related phenomena, and potential learning approaches. However, this framework should be interpreted as a preliminary mapping rather than a validated instructional model. The relationship between cultural practices and science concepts was established through interpretation of cultural meanings, observable phenomena, and their possible relevance to secondary science education.

The validity of such mapping requires consideration of three interconnected aspects: cultural authenticity, scientific accuracy, and pedagogical suitability. Cultural traditions should not be selected solely because they appear to contain scientific concepts, but because they provide meaningful opportunities for students to investigate phenomena, construct scientific understanding, and engage with authentic contexts. For example, keris craftsmanship and traditional musical instruments provide observable processes related to materials science, heat transfer, and sound phenomena, making them potentially suitable contexts for inquiry-based or STEAM-oriented learning. However, the effectiveness of such approaches requires further investigation through classroom implementation and evaluation.

Therefore, future research should involve science teachers, curriculum experts, cultural experts, and students to examine the feasibility and educational impact of the proposed framework. Such validation is necessary to determine whether the identified cultural contexts can effectively support scientific literacy, conceptual understanding, and culturally responsive learning experiences (Govender & Mudzamiri, 2022; Zidny et al., 2020).

3.2.4. Ethical Considerations in Integrating Cultural Heritage into Science Education

The integration of cultural heritage into science education also requires careful ethical consideration. Cultural traditions should not be treated merely as instructional materials extracted from communities without acknowledging their cultural ownership, historical background, and social significance. Transforming cultural practices into learning resources requires respect toward communities that maintain and transmit these traditions across generations. An ethical ethnopedagogical approach requires maintaining a balance between educational purposes and cultural integrity. Teachers and curriculum developers should avoid simplifying complex cultural practices into isolated scientific examples while ignoring their philosophical, social, and symbolic meanings. Instead, cultural integration should involve meaningful engagement with communities and recognition of local knowledge holders as contributors to educational development.

ISSN: 2797-3174

This perspective aligns with culturally sustaining pedagogy, which emphasizes that education should not only acknowledge students' cultural backgrounds but also maintain and strengthen cultural identities within learning processes (Paris, 2012). Similarly, indigenous knowledge frameworks highlight the importance of recognizing local communities as active producers of knowledge rather than passive sources of cultural information (Brayboy & Maughan, 2009).

3.2.5. Implications for Culturally Responsive Science Education

The findings of this study contribute to broader discussions regarding culturally responsive science education by demonstrating how local cultural heritage can function as a bridge between community knowledge and formal scientific learning. Unlike approaches that merely add local examples into existing curricula, ethnopedagogical integration requires systematic analysis of cultural practices, knowledge systems, scientific phenomena, and pedagogical possibilities.

The proposed mapping suggests that different cultural traditions provide different opportunities for science learning. Traditions involving observable physical processes, such as keris craftsmanship and traditional musical instruments, may support inquiry-based and STEAM activities because students can investigate materials, energy, vibration, and technological processes. Meanwhile, environmental traditions such as *Nyadder, Ojung*, Sleeping on Sand, and *Taneyan Lanjheng* may provide meaningful contexts for sustainability-oriented science education by connecting scientific concepts with local environmental experiences.

From a theoretical perspective, this study strengthens ethnopedagogical perspectives by demonstrating that local cultural traditions can be analyzed as interconnected knowledge systems rather than isolated cultural examples. From a practical perspective, the findings provide an initial foundation for developing culturally responsive science-learning materials and activities. Nevertheless, classroom implementation and empirical validation remain necessary before conclusions regarding learning effectiveness can be established.

3.2.6. Limitations and Future Research Directions

Despite providing insights into the potential of Madurese cultural heritage for secondary science education, this study has several limitations that should be considered. First, this study focused on identifying and mapping cultural traditions rather than implementing an ethnopedagogical approach in actual classroom settings. Therefore, conclusions regarding its effectiveness in improving students' scientific literacy, conceptual understanding, motivation, or learning outcomes cannot yet be established.

Second, the cultural knowledge explored in this study was primarily obtained from cultural informants, including cultural practitioners, community leaders, and individuals involved in cultural preservation activities. Although these informants provided valuable perspectives regarding local traditions, future research should involve additional educational stakeholders, including science teachers, curriculum experts, and students, to evaluate classroom feasibility and pedagogical relevance.

Third, the ethnopedagogical mapping developed in this study is contextually situated within Sumenep Regency. Although the identified traditions provide meaningful examples of local knowledge systems, transferability to other regions requires consideration of different historical, environmental, and cultural contexts. Furthermore, the proposed relationships between cultural practices and science concepts require further validation through expert review and empirical classroom studies.

Future research may therefore focus on developing and validating instructional materials, learning models, or classroom interventions based on the proposed mapping framework. Such studies are necessary to examine how culturally responsive science education can support students' scientific understanding while maintaining respect for cultural authenticity and epistemological diversity.

4. Conclusion

This study demonstrates that Madurese cultural heritage in Sumenep represents a community-based knowledge system containing educational values, environmental understanding, technological practices, and science-related phenomena relevant to secondary science education. Through qualitative exploration of cultural practices, interviews, observations, and document analysis, thirteen traditions were identified and mapped across interconnected cultural domains, including ritual practices, environmental and animal-related traditions, traditional technology, performing arts, and social-cultural practices. The findings indicate that these traditions provide meaningful contexts for connecting local knowledge with scientific concepts such as ecosystems, weather systems, biomechanics, materials science, heat transfer, and sound phenomena. However, this study emphasizes that ethnopedagogical integration should not reduce cultural practices into scientific examples alone, but should facilitate dialogue between local knowledge systems and formal science knowledge while maintaining cultural authenticity and scientific accuracy. The main contribution of this study lies in developing a preliminary ethnopedagogical mapping framework that connects cultural traditions, science-related

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phenomena, and potential learning approaches for secondary science education. Nevertheless, the proposed framework remains exploratory and requires further validation through collaboration with science teachers, curriculum experts, cultural communities, and classroom implementation studies. Future research should examine how culturally responsive science education based on local knowledge systems can support students' scientific literacy, conceptual understanding, and appreciation of cultural diversity.

Author Contributions

All authors contributed equally to this paper. All authors have read and approved the final manuscript.

Funding

This research was funded by the Institute for Research and Community Service (LPPM) of Jember University through the 2024 postgraduate research grant.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethics and Consent Declarations

This research was conducted in accordance with research ethics standards. Ethical approval was obtained from Jember University (No. 9967/UN25.1.5/SP/2024) and the Unity and Political Affairs Agency of Sumenep Regency (No.400.14.5.4/448/205.2/2024). This approval ensures that all research procedures adhere to the moral principles of social research involving direct interaction with cultural experts, community members, and practitioners of cultural traditions. Before data collection, the researcher obtained verbal and written approval from the Unity and Political Affairs Agency after explaining the purpose, benefits, and their right to refuse or withdraw at any time without consequence. To maintain confidentiality and anonymity, respondents' identities were replaced with codes or pseudonyms. Interview data, photographs, and field notes were securely stored and accessible only to the principal investigator. Sensitive information is presented in general and aggregated forms, without revealing the identities of specific individuals or groups. The entire research process was conducted with ethical principles in mind, respecting local culture, and maintaining the scientific integrity of the research.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declaration on AI Use

The authors declare that the generative artificial intelligence (AI) tool ChatGPT 5 was used exclusively for language editing and grammatical improvement. The use of AI did not influence the scientific content, study design, data analysis, data interpretation, results, or conclusions of the manuscript. Full responsibility for the content remains with the authors.

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ISSN: 2797-3174