Jurnal Pendidikan Fisika
Vol. 14 No. 2, Desember 2025_269-277
DOI: 10.24114/jpf.v14i2.70292
p-ISSN: 2552-732X
e-ISSN: 2301-7651

Research Article

OPEN ACCESS

Integration of Ethnoscience in STEAM-Based Physics Learning to Enhance High School Students' Scientific Literacy and 21st-Century Skills

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INFO ARTIKEL

Article History:
Submitted: 12-10-2025
Revised : 25-11-2025
Accepted : 31-12-2025
Published: 31-12-2025

Keywords:
ethnoscience
STEAM
scientific literacy
21st-century skills
Physics learning

Kata Kunci:
Etnosains
STEAM
literasi sains
kecakapan abad ke-21
pembelajaran Fisika

ABSTRACT

*Physics learning at the senior high school (SMA) level still largely focuses on cognitive aspects and formula memorization, making it difficult for students to connect scientific concepts with real-life situations and local cultural contexts. This study aims to describe the forms of ethnoscience integration in STEAM-based (Science, Technology, Engineering, Art, and Mathematics) Physics learning and to analyze its contribution to enhancing students' scientific literacy and developing their 21st-century skills. This research employed a qualitative approach with a descriptive–exploratory design and was conducted at a public senior high school (*SMA Negeri*) in Subang Regency, West Java. Data were collected through participatory observation, in-depth interviews, and documentation, then analyzed thematically using the Miles and Huberman (2014) model with source and method triangulation. The findings revealed that ethnoscience integration was implemented through the use of local cultural phenomena—such as pottery making, traditional waterwheels, and simple irrigation systems—as contexts for STEAM-based project learning in Physics. The integration effectively facilitated the development of students' scientific literacy, strengthened higher-order thinking skills, and fostered collaborative and communicative attitudes. In conclusion, STEAM-based Physics learning integrated with ethnoscience serves as an effective pedagogical innovation that bridges science and culture, enhances scientific literacy, and nurtures students' character to become culturally grounded individuals who are well-prepared to face the challenges of the 21st century.*

ABSTRAK

Pembelajaran Fisika di tingkat Sekolah Menengah Atas (SMA) masih banyak berfokus pada aspek kognitif dan hafalan rumus, sehingga siswa kesulitan mengaitkan konsep ilmiah dengan kehidupan nyata dan konteks budaya lokal. Penelitian ini bertujuan untuk mendeskripsikan bentuk integrasi etnosains dalam pembelajaran Fisika berbasis STEAM (Science, Technology, Engineering, Art, and Mathematics) serta menganalisis kontribusinya terhadap peningkatan literasi sains dan pengembangan kecakapan abad ke-21 siswa SMA. Penelitian menggunakan pendekatan kualitatif dengan desain deskriptif eksploratif, dilaksanakan di salah satu SMA Negeri di Kabupaten Subang, Jawa Barat. Data dikumpulkan melalui observasi partisipatif, wawancara mendalam, dan dokumentasi, kemudian dianalisis secara tematik menggunakan model Miles dan Huberman (2014) dengan triangulasi sumber dan metode. Hasil penelitian menunjukkan bahwa integrasi etnosains dilakukan melalui pemanfaatan fenomena budaya lokal, seperti pembuatan gerabah, kincir air tradisional, dan sistem irigasi sederhana, sebagai konteks pembelajaran Fisika berbasis proyek STEAM. Integrasi tersebut terbukti meningkatkan literasi sains siswa, memperkuat kemampuan berpikir tingkat tinggi, serta menumbuhkan sikap kolaboratif dan komunikatif. Kesimpulannya, pembelajaran Fisika berbasis STEAM yang terintegrasi dengan etnosains merupakan inovasi pedagogis yang efektif untuk menghubungkan sains dan budaya, meningkatkan literasi sains, serta membentuk siswa yang berkarakter dan siap menghadapi tantangan abad ke-21. Kata kunci: etnosains, STEAM, literasi sains, kecakapan abad ke-21, pembelajaran Fisika.

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INTRODUCTION

The 21st-century education paradigm requires students to possess essential competencies such as critical thinking, creativity, collaboration, communication, and a high level of scientific and technological literacy (Thornhill-Miller et al., 2023). These competencies serve as crucial foundations for navigating a global era filled with complex challenges and uncertainties. In the context of science learning particularly Physics at the Senior High School (SMA) level there has been a shift in learning paradigms, from merely mastering concepts to emphasizing application and meaningful understanding. Students are expected not only to memorize formulas but also to connect physics concepts with real-life phenomena they encounter in their daily experiences.

The reality of education shows that the process of learning Physics in schools is still dominated by conventional approaches that are abstract, theoretical, and memorization-oriented (Sutaryani et al., 2024). Teachers often act primarily as information transmitters, while students tend to become passive recipients. This non-contextual learning approach results in students' low conceptual understanding and their limited ability to connect theory with real-life situations (Buar & Obiedo, 2025). Consequently, many students perceive Physics as a difficult, uninteresting subject that lacks relevance to their everyday lives.

National survey results, such as the Programme for International Student Assessment (PISA), indicate that Indonesian students' scientific literacy remains below the average of OECD member countries. According to the 2022 PISA report, Indonesia's average science literacy score was around 396, lower than the OECD average of 489. This low level of scientific literacy reflects that students have not yet developed the ability to connect scientific knowledge with the social and cultural contexts around them (Rahmi et al., 2024). In practice, Physics learning in high schools is often disconnected from local life contexts that are rich in scientific and cultural values, resulting in the underutilization of local wisdom as a potential basis for meaningful learning (Fianti & Neratania, 2024).

Empirical studies conducted by several researchers have shown that most Physics teachers in Indonesia still rely on lecture-based methods and problem-solving exercises without connecting the material to cultural contexts or local phenomena (Sudirman et al., 2023). Research by Eliezanatalie & Deta (2023) revealed that 78% of high school Physics teachers have not utilized local wisdom as a learning resource. As a result, the learning process tends to be monotonous and fails to foster students' critical scientific thinking skills. In fact, Indonesia possesses a rich variety of cultural phenomena such as traditional irrigation systems, pottery-making processes, folk games, and local technologies that inherently embody fundamental Physics principles such as force, pressure, and energy.

The Science, Technology, Engineering, Art, and Mathematics (STEAM) approach has also been proven effective in developing higher-order thinking skills (HOTS) (Rosyida et al., 2025). However, research that integrates both approaches ethnoscience and STEAM within the context of Physics learning at the senior high school level remains very limited. Most studies still focus on implementing these approaches separately, rather than exploring their synergy as an innovative learning model that holistically connects science, technology, and culture. Based on these conditions, the focus of this research is how to integrate ethnoscience values into STEAM-based Physics learning to enhance high school students' scientific literacy and 21st-century skills. This study also aims to analyze relevant forms of integration, the implementation of such learning in the classroom, and its impact on students' critical, creative, collaborative, and communicative thinking abilities.

One innovative effort that can be undertaken is the development of STEAM-based Physics learning grounded in ethnoscience. The STEAM approach provides opportunities for students to learn through projects, experiments, and contextual problem-solving that integrate science, technology, engineering, art, and mathematics (Perales & Aróstegui, 2024). By incorporating elements of ethnoscience, learning activities become more contextual and rooted in local cultural realities. Students can explore principles of energy and mechanics through projects such as creating traditional water wheels, or study the concept of heat conduction by analyzing the pottery-making process in their local area.

This study is designed to explore how the integration of ethnoscience within the STEAM approach can enhance the overall quality of Physics learning. The research focuses on three main aspects: (1) the design of ethnoscience integration in STEAM-based learning; (2) the implementation of this model in high school classroom contexts; and (3) the outcomes or impacts on improving students' scientific literacy and 21st-century skills (Putri & Nisa, 2025). Thus, this study is not only conceptual but also practical, aiming to produce a learning model that is both culturally adaptive and relevant to the demands of the digital era.

Ethnoscience-based STEAM learning is also in line with the direction of the *Merdeka Curriculum* policy, which emphasizes project-based learning, character development, and the cultivation of the *Pancasila Student Profile*. Through projects rooted in local culture, students are encouraged to think globally while staying grounded in national and local values. This approach not only supports the achievement of academic competencies but also fosters character traits such as cooperation, independence, and integrity.

The urgency of this research lies in the pressing need to revitalize Physics learning so that it becomes more contextual, innovative, and rooted in the nation's cultural values (Fitria et al., 2025). Amid the rapid flow of globalization and digitalization, the integration of ethnoscience and STEAM serves as a strategy that not only strengthens scientific literacy but also preserves cultural identity. By utilizing local potential as a learning resource, Physics education can become a means to foster independent thinking and promote sustainable innovation.

The main objective of this study is to provide a comprehensive description of the forms of ethnoscience integration in STEAM-based Physics learning at the senior high school level (Adriyawati et al., 2020). This research seeks to illustrate how local wisdom values and cultural practices can be contextualized into modern and innovative Physics learning through the STEAM approach, thereby creating an integration between science, technology, engineering, art, and mathematics with the living local culture of society. In addition, this study aims to analyze the implementation and pedagogical contribution of ethnoscience integration in enhancing students' scientific literacy. Through learning processes that connect Physics concepts with cultural phenomena and real-life activities, students are expected not only to understand theoretical concepts but also to apply them critically in everyday life.

Furthermore, the study aims to evaluate the contribution of ethnoscience integration in STEAM-based Physics learning to the development of students' 21st-century skills, particularly their critical, creative, collaborative, and communicative abilities. Thus, this research is expected to produce a learning model that not only improves scientific literacy but also cultivates a generation of learners who are innovative, character-driven, and deeply rooted in the nation's cultural values.

METHODS

This study employed a qualitative approach with a descriptive–exploratory design. This approach was chosen to provide an in-depth description of the forms of ethnoscience integration in STEAM-based Physics learning and its impact on high school students' scientific literacy and 21st-century skills. The exploratory design allowed the researcher to naturally investigate the learning process, understand teachers' strategies, and interpret students' learning experiences within the context of local culture.

The research was conducted at a public senior high school (*SMA Negeri*) in Subang Regency, West Java Province. The participants included Physics teachers, 11th-grade science stream (*MIPA*) students, and the school principal. Informants were selected through purposive sampling based on their direct involvement in ethnoscience and STEAM based learning. Data sources consisted of primary data (observation results, interviews, and documentation) and secondary data (lesson plans, teaching modules, student worksheets, and project outcomes).

Data were collected through participatory observation, in-depth interviews, and documentation. Observation was used to record classroom learning activities and identify the forms of local cultural integration in Physics content. Semi-structured interviews were conducted with teachers and students to explore their perspectives and experiences, while documentation served to complement and validate the data obtained from observations and interviews. The researcher acted as the main instrument (human instrument), supported by observation sheets and interview guidelines.

Data validity was ensured through triangulation of sources, methods, and time, as well as *member checking* to confirm that the interpretations aligned with the informants' experiences. The collected data were analyzed inductively, which includes data reduction, data display, and conclusion drawing/verification. Additionally, thematic analysis was employed to identify major themes such as the forms of ethnoscience integration, teacher strategies, and the effects of learning on scientific literacy and 21st-century skills.

The entire research process consisted of three stages: preparation, data collection, and data analysis, conducted in adherence to research ethics, including maintaining informant confidentiality and obtaining official permission from the school. Through this methodology, the study aimed to produce a comprehensive understanding of the implementation of ethnoscience integration in STEAM-based Physics learning as an effort to enhance students' scientific literacy and 21st-century competencies.

RESULT AND DISCUSSION

This study demonstrated that the integration of ethnoscience into STEAM-based Physics learning facilitated the development of students' scientific literacy and supported the emergence of 21st-century skills, as reflected in students' learning behaviors, engagement, and participation in project-based activities. Learning practices that were previously centered on memorization and formula application became more contextual as teachers deliberately connected physics concepts with local cultural phenomena familiar to students' daily lives. Classroom observations indicated that teachers not only presented theoretical explanations but also encouraged students to explore how physics principles were embedded in surrounding cultural practices. This learning approach fostered more meaningful learning experiences and stimulated students' curiosity regarding the relationship between science and everyday life. Students demonstrated facilitated the development of involvement by asking questions, actively participating in discussions, and relating their cultural experiences to the scientific concepts being studied.

When discussing the topic of energy and work, the teacher used the example of a traditional waterwheel as a learning context. The teacher presented documentation and real-life examples of waterwheels being used to power agricultural tools or channel irrigation water. Through this activity, students not only understood the concepts of potential and kinetic energy theoretically but also examined how local communities harnessed water power as a source of mechanical energy. This activity encouraged students to conduct observation, analysis, and reflection on the application of the law of conservation of energy in community life.

During the group discussion, students actively debated the most efficient blade design. Student A argued that a wider blade would capture more water flow, while Student B suggested adjusting the blade angle to increase rotational speed. The discussion continued until the group tested both ideas using a prototype.

The integration of local culture into the context of Physics learning made the lessons more meaningful, relevant, and humanistic. Students not only gained scientific knowledge but also developed an awareness of the cultural values and local wisdom embedded in community practices. The learning process became a means of appreciating cultural heritage while understanding how humans adapt to nature through simple technologies. Consequently, Physics was no longer perceived as an abstract or distant discipline but as a science that grows from human experience and interaction with the environment. This approach fostered a sense of pride in cultural identity while strengthening contextual and character-based scientific literacy.

Ethnoscience integration was also evident in the way teachers designed project-based learning activities that incorporated elements of STEAM Science, Technology, Engineering, Art, and Mathematics (Arpaci et al., 2023). In these projects, students were assigned to design simple tools inspired by local wisdom, such as miniature waterwheels, bamboo water pressure gauges, or models of traditional houses demonstrating the principles of force equilibrium. These projects focused not only on the final product but also emphasized scientific reasoning, technical design, and artistic creativity. Teachers encouraged students to combine logical thinking with aesthetic imagination so that the resulting projects were not only functional but also visually engaging. This collaborative process required students to communicate and exchange ideas, thereby strengthening their social and teamwork skills. The STEAM approach integrated with ethnoscience thus helped students develop multidisciplinary competencies that align with the demands of 21st-century education (Choirunnisa et al., 2023).

One student explained the challenge encountered during the project: *"At first, our waterwheel did not rotate properly because the blade angle was too flat. After discussing it with the group, we changed the design and tested it again."* (Student Interview).

In the learning process, the teacher acted as a facilitator who guided students to independently discover physics concepts embedded within cultural practices. The teacher was no longer the sole source of knowledge but rather a mentor who directed students' scientific thinking processes. Through exploration activities, simple experiments, and group discussions, students were given the opportunity to investigate the relationships between cultural phenomena and the physical principles they were studying. When discussing the topic of fluid pressure, for instance, the teacher stimulated students' curiosity by presenting examples such as traditional clay jars used to store water or irrigation systems in rice fields that rely on differences in water height. The teacher then encouraged students to make direct observations, measure pressure differences, and analyze how these phenomena reflected the laws of physics. This form of learning shifted the pattern from merely receiving information to a process of *discovery learning* that fostered independent thinking. Through this approach, students not only understood theoretical concepts but also experienced the scientific process as practiced by scientists in real-world contexts.

This ethnoscience-based and teacher-facilitated interactive learning also fostered students' appreciation for cultural values and local wisdom. Through the analysis of cultural practices, students realized that modern science has its roots in traditional life passed down through generations. They learned to appreciate that traditional communities have long applied scientific principles such as pressure, force, and energy in their daily activities, even without using formal terminology or equations. This awareness nurtured respect for local knowledge and reinforced the understanding that science is universal yet deeply rooted in cultural contexts. Consequently, the integration of ethnoscience not only enriched students' conceptual understanding of physics but also broadened their perspectives on the relationship between science, culture, and social life. Such learning helped students perceive science as a humanistic, grounded, and value-laden discipline rather than a mere collection of abstract theories existing in isolation.

Interviews with teachers and students revealed that the ethnoscience- and STEAM-based learning approach enhanced students' motivation and curiosity toward Physics (Wahyudi et al., 2025). Students found it easier to grasp the material because it was presented in familiar, real-life contexts. They no longer focused merely on memorizing formulas but aimed to understand their meaning and applications. One student even stated that learning Physics became "more enjoyable because I can see directly how the knowledge works in the real world." This indicates that culturally contextualized learning fosters deeper learning experiences. Teachers also noted that the approach made students more active during discussions and experiments and that they showed improvement in critical thinking when facing problems requiring scientific analysis.

Students' improvement in scientific literacy was also evident in their ability to explain natural phenomena using scientific language. Through project-based activities, students became accustomed to formulating hypotheses, conducting experiments, and drawing conclusions based on empirical data (Ardianti & Raida, 2022). They were also trained to present their findings through written scientific reports and classroom presentations. This process enhanced students' scientific communication skills as they learned to articulate ideas and research findings logically and coherently. In this context, scientific literacy encompassed not only an understanding of scientific concepts but also the ability to think scientifically and recognize the interconnectedness between science, technology, and society. Thus, ethnoscience- and STEAM-based learning not only built students' knowledge but also fostered critical and reflective scientific attitudes.

A Physics teacher noted a change in students' learning attitudes: *"Students became more confident in expressing ideas and asking questions because the examples came from their own environment."* (Teacher Interview)

Field findings also showed that STEAM-based learning integrated with ethnoscience provided opportunities for students to develop their creativity. When designing their projects, students were faced with open-ended problems that could be solved in various ways. They had to innovate to create efficient designs while maintaining the cultural values embedded within them. This creative process nurtured students' confidence and independent decision-making skills. Moreover, the "Art" component of STEAM allowed students to express their ideas aesthetically for example, by enhancing their project designs to make them both appealing and culturally meaningful (Tresnawati et al., 2020). Therefore, this integration fostered not only scientific competence but also emotional intelligence and aesthetic awareness.

Collaborative learning activities also helped students strengthen their teamwork and communication skills. In each project, students were divided into small groups of four to five members, each with specific roles such as designer, data recorder, tester, and presenter. This division of roles encouraged active interaction, discussion, and idea-sharing to achieve a common goal (Hidaayatullaah et al., 2021). Teachers acted as mediators to ensure that every member contributed actively. This collaborative process not only facilitated the development of learning outcomes but also fostered empathy and respect for differing opinions. These skills are essential components of 21st-century collaborative competence, particularly in preparing students for future workplaces that demand interdisciplinary teamwork.

Despite the positive outcomes, the study identified several challenges in implementing ethnoscience and STEAM integration in schools (Suryanti et al., 2024). One major obstacle was the limited time allocation in the existing curriculum schedule. Teachers needed additional time to organize project activities, collect materials, and prepare culturally relevant teaching aids. Furthermore, the scarcity of learning resources featuring examples of local cultural phenomena required teachers to take the initiative to create contextual materials themselves. Another challenge was the varying levels of teachers' understanding of ethnoscience concepts, highlighting the need for professional development and mentoring to ensure appropriate cultural integration into science content.

To overcome these challenges, teachers implemented adaptive strategies. One effective approach was cross-disciplinary collaboration, such as working with art and technology teachers to design more comprehensive project activities (Wu, 2022). Teachers also involved community members and cultural figures as resource persons to provide students with firsthand insights into the cultural practices being studied. Some teachers even organized field trips to cultural sites, such as pottery workshops or traditional irrigation areas, as part of the learning process. These strategies not only enriched students' experiences but also strengthened the connection between schools and local communities as part of a broader educational ecosystem.

From the students' perspective, ethnoscience- and STEAM-based learning provided experiences that were both challenging and meaningful. Students reported feeling emotionally engaged because the learning topics were closely connected to their regional cultural identity. This connection fostered a sense of pride in local culture and increased students' awareness that science is not limited to modern contexts but is also embedded in ancestral knowledge and everyday practices. Through these learning activities, students came to recognize that scientific knowledge has developed from humanity's long-standing efforts to understand and manage the natural environment. In this sense, ethnoscience functioned as a conceptual bridge between modern scientific understanding and traditional values grounded in balance and sustainability.

The engineering component of the STEAM approach was enacted through an Engineering Design Process (EDP), in which students were guided to identify problems, design potential solutions, construct prototypes, test their designs, and refine them based on trial outcomes. In the waterwheel project, for example, students produced initial simple prototypes, assessed their functionality, and revised blade shapes and angles following testing activities. This iterative design process supported students' engagement in problem-solving, critical evaluation, and design-oriented thinking.

Overall, the findings of this study indicated that integrating ethnoscience into STEAM-based Physics learning created a more participatory, reflective, and contextual learning environment. This approach transformed Physics learning from a purely cognitive activity into a holistic social and cultural experience. Students became not just recipients of information but also creators of knowledge through their interaction with their environment and culture. Such learning experiences helped cultivate students who think critically, creatively, and ethically while maintaining cultural awareness qualities essential for navigating globalization and the challenges of the Fourth Industrial Revolution.

From an educational theory perspective, the findings reinforced the idea that contextual and culturally grounded science learning enhances students' learning meaning (Giamellaro et al., 2025). The integration of ethnoscience and STEAM proved to be an effective strategy for developing multidimensional competencies encompassing knowledge, skills, and values. This approach also aligns with the vision of the *Merdeka Curriculum* and the *Pancasila Student Profile*, which emphasize independence, collaboration, and critical thinking. Therefore, the outcomes of this study provide not only practical contributions to improving Physics education but also theoretical contributions to the development of a more humanistic and contextual educational paradigm.

The integration of ethnoscience into STEAM-based Physics learning represents an effective pedagogical innovation for fostering scientific literacy and 21st-century skills among students. Through cultural contexts, students are encouraged to understand science in a more meaningful and applicable way while developing awareness of local cultural values. The resulting learning experience becomes more dynamic, relevant, and character-building. Teachers serve as transformative agents who bridge modern scientific knowledge with traditional wisdom. Thus, this approach not only enhances the quality of Physics education but also strengthens the nation's cultural identity in navigating an increasingly competitive and innovation-driven global era.

CONCLUSION

This study provides qualitative evidence that the integration of ethnoscience into STEAM-based Physics learning made the learning process more contextual, meaningful, and rooted in local culture. By integrating local wisdom with modern scientific principles, students demonstrated an improved ability to understand physics concepts in relation to real-life situations, as reflected in their engagement during learning activities and project-based tasks. Project-based learning that connected science, technology, engineering, art, and mathematics with cultural contexts showed indications of supporting students' scientific literacy and the development of 21st-century skills, including critical thinking, creativity, collaboration, and communication. This approach functioned as a bridge between science and culture, shifting the learning paradigm from rote memorization toward meaningful exploration and knowledge construction. Furthermore, the integration of ethnoscience and STEAM contributed to the nurturing of students' cultural identity, ethical awareness, and appreciation of local heritage. Based on these qualitative findings, it can be concluded that STEAM-based Physics learning integrated with ethnoscience represents a promising pedagogical innovation for supporting the development of scientifically literate, character-oriented students who are prepared to navigate the challenges of the 21st century.

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