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Integrating Ethnoscience into Physics Education: Enhancing Heat Transfer Understanding through Traditional Tobacco Drying Practices in Jember

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Abstract: Heat transfer is a fundamental yet conceptually challenging topic in physics, often taught in abstract ways that hinder students' ability to relate concepts to real-life phenomena. This study investigates the effectiveness of ethnoscience-based learning, grounded in traditional tobacco drying practices in Jember, Indonesia, in improving students' conceptual understanding of heat transfer. A sequential explanatory mixed-methods design was employed involving undergraduate preservice science teachers. Quantitative data were collected through pre-test and post-test assessments on conduction, convection, and radiation concepts, while qualitative data were obtained from classroom observations, interviews, and reflective writings. The results show a moderate-to-high improvement in students' conceptual understanding (N-gain = 0.67), with a significant shift from intuitive to scientifically accepted reasoning. Qualitative findings indicate that culturally familiar practices serve as epistemic bridges that facilitate conceptual change and enhance learning relevance. This study concludes that integrating local agricultural knowledge effectively supports meaningful physics learning. The research contributes to science education by positioning ethnoscience as an epistemic foundation in domain-specific physics instruction and by demonstrating its potential to promote conceptual understanding and sustainability-oriented education simultaneously.

Keywords: *ethnoscience-based learning; heat transfer; physics education; sustainability education; traditional tobacco drying*

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INTRODUCTION

Heat transfer is one of the most conceptually challenging topics in physics, involving the transfer of thermal energy through conduction, convection, and radiation. Many studies report that students struggle to distinguish heat and temperature, understand thermal equilibrium, and apply the wrong heat transfer mechanisms when reasoning about real phenomena (Prince et al., 2012; Docktor & Mestre, 2014; Duit & Treagust, 2003; Çengel & Ghajar, 2020). Instructional practices that emphasize mathematical abstraction and disregard context and experiential learning strongly correlate with these challenges. As a result, students often struggle to connect formal physics ideas to everyday thermal phenomena.

Amid these challenges, ethnoscience has emerged as a promising approach to situate science learning within indigenous and local knowledge systems. Ethnoscience recognizes that cultural practices are built on empirical observations, experiments, and intergenerational knowledge transfer that follow scientific processes of inquiry. Ethnoscience-based learning has been shown to improve conceptual and active learning and increase cultural relevance by placing local knowledge on a level playing field with scientific knowledge, rather than merely providing anecdotal background. This also helps facilitate inclusiveness and the continuity of intangible cultural heritage in formal education in multicultural societies, such as Indonesia (Aikenhead & Ogawa, 2007; Snively & Corsiglia, 2001; Aikenhead et al., 2015; Kasi et al., 2021).

Farming is one of the most knowledge-rich fields of ethnoscience, where farmers engage in continual resource management to maintain productivity, including energy flow, heat exchange, and environmental variability. Agroecological research shows that traditional agricultural systems include very complex mechanisms of microclimate management, energy use, and thermal balance that have evolved over generations to respond to local agroecological systems. In science education, research shows that "contextualizing" the curriculum with agricultural and food-processing experiences helps students connect abstract scientific concepts to practical experiences (Altieri et al., 2015; Altieri, 2018; Gliessman, 2015). Most of the ethnoscience-based learning research that has been conducted, however, focuses on biology, environmental science, and chemistry (Sudarmin et al., 2018; Sudarmin et al., 2019; Kasi et al., 2021), except physics, which is largely under-researched, especially in the context of heat transfer (Kasi et al., 2021; Amaliah et al., 2022; Sunarti et al.,

2024). Tobacco cultivation and drying are culturally embedded agricultural practices with significant socio-economic importance, particularly in Jember, East Java, Indonesia. Conventional tobacco drying involves controlled management of solar radiation, airflow, humidity, and ambient temperature to reduce moisture and improve the quality of the drying tobacco leaves (Muktianto & Herman, 2018; Amaliah et al., 2022). Physically, these processes are a natural part of solar radiative absorption, convective heat transfer through natural ventilation, and conductive heat transfer between leaves and supporting structures (Bergman et al., 2011; Çengel & Ghajar, 2020). Despite this conceptual similarity, very few research works have been conducted on the pedagogical aspects of tobacco drying, and most of the research reported in the literature has dealt with agronomy and climate effects and/or post harvest technology (Altieri et al., 2015; Muktianto & Herman, 2018). A notable exception is Amaliah et al. (2022), who described conduction, convection, and radiation in tobacco drying in Jember but did not test an instructional intervention.

Currently, studies on ethnoscience as physics education in Indonesia have proven to have positive results on students' conceptual understanding and attitudes towards science, but the studies are limited to the elementary and junior secondary levels, and focus on relatively simple concepts, including measuring temperature and simple energy transformation (Sudarmin et al., 2018; Kasi et al., 2021). Furthermore, local wisdom as a learning center is rarely used as an epistemological axis for structuring learning activities and reasoning processes (Aikenhead & Ogawa, 2007; Snively & Corsiglia, 2001). This reveals a clear research gap: empirically based instructional designs that incorporate complex local agricultural heat-transfer practices into formal physics learning, especially learning that requires higher-level reasoning and conceptual abstraction (Docktor & Mestre, 2014; Vosniadou, 2013).

Another limitation in the literature is the lack of integration between ethnoscience and sustainability education. Education for sustainable development emphasizes that science is relevant to local practices that ensure resource efficiency, environmental care, and adaptive resilience (UNESCO, 2017; Sterling, 2001). Traditional tobacco drying illustrates adaptive practice by using the sun's energy and natural ventilation to optimize energy use without relying on high-energy industrial technologies, providing an authentic context for learning physics in the context of sustainability (Altieri, 2018; Gliessman, 2015; Muktianto & Herman, 2018). However, few studies explicitly discuss promoting both conceptual understanding of heat transfer and sustainability awareness through these practices (Kasi et al., 2021; Sunarti et al., 2024).

Based on empirical evidence from a preliminary study, this study seeks to address these knowledge gaps in instructional interventions. The initial results showed that preservice science teachers had persistent misconceptions about heat transfer mechanisms, especially in differentiating conduction, convection, and radiation. Students often used intuitive reasoning patterns, which were revealed by diagnostic evaluations, in which thermal phenomena were exclusively correlated with temperature but not related to the underlying energy transfer processes. The physics education literature well documents these challenges, as thermodynamics is a cognitively difficult topic for which students often hold alternative conceptions (Docktor & Mestre, 2014; Duit & Treagust, 2003; Treagust & Duit, 2008; Vosniadou, 2013).

In addition, the preliminary study revealed that the heat transfer concepts were mainly communicated via abstract and symbolic representations, which made it difficult for the students to develop meaningful conceptual links. Learning activities were primarily formula-based explanations and textbook-based problem solving, with little experiential or contextual problem solving. This made it difficult for students to connect abstract concepts with real-world phenomena. Previous research indicates that decontextualized physics teaching can lead to poor contextual understanding and the persistence of misconceptions (Treagust & Duit, 2008; Redish & Hammer, 2009; Hammer, 2000). These teaching practices can lead to fragmented thinking, making it difficult for students to understand the concepts. In this light, traditional tobacco drying practices in Jember offer a culturally based system with multiple heat transfer processes that are directly observable. These activities provide tangible examples of how energy can be transferred, helping students make the abstract concept concrete. Therefore, integrating these contexts could be a useful way to support conceptual restructuring and meaningful knowledge integration. This research innovates by including local agricultural knowledge not merely as illustration but as an epistemological basis for understanding conduction, convection, and radiation. This research continues the ethnoscience domain, which has been scarcely explored in physics learning, namely the process of drying traditional tobacco (Aikenhead & Ogawa, 2007; Amaliah et al., 2022; Kasi et al., 2021). This aligns with a pedagogical approach to culturally responsive, sustainability-oriented learning that focuses on the interconnections among culture, environment, and scientific reasoning (Sterling, 2001; UNESCO, 2017).

METHODS

This study used a sequential explanatory mixed-methods design, combining quantitative and qualitative methods to thoroughly explore the effectiveness of ethnoscience-based learning grounded in traditional knowledge about drying tobacco, which involves understanding concepts of heat transfer (Johnson & Onwuegbuzie, 2004; Creswell & Clark, 2018). This design was chosen to reflect measurable learning outcomes

and the cognitive processes affecting conceptual development. The quantitative phase mainly aimed to identify the conceptual change pattern by comparing pre-test and post-test scores. The qualitative phase, on the other hand, was designed to describe the conceptual interpretation, reconstruction, and stabilization processes students experienced. The methodological integration allows a more complete understanding of the effectiveness of the teaching-learning process than statistical analysis alone. In addition, the design supports the investigation of learning contexts and learning epistems. The numerical trends and interpretative insights provide a broad and deep analysis. This is especially suitable for culturally responsive educational research, which focuses on outcomes and processes.

The participants were university undergraduates, preservice science teachers at an open university in East Java, Indonesia who were enrolled in basic physics course. Participants were selected through purposive sampling to ensure similar academic backgrounds and no prior experience with ethnoscience-based instruction on heat transfer. The sampling was designed to improve consistency within the sample and to minimize instructional bias. The learning intervention was implemented in regular classes for four weeks. All participants received the same ethnoscience-based instructional module based on the traditional tobacco drying method. The classroom was used in the standard course, with classroom activities used to preserve ecological validity. Ethical issues were addressed, including participant consent and confidentiality. The participant framework enabled systematic analysis of conceptual change in an authentic instructional context.

The learning materials were part of an ethnoscience-based instructional module based on the traditional tobacco drying process in Jember. The module was carefully planned to translate observed local practices into structured conceptual learning experiences. It includes a detailed description of the drying stages, highlighting key aspects of temperature changes, airflow, and solar exposure patterns. The study also introduced guided inquiry worksheets to explicitly connect drying processes with the mechanisms of conduction, convection, and radiation. Discussion prompts enabled students to critically compare intuitive explanations with formal physics models. Visual representations and contextual illustrations facilitated cognitive bridging between the material's concrete and abstract aspects. The learning activities were facilitated with the use of standard classroom equipment (presentation slides, printed worksheets, thermometers, and whiteboards). Overall, the materials served as epistemic scaffolds for conceptual coherence and reasoning development.

A quantitative data collection technique was employed, based on a concept test in heat transfer that included conduction, convection, and radiation. It was designed to measure students' conceptual understanding, not their problem-solving skills. Test items focused on mechanistic thinking, conceptual differentiation, and the common misconceptions regarding heat transfer. The instrument adapts conceptual change instruments already developed for heat and energy and is administered as a pre-test and post-test to examine conceptual change (Prince et al., 2012). Data analysis was carried out using descriptive statistics to reveal the overall performance patterns and the distributional trends. Normalized gain (N-gain) scores were calculated to measure the intensity of concept growth after the intervention (Hake, 1998). With this analytical approach, learning effectiveness was systematically evaluated. The findings provided quantitative evidence for interpreting conceptual restructuring.

The classroom observation, semi-structured interview, and students' reflective written responses were used to collect the qualitative data after the quantitative phase. Patterns of students' engagement, cognition and interactions with ethnoscience-based materials were observed. Special focus was placed on the students' explanations of the connection between traditional practices and physics concepts. Conceptual reasoning, epistemic interpretations, and perceived learning experiences were explored in semi-structured interviews. Reflective responses helped further understand students' understanding and cognition. Data condensation, data display, and conclusion drawing (Miles et al., 2014) were used interactively to analyze the qualitative data. The categories were defined and then combined with preexisting categories derived from participants' responses related to heat transfer concepts. To increase credibility, consistency, and interpretive trustworthiness (Creswell & Poth, 2018), the study used data triangulation.

In the interpretation phase, integration was attempted by systematically using qualitative evidence to explain patterns in quantitative learning outcomes. This integrative approach allowed for better understanding of measurable and underlying cognitive mechanisms. Both qualitative and quantitative indicators of reasoning shifts and conceptual coherence were interpreted as quantitative improvements. The integration emphasized complementarity rather than simple corroboration of findings. Where present, divergent patterns were tested to strengthen the theoretical interpretations. This method allowed for the entire effectiveness and learning processes of ethnoscience-based instruction of heat transfer to be understood (Creswell & Clark, 2018). The analysis was presented in both distinct and composite forms, strengthening the study's explanatory power. It also strengthened the methodological rigor and interpretive soundness of the findings.

RESULT AND DISCUSSION

Students' conceptual understanding of heat transfer was measured before and after the ethnoscience-based learning intervention. Table 1 summarizes students' performance across conduction, convection, and radiation concepts.

Table 1. Heat Transfer Concept Test Results

Concept	Pre-test Mean (SD)	Post-test Mean (SD)	Normalized Gain (g)
Conduction	42.1 (9.5)	77.8 (8.3)	0.62
Convection	39.4 (10.1)	80.6 (7.6)	0.68
Radiation	46.3 (8.7)	84.9 (6.5)	0.72
Overall	42.6 (9.4)	81.1 (7.5)	0.67

A closer reading of Table 1 clarifies the structure of these gains. The results indicate moderate-to-high conceptual improvement, with the largest gains in radiation-related concepts. Mean scores rose by 35.7 points for conduction, 41.2 for convection, 38.6 for radiation, and 38.5 points overall (Table 2). Although convection showed the largest raw increase, radiation produced the highest normalized gain (g = 0.72) because its pre-test mean was already the highest (46.3), leaving less room for improvement. N-gain adjusts for this ceiling effect and therefore gives a fairer comparison of learning across concepts (Hake, 1998). Using Hake's (1998) conventional thresholds, the gains for conduction (0.62), convection (0.68), and the overall score (0.67) fall in the medium category, whereas radiation (0.72) reaches the high category. This pattern is consistent with the description of overall improvement as moderate-to-high.

The dispersion of scores also changed. Standard deviations decreased for every concept, from 9.4 to 7.5 overall, with the largest reductions in convection (10.1 to 7.6) and radiation (8.7 to 6.5), and a smaller one in conduction (9.5 to 8.3). A narrower spread suggests that the intervention not only raised the class average but also reduced differences between students, leaving fewer students at low levels of understanding. Convection began with the lowest pre-test mean (39.4) and the greatest variability (SD = 10.1), yet it showed the largest raw improvement and a marked gain in consistency. This is notable because, like radiation, convection is difficult to observe directly in conventional instruction (Prince et al., 2012).

Table 2. Absolute Gains, Normalized Gain Categories, and Change in Score Dispersion by Concept

Concept	Absolute gain (points)	N-gain (g)	Category (Hake, 1998)	SD pre → post
Conduction	35.7	0.62	Medium	9.5 → 8.3
Convection	41.2	0.68	Medium	10.1 → 7.6
Radiation	38.6	0.72	High	8.7 → 6.5
Overall	38.5	0.67	Medium	9.4 → 7.5

Table 3 shows changes in students' conceptual reasoning patterns, indicating a substantial shift toward scientifically accepted explanations.

Table 3. Distribution of Students' Reasoning Models (%)

Reasoning Model	Pre-test	Post-test
Intuitive / Everyday	54	12
Partial Scientific	33	26
Scientific	13	62

Table 3 shows that the proportion of students using intuitive or everyday reasoning fell from 54% to 12% (a 42-percentage-point reduction), while the proportion using scientific reasoning rose from 13% to 62% (a 49-percentage-point increase). The partial scientific category changed less (33% to 26%). This is expected in a distribution like this, because the category loses students who progress to fully scientific explanations but also gains students who move up from intuitive reasoning, so its net size can remain relatively stable even when many individual students change. Because Table 2 reports distributions rather than individual trajectories, the data cannot show how many students moved between categories, a caveat that is returned to in the limitations. Even so, the combined share of students using partial or fully scientific reasoning increased from 46% to 88%, indicating that most of the class had moved beyond purely intuitive explanations by the end of the four-week intervention.

The quantitative patterns converge with the logic of the sequential explanatory design. Radiation and convection, which are often the hardest mechanisms to visualize in conventional instruction, showed the highest normalized gain and the largest raw gain, respectively, and they are also the mechanisms most visibly linked to the drying practice, namely exposure of the leaves to sunlight and the control of airflow through the drying space. Conduction, which operates through contact between leaves and supporting materials and is less visually salient, showed the lowest normalized gain (0.62). This ordering does not, by itself, demonstrate causality, but it reflects what would be expected if the observability of the cultural practice contributed to learning, and it guided the interpretation of the qualitative data presented next. Qualitative findings from observations, interviews, and reflective writing revealed consistent learning mechanisms underlying these changes. Figure 1 synthesizes these relationships visually.

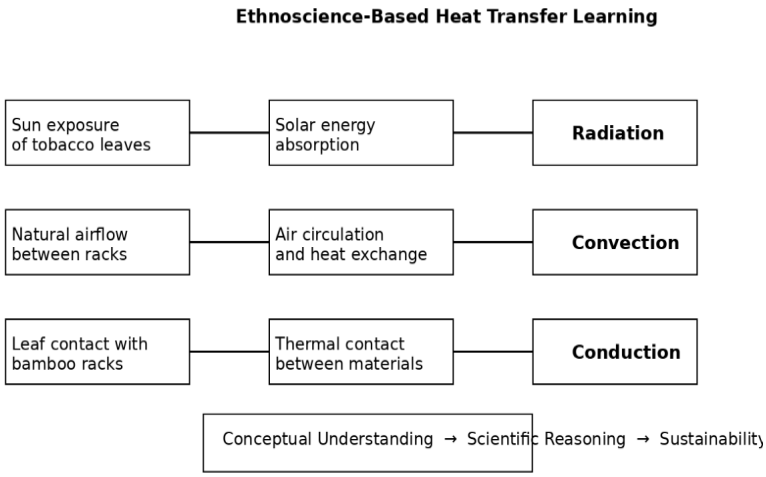


Figure 1. Ethnoscience-Based Heat Transfer

Three interrelated mechanisms emerged from the qualitative data and are organized in Figure 1. The first was observational anchoring: students tied each heat transfer mechanism to a visible stage of the drying process, associating sun exposure of the leaves with radiation, air movement through the drying space with convection, and contact between leaves and supporting structures with conduction. This mapping mirrors how these processes have been described for tobacco drying in Jember, where conduction, convection, and radiation correspond to fire curing, air curing, and sun drying, respectively (Amaliah et al., 2022). The second mechanism was explanatory conflict: single-factor explanations such as "drying happens when it is hot" could not account for observed differences in drying outcomes that varied with air flow, material contact, and sunlight exposure, which prompted students to look for more specific mechanisms. The third was explanatory reconstruction, in which students replaced temperature-only explanations with accounts that identified how energy was transferred and through which pathway. Together, these mechanisms describe a shift from intuitive description to mechanistic explanation and help interpret the change in reasoning models reported in Table 2.

This study shows that introducing a conventional tobacco drying system into heat-transfer instruction significantly improves students' concepts and scientific reasoning. This improvement may be attributed to the close linkage between abstract physics concepts and concrete cultural practices, which helps students build meaning from familiar experiences. Heat transfer is a challenging topic for students because they often struggle to observe and understand invisible transfer processes, such as radiation and convection, especially in decontextualized instruction, as shown in previous studies (Prince et al., 2012; Docktor & Mestre, 2014; Çengel & Ghajar, 2020). In contrast, natural tobacco drying provides constant in situ exposure to these mechanisms, making them cognitively accessible and conceptually coherent. In terms of conceptual change, the effectiveness of this ethnoscience approach can be explained because it fulfills the following conditions for replacing alternative conceptions: The conceptual change theory focuses on the need for students to view the scientific explanations as intelligible, plausible, and productive in order to dislodge their intuitive explanations (Posner et al., 1982; Vosniadou, 2013). While students were asked to explain the process in intuitive terms, such as "drying happens when it is hot", this was not enough when they were presented with observable differences in drying results that were correlated with such factors as air flow, material contact, and exposure to sunlight. In turn, formal heat-transfer notions provided greater explanatory power, supporting epistemic restructuring rather than superficial learning.

The four conditions Posner et al. (1982) propose for conceptual change, dissatisfaction with an existing conception and the intelligibility, plausibility, and fruitfulness of a new one, map onto the learning sequence observed here. Dissatisfaction arose when temperature alone could not explain differences in drying results; intelligibility and plausibility were supported because students could observe the relevant variables in a practice they already knew; and fruitfulness was demonstrated when conduction, convection, and radiation explained why particular drying arrangements worked better than others. At the same time, contemporary views of conceptual change do not treat intuitive ideas only as errors to be replaced. Hammer (2000) argued that students' everyday ideas can serve as resources that students refine and recombine, and Vosniadou (2013) described students as building synthetic models that blend prior and scientific ideas before reaching a coherent framework. The 26% of students who remained in the partial scientific category after the intervention can be read in this light as students holding hybrid models, rather than simply as students who failed to learn. Treagust and Duit (2008) similarly noted that conceptual change involves more than cognitive restructuring and depends on the student's context, motivation, and epistemological commitments, making a culturally familiar context a plausible lever for change.

The differences among the three concepts also deserve attention. The relatively lower normalized gain for conduction suggests that the drying context provides the least conspicuous evidence for this mechanism, since conduction occurs at contact points between leaves and supporting structures rather than across visible space. This reading aligns with Amaliah et al.'s (2022) account of tobacco drying, in which conduction is linked mainly to fire curing, a stage students may observe less directly than sun drying or ventilation. Instructional designs that rely on culturally familiar practices may therefore benefit from supplementary activities, such as simple contact-heating demonstrations with thermometers, that make less visible mechanisms explicit. In addition, the large variability in convection at pre-test (SD = 10.1) and its reduction at post-test (SD = 7.6) suggest that students entered with very different levels of prior understanding of airflow and heat, and that the module was able to bring them closer together.

The improvement in understanding of radiation is evident because radiation plays a major role in traditional tobacco drying. Unlike classroom models that typically discuss radiation as an abstract method of energy transfer, tobacco drying makes its effects visible through direct exposure to the sun and its impact on drying efficiency. This aligns with previous studies showing that contexts focused on direct observation and connections to the real world significantly enhance students' understanding of abstract physics concepts (Redish, 2003; Hake, 1998). Similarly, regulating airflow while drying gave students a realistic setting for convection, enabling them to make natural and intuitive connections between moving air and heat transfer. However, these findings go beyond cognitive gains to include the epistemic value of local knowledge in science learning. Ethnoscience theory states that indigenous and local practices are not only cultural artifacts but also represent systematic empirical knowledge gained over long periods through exchange with the environment (Snively & Corsiglia, 2001; Aikenhead & Ogawa, 2007). In this study, tobacco drying served as an epistemic resource for scientific reasoning rather than an ancillary example. This finding is contrary to previous studies of ethnoscience that were carried out in the islands of Indonesia, which generally viewed local wisdom as an enrichment for the context, rather than as a basis for learning itself (Sudarmin et al., 2018; Kasi et al., 2021).

Compared with earlier work, the present study differs in design and scope. Reviews of ethnoscience research in Indonesia indicate that most studies examine achievement and attitudes, largely through research-and-development or experimental designs and frequently at the junior secondary level (Kasi et al., 2021), and a bibliometric analysis shows that research on ethnoscience in physics learning has grown rapidly, peaking in 2021 (Sunarti et al., 2024). Within this literature, the closest antecedent is Amaliah et al.'s (2022) qualitative description of heat transfer in tobacco drying in Jember, which identified the relevant physics but did not evaluate a learning intervention. The present study extends that work by measuring conceptual change among preservice teachers. Other heat-related ethnoscience studies illustrate both the approach's potential and its challenges. Liwun et al. (2025) identified heat and temperature principles in the drying and firing stages of pottery making in Kasongan and concluded that ethnoscience can bridge scientific knowledge and local practice. However, their qualitative study of two artisans did not measure student learning. Tamaela et al. (2024), working with Uha food making in Central Maluku, found that students' science process skills remained poor and attributed this to limited class time, teachers' unfamiliarity with integrating ethnoscience, and students' lack of experience with such skills. A recent systematic review of 27 studies reported that 23 of them (85%) found positive effects of ethnoscience on science literacy (Jurianti et al., 2026), although positive results are also more likely to be published, so such figures should be read with caution. Taken together, these studies suggest that ethnoscience contexts contain rich heat transfer content, but that learning gains depend on structured guidance and on explicit linking of the practice to the concepts. This is the role played by the guided inquiry worksheets and discussion prompts in the present module, which may help explain why conceptual gains were observed here.

Pedagogically, the results indicate that ethnoscience-based physics learning can increase students' involvement and their perception of the relevance of the learning process. Learning materials that recognize and validate students' cultural backgrounds lead students to see physics as relevant to real-life problem solving (Aikenhead et al., 2015; Sudarmin et al., 2019). This relevance fosters motivation and supports deeper cognitive processing, contributing to long-term conceptual understanding. These outcomes are especially relevant in Physics instruction, where the content and complexity of the material can lead students to disengage and hold on to persistent misconceptions (Docktor & Mestre, 2014; Duit & Treagust, 2003).

For teacher education, the results have practical implications. Because the participants were preservice science teachers, the module served a double purpose: it developed their understanding of heat transfer and modeled a way of teaching that treats local practices as an epistemic resource. Preservice teachers who experience such learning firsthand may be better prepared to design similar activities in their own classrooms, addressing the concern Tamaela et al. (2024) note about teachers' limited knowledge of how to plan and evaluate ethnoscience-based instruction. Teacher education programs could therefore include ethnoscience modules as both content and pedagogy, supported by guidance on identifying practices whose physical principles are accessible, verifying the scientific accuracy of the mapping between practice and concept, and designing assessments that capture mechanistic reasoning rather than recall. These design principles align with Aikenhead and Ogawa's (2007) caution that local and Indigenous knowledge should be treated as a knowledge

system in its own right, rather than reduced to examples that illustrate Western science. The outcomes also feed into the debates on sustainability education. Traditional tobacco drying is an adaptive, low-energy practice that uses mostly renewable solar energy and natural ventilation, rather than energy-intensive industrial technologies. These practices exemplify traditional ecological knowledge (TEK) and show how local communities manage environmental variables based on empirical experience (Berkes, 2018). By embedding such culturally relevant practices into heat transfer instruction, students can make more meaningful links between abstract physics knowledge and sustainable resource management practices. This contextual alignment reinforces conceptual understanding and fosters awareness of responsible environmental decision-making. In addition, the learning experience makes students aware of the interplay between scientific principles and real-world sustainability challenges. These results align with education for sustainable development frameworks, which focus on the convergence of scientific knowledge, local knowledge, and environmental responsibility (UNESCO, 2017; Sterling, 2001). Ethnoscience-based physics learning has great potential to advance conceptual learning and awareness of sustainability.

The sustainability dimension warrants a careful reading. UNESCO (2017) frames education for sustainable development in terms of cognitive, socio-emotional, and behavioral learning objectives, and Sterling (2001) argues that sustainable education requires learning that changes how students understand their relationship with the environment, not merely the addition of environmental content. In this study, the evidence mainly concerns the cognitive domain, namely understanding energy transfer in a practice that relies on solar energy and natural ventilation. The claim that students also developed sustainability awareness rests on qualitative evidence about relevance and meaning-making and was not measured with a dedicated instrument, so it is best treated as a plausible contribution rather than an established outcome. It should also be acknowledged that tobacco is a socio-economically important but contested crop, and the study does not evaluate tobacco cultivation itself; the focus is on the physics of a low-energy drying practice as a learning context. Future work could pair such modules with explicit tasks on energy efficiency, for example, comparing energy use in sun drying and in fuel-based curing, to develop the socio-emotional and behavioral dimensions of sustainability learning. It could draw on Berkes (2018) to examine how traditional ecological knowledge is transmitted and adapted.

In terms of methods, the mixed-methods design enhanced data interpretation by enabling analysis of both quantitative data on conceptual change and qualitative data on students' reasoning processes. This methodological integration led to a more holistic understanding of learning outcomes and the cognitive mechanisms associated with conceptual change. Mixed methods research is especially suitable for culturally based education studies because it captures measurable growth patterns and meaning-making processes within context (Johnson & Onwuegbuzie, 2004; Creswell & Clark, 2018). While quantitative results might show the degree of conceptual change, qualitative results can show how the students' understanding is being reframed as a result of their interactions with the instructional contexts. This study focused on the process of conceptual development, and qualitative evidence showed how the students' traditional beliefs were approached from a scientific perspective. Multiple data sources converge to boost interpretive validity and analytical strength. Methodological triangulation ultimately strengthens the credibility, dependability, and transferability of the study results (Creswell & Poth, 2018; Miles et al., 2014).

In terms of generalizability, the teaching method in the present study could be applied to other physics concepts or cultural contexts related to energy transformation, heat control, or material interactions. Several traditional practices have implicit scientific principles that can be used as epistemically rich learning resources. Other practices, such as traditional food processing, vernacular architecture, or craft production, can provide similar contexts for conceptual learning. These contexts let students see physical mechanisms in real settings. However, effective instructional transfer requires carefully identifying practices that can be explicitly and clearly tied to targeted scientific concepts. Careful pedagogical planning is critical to ensure cultural contexts serve as conceptual bridges, not just illustrations. If this conceptual alignment is not achieved, there is the danger of reinforcing intuitive explanations rather than promoting scientific reasoning. Thus, effective teaching depends on a systematic connection between cultural knowledge and the discipline's concepts.

Taken together, the findings suggest four design principles for this kind of instruction. The first is observability: the cultural practice should make the target mechanism visible or measurable, as sun exposure and airflow did here. The second is explicit conceptual mapping, in which guided inquiry worksheets deliberately link each stage of the practice to one heat transfer mechanism rather than leaving students to infer, in line with the curriculum's emphasis on making expected reasoning explicit (Redish & Hammer, 2009). The third is productive conflict, meaning discussion prompts place students' intuitive explanations alongside observed differences in outcomes so the limits of temperature-only explanations become apparent (Posner et al., 1982). The fourth is assessment that matches the reasoning goals: concept tests that probe mechanistic differentiation, combined with interviews and reflective writing, can capture changes that a computational problem set would not show (Prince et al., 2012). These principles are offered as hypotheses grounded in the present data and should be tested in further studies rather than treated as established rules. Another contribution concerns how

local knowledge is positioned. When tobacco drying is used only as an illustration, students may treat it as a decorative example that is peripheral to the physics. In this study, the practice was instead treated as empirical evidence, so students reasoned from observations of drying outcomes to physical explanations. This positioning aligns more with the view of traditional ecological knowledge as a body of knowledge, practice, and belief that evolves through adaptive processes (Berkes, 2018) and with the argument that Indigenous and local knowledge systems should be engaged on their own terms (Snively & Corsiglia, 2001). It also reduces the risk noted above that cultural contexts reinforce intuitive explanations rather than promoting scientific reasoning, because students make the mapping between practice and concept explicit and examine it critically.

Several limitations qualify these findings. First, the design involved a single group of purposively selected preservice teachers who all received the same module, so there was no comparison group. Improvements therefore cannot be attributed to the ethnoscience context alone, since part of the gain may reflect repeated testing, the general benefit of guided inquiry, or the four weeks of instruction in the basic physics course. Second, the quantitative analysis relied on descriptive statistics and normalized gains, so the conclusion that improvement was substantial rests on the magnitude and consistency of the gains rather than on a formal inferential test; future analyses should report paired-sample tests with effect sizes and confidence intervals. Third, the reasoning models in Table 2 are distributions, so individual transitions between categories could not be traced. Fourth, the sample came from one institution in East Java and one local practice, which limits generalization to other settings. Fifth, learning was measured immediately after the intervention, so the long-term retention of conceptual understanding remains unknown.

These limitations point to several directions for future research. Quasi-experimental studies with comparison groups taught using conventional or non-ethnoscience contextual examples would help isolate the contribution of the cultural context. Delayed post-tests would show whether conceptual gains persist, and repeated interviews with a purposive subset of students would trace individual trajectories between reasoning models. Replicating the approach with students at other educational levels would be valuable, since ethnoscience studies in Indonesia have mostly involved junior secondary students (Kasi et al., 2021), and pairing physics modules with instruments for sustainability attitudes would allow the sustainability claim to be tested directly. Finally, comparative work across other agricultural and craft practices, such as those examined by Liwun et al. (2025) and Tamaela et al. (2024), could test whether the design principles identified here, namely observability, guided inquiry, and explicit conceptual mapping, transfer across contexts.

In conclusion, this study contributes to the literature on culturally responsive and sustainability-oriented science education by showing the systematic integration of ethnoscience into domain-specific physics lessons. This research expands the theoretical model of culturally embedded physics teaching and learning by positioning traditional ways of doing physics as epistemic foundations rather than contextual add-ons. The results suggest that scientifically meaningful, real-world context effectively strengthens conceptual understanding. Moreover, the study highlights the educational importance of local knowledge systems in conceptual change and cognitive engagement. This integration shifts ethnoscience applications from descriptive cultural relevance to epistemic and conceptual ones. The results highlight the need to consider contextual coherence when addressing conceptual difficulties in physics education. In summary, ethnoscience-based approaches have great potential to improve scientific reasoning, learning relevance, and awareness of sustainability. The results highlight the educational innovativeness and sustainable development potential of culturally based pedagogies.

CONCLUSION

This study concludes that integrating traditional tobacco drying practices in Jember as an ethnoscience-based learning context significantly enhances students' conceptual understanding and scientific reasoning in heat transfer. The findings reveal moderate-to-high conceptual gains across conduction, convection, and radiation concepts, accompanied by a substantial shift from intuitive reasoning toward scientifically accepted explanations. These results indicate that culturally embedded, observable practices serve as effective epistemic bridges, helping students reconcile prior intuitive models with formal physics principles. Beyond demonstrating instructional effectiveness, this approach improves learning relevance, deepens cognitive engagement, and strengthens conceptual coherence. Importantly, the study highlights the pedagogical value of local agricultural knowledge as a core epistemic resource rather than a supplementary contextual illustration. The broader impact of applying this instructional framework lies in its potential to foster sustainability awareness by linking scientific understanding with adaptive, low-energy traditional practices. Consequently, this research advances culturally responsive and sustainability-oriented physics education while offering a transferable model for integrating local knowledge systems into domain-specific science learning without compromising conceptual rigor.

DECLARATION OF GENERATIVE AI

The authors declare that no generative AI or AI-assisted technologies were used in the writing process of this manuscript.

CONFLICTING INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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