



INTEGRATING LOCAL WISDOM INTO STEM EDUCATION TO ENHANCE SCIENTIFIC LITERACY IN REMOTE AND UNDERSERVED REGIONS

Ni Wayan Suparmi^{1*}, Brianna Le Busque², Anna Julita Foa³

^{1,3}Sekolah Tinggi Keguruan dan Ilmu Pendidikan Citra Bakti, Bajawa, Indonesia

²Adelaide University, Adelaide, Australia

*Corresponding Author: 📧 wayansuparmi458@gmail.com

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Abstract. Science education in underdeveloped, frontier, and outermost regions faces major challenges, including low levels of scientific literacy among students, limited educational resources, and restricted access to quality education. To address these issues, this study aimed to develop and evaluate the effectiveness of a STEM learning model grounded in local wisdom (ethno-STEM) for enhancing students' scientific literacy. This research employed a Research and Development (R&D) approach using the 4-D development model (Define, Design, Develop, Disseminate). The trial was conducted with 56 eighth-grade students from two junior high schools located in 3T areas in Ngada Regency, Indonesia. A quasi-experimental design was used, involving both experimental and control groups. Instruments included a scientific literacy test, student engagement observation sheets, and a student response questionnaire. The results indicated a significant improvement in scientific literacy within the experimental group. The average pre-test score increased from 54.6 to 82.3 in the post-test, with an N-Gain of 0.72 (classified as high) and a statistically significant t-test result ($p < 0.05$). In contrast, the control group showed an increase from 55.1 to 67.8 (N-Gain = 0.41, classified as moderate). Additionally, student engagement and enthusiasm improved, with 86% of students stating that the learning process was more engaging because it connected science content with local culture. In conclusion, the ethno-STEM model was found to be effective in improving students' scientific literacy and is highly relevant for implementation. It is recommended that this model be more widely adopted as a culturally contextualized instructional strategy.

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Correspondence address:

Jalan Trans-Flores, Malanua, Kec. Golewa, Kab. Ngada Flores.

📧 wayansuparmi458@gmail.com

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Kelurahan Paupire, Ende, Flores.

📧 primagistrauniflor@gmail.com

INTRODUCTION

Science education plays a pivotal role in equipping students with the competencies required to navigate the complexities of the 21st century. These competencies extend beyond the acquisition of scientific knowledge to include critical thinking, problem solving, and evidence-based decision-making skills (OECD, 2019). In this context, the concept of scientific literacy has evolved from a content-oriented perspective to a more functional and contextual understanding of how individuals engage with science in everyday life. As emphasized by Holbrook and Rannikmäe (2009), scientific literacy involves the ability to interpret scientific information, evaluate arguments, and apply scientific reasoning in real-world situations. Therefore, fostering scientific literacy is fundamental to developing a scientifically informed and responsible society (Suparmi, 2025). Despite its recognized importance, Indonesia continues to face significant challenges in achieving adequate levels of scientific literacy. The PISA 2018 results indicate that Indonesian students ranked 71st out of 79 participating countries in scientific literacy (Kemendikbud, 2020), highlighting persistent systemic issues in science education. These challenges include the dominance of teacher-centered pedagogies, limited contextualization of learning materials, and insufficient integration of students' socio-cultural backgrounds into instructional practices. Such issues are particularly pronounced in remote and underserved regions, where geographical isolation, socio-economic constraints, and limited educational resources further exacerbate disparities in learning outcomes.

In these contexts, science is often perceived by students as abstract and disconnected from their daily lives. Instructional practices tend to rely heavily on standardized textbooks and

generalized curricula that do not adequately reflect local realities (Le Busque et al., 2025). Consequently, students struggle to construct meaningful understanding, leading to low engagement and reduced learning outcomes. For example, students may learn about modern agricultural technologies without recognizing the scientific principles embedded in their own communities' traditional farming practices. This disconnect not only hinders conceptual understanding but also contributes to the marginalization of local knowledge systems in formal education (Suparmi, 2024). To address these challenges, there has been increasing scholarly attention toward culturally responsive approaches in science education. One such approach is the integration of STEM (Science, Technology, Engineering, and Mathematics) education with local wisdom, often referred to as ethno STEM. STEM education has been widely recognized for its potential to foster interdisciplinary learning, innovation, and problem-solving skills (Bybee, 2013). However, conventional STEM implementations frequently overlook cultural diversity and contextual relevance, limiting their effectiveness in diverse educational settings, including remote and underserved regions. Agusningtyas et al (2024) argue that embedding local cultural knowledge into STEM learning can enhance relevance, authenticity, and student engagement.

Local wisdom represents a rich body of knowledge, practices, and beliefs developed through long-term interactions between communities and their environments (Damopolii et al., 2024). It is deeply rooted in cultural traditions and ecological adaptation, making it highly relevant for contextualized learning. In science education, local wisdom can serve as both a pedagogical resource and a means of strengthening students' cultural identity. For instance, traditional knowledge related to agricultural systems, water management, and natural resource conservation can be linked to scientific concepts such as ecosystems, sustainability, and environmental science. As noted by Geertz (1983), such knowledge systems reflect coherent and rational frameworks that deserve recognition alongside formal scientific knowledge. A growing body of empirical research supports the integration of local wisdom into science learning. Research shows that when students connect course material to their personal lives, especially those with low expectations of success, their interest and performance in science increases (Hulleman & Harackiewicz, 2009). Similarly, Khotimah et al. (2024) found that ethno STEM approaches enhanced students' critical thinking skills and scientific literacy, particularly when learning materials were contextualized. Jain and Braden (2024) found that AI-supported narrative-based learning in Earth Science fostered increased student confidence and desire to explore scientific topics, especially among a diverse student population. In addition, studies by Verawati et al. (2024) and Lubis et al. (2022) have shown that ethnosience-based learning can effectively bridge the gap between scientific concepts and local knowledge.

STEM education (Science, Technology, Engineering, and Mathematics) is widely recognized as an interdisciplinary approach that develops students' critical thinking, creativity, and problem-solving skills to address real-world challenges grounded in science and technology (Bybee, 2013). Its implementation has been shown to contribute significantly to the development of scientific literacy, which encompasses the ability to understand scientific concepts, evaluate scientific information, and apply such knowledge in everyday contexts (Holbrook & Rannikmäe, 2009). However, conventional STEM approaches, often designed with universal frameworks, tend to overlook the diverse cultural, environmental, and social contexts of learners. This limitation becomes particularly evident in remote and underserved regions, where students' lived experiences differ substantially from those represented in standardized curricula (Fatimah et al, 2023). As a result, STEM learning may appear abstract and less meaningful, reducing its effectiveness in fostering scientific literacy.

The integration of indigenous knowledge into STEM education, known as the ETHjorma approach, has emerged as a significant educational strategy that combines indigenous knowledge systems with formal scientific concepts. This approach not only increases student engagement but also fosters a deeper appreciation for cultural diversity in STEM fields. For example, research has shown that EthnoSTEM-based learning tools can increase student engagement by up to 30% compared to traditional methods, highlighting their effectiveness in creating dynamic learning environments (Listiyani et al., 2025). Ethno STEM serves as a vital educational approach that



contextualizes science learning while strengthening students' cultural identity and sense of belonging. By integrating local cultural values and indigenous knowledge into science education, Ethno STEM increases the relevance of learning materials, thereby fostering greater engagement and understanding among students (Fitri et al., 2025; Hikmah et al., 2025). In science education, local wisdom, such as traditional agricultural systems, water management practices, and indigenous technologies, can serve as meaningful entry points for understanding scientific principles, including ecosystems, energy transfer, and material properties (Le Busque & Litchfield, 2025). Empirical studies further indicate that the ethno-STEM approach can enhance students' engagement, critical thinking skills, and scientific literacy (Khotimah et al., 2024). Therefore, integrating local wisdom into STEM education offers a promising, contextually relevant strategy for improving science learning outcomes, particularly in remote and underserved regions. The development and evaluation of a local wisdom-based STEM learning model, referred to as Ethno STEM, through a structured Research and Development (R&D) process using the 4-D framework, aims to enhance students' scientific literacy, engagement, and perceptions, particularly in remote and underserved regions. The Ethno STEM approach integrates cultural elements into STEM education, as demonstrated by the development of learning modules based on Javanese gamelan, which have been validated and deemed suitable for independent learning among junior high school students (Yuliana et al., 2023). Similarly, the effectiveness of Ethno STEM in improving scientific literacy is highlighted in a study focusing on vibrations and waves, which shows that such modules can significantly enhance students' understanding (Bramastia et al., 2023). The 4-D model comprising the stages of define, design, develop, and disseminate serves as the primary framework in this study, ensuring the systematic development and validation of educational materials (Marliana, 2023; Johnson, 2007). Furthermore, integrating local wisdom, such as Sasak culture, into learning modules has been shown to facilitate better understanding and engagement by linking educational content to students' cultural backgrounds (Toharudin et al., 2017). In addition, STEM-based modules have been validated for their practicality and effectiveness in improving scientific literacy and critical thinking skills, underscoring the potential of the Ethno STEM model to address educational disparities across diverse contexts (Ilham et al., 2019).

Overall, these studies affirm the feasibility and benefits of the Ethno STEM model for enhancing educational outcomes in scientific literacy and student engagement through culturally relevant, contextually adapted learning materials. However, despite these promising findings, several critical gaps remain. First, most existing studies focus on small-scale implementations or specific instructional strategies, without developing a comprehensive and systematically validated STEM learning model. Second, there is limited research that explicitly examines the effectiveness of ethno STEM approaches in remote and underserved regions, where contextual challenges differ significantly from those in urban settings. Third, previous studies often rely on descriptive or qualitative methods, with fewer employing rigorous experimental or quasi-experimental designs to measure impacts on scientific literacy. Finally, there is a lack of research integrating local wisdom into STEM learning through a structured development framework, which is essential to ensuring the model's validity, practicality, and scalability. Positioning this study within the existing literature, the present research seeks to address these gaps by developing and empirically testing a local wisdom-based STEM learning model (ethno STEM) using a systematic Research and Development (R&D) approach. The model is constructed based on the 4-D framework proposed by Thiagarajan, Semmel, and Semmel (1974), encompassing the stages of Define, Design, Develop, and Disseminate. Unlike prior studies, this research not only integrates culturally relevant content but also incorporates structured pedagogical design and empirical validation through quasi-experimental methods.

The study is conducted in Ngada Regency, East Nusa Tenggara, Indonesia, which represents a typical context of remote and underserved regions in Indonesia. This setting provides a meaningful context for examining how local wisdom can be effectively integrated into STEM education to address real educational challenges. Accordingly, this study aims to answer the following research question: To what extent is the ethno-STEM model effective in enhancing



scientific literacy among junior high school students in remote and underserved regions? To achieve this, the study is guided by three specific objectives: (1) to design a culturally integrated STEM learning model using the 4-D framework, (2) to examine the effectiveness of the model in improving students' scientific literacy through quasi-experimental methods, and (3) to explore students' engagement and perceptions during the learning process. The significance of this research lies in its contribution to advancing culturally responsive science education, particularly in underrepresented contexts. By providing an empirically validated and contextually grounded ethno STEM model, this study offers a novel approach to enhancing scientific literacy while preserving and valuing local knowledge systems. Furthermore, the findings are expected to inform educators, curriculum developers, and policymakers in designing more inclusive, relevant, and effective science education practices for students in remote and underserved regions. In conclusion, integrating local wisdom into STEM education is not only a pedagogical innovation but also a strategic approach to addressing educational inequality. It bridges the gap between scientific knowledge and students' lived experiences, fosters meaningful learning, and supports sustainable and inclusive education.

RESEARCH METHODS

This study employed a Research and Development (R&D) approach using the 4-D model developed by [Thiagarajan, Semmel, and Semmel \(1974\)](#), which includes four sequential phases: Define, Design, Develop, and Disseminate (see [Figure 1](#)). The purpose of this model is to facilitate the structured development and evaluation of instructional materials. It was particularly suitable for this study, as the goal was to design a culturally integrated STEM learning model, referred to as ethno STEM, to address the needs of students in marginalized, underserved regions. The development phase focused not only on content alignment but also on pedagogical strategies that incorporate elements of local wisdom and socio-cultural realities. To evaluate the effectiveness of the developed model, the study also employed a quasi-experimental design, specifically a nonequivalent control group design, in which pretest and posttest scores were compared between two groups. This design was selected due to its practical suitability for classroom-based interventions in real school settings, where random assignment was not feasible. The study was conducted in two junior high schools in Ngada Regency, East Nusa Tenggara, a designated Ngada of Indonesia. These schools were selected due to their geographic isolation, cultural richness, and limited access to context-based educational innovation. A total of 56 eighth-grade students were selected through purposive sampling. The experimental group ($n=28$) received science instruction through the newly developed ethno STEM model, while the control group ($n=28$) received instruction using conventional teaching methods aligned with national curriculum guidelines.

During the Define stage, the researcher conducted field studies, curriculum analysis, and interviews with teachers and local community leaders to identify relevant elements of local wisdom, including indigenous agricultural systems, traditional irrigation practices, and natural disaster mitigation practices. These elements were then used to design learning materials during the Design phase, including lesson plans, worksheets (LKPD), assessment instruments, and teaching media. The materials were validated by subject matter experts, STEM education specialists, and cultural practitioners. Revisions were made accordingly based on expert feedback. The Develop stage involved a limited trial with iterative revisions, followed by a classroom implementation in the Disseminate phase, which lasted four meetings (4×80 minutes). The implementation process was documented through video recordings, field notes, and observational checklists. The assessment of scientific literacy through a test aligned with the PISA framework effectively captures multiple dimensions of students' competencies, including knowledge, attitudes, and contextual understanding. The test design, consisting of 20 multiple-choice items contextualized within local phenomena, reflects PISA's emphasis on the application of scientific knowledge to real-life situations, as highlighted by Bybee and McCrae ([Bybee & McCrae, 2011](#)). Furthermore, integrating student perception questionnaires and observation sheets enables a comprehensive evaluation of engagement and motivation, which are essential for fostering positive attitudes toward science, as demonstrated by citizen science initiatives that enhance



scientific literacy and awareness of sustainable development goals (Queiruga-Dios et al., 2020). In addition, contextual factors influencing scientific literacy, such as instructional quality and parental involvement, play a crucial role in understanding student performance, as evidenced in analyses of high performing systems in PISA assessments (Chen et al., 2021).

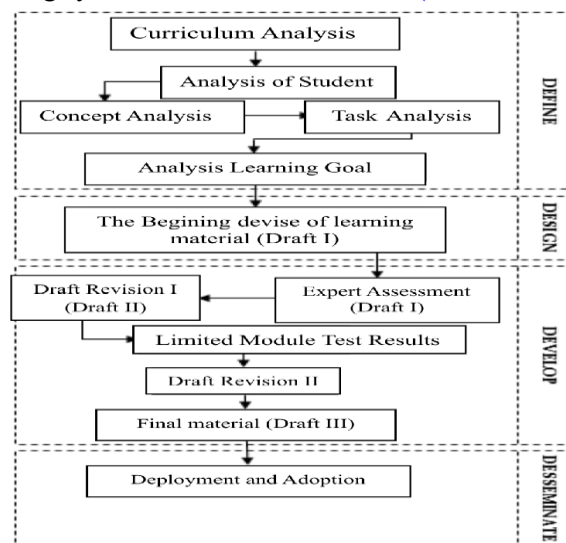


Figure 1. Research and Development (R&D) Model 4-D by Thiagarajan

Data analysis employed a mixed-methods approach. Quantitative data from pretest and posttest scores were analyzed using paired-sample t-tests and independent-sample t-tests, with normalized gain (N-Gain) calculations to assess learning gains. Data analysis employed a mixed-methods approach. Prior to inferential analysis, the data were screened for normality using the Shapiro-Wilk test, which indicated normality. Therefore, quantitative data from pretest and posttest scores were analyzed using paired-samples and independent-samples t-tests, with normalized gain (N-Gain) calculations to assess learning gains. These analyses were conducted using SPSS software. Meanwhile, qualitative data collected from observations, open-ended responses, and interviews were analyzed using the Miles and Huberman (1994) method: data reduction, data display, and conclusion drawing. These analyses were conducted using SPSS software. Qualitative data collected from observations, open-ended questionnaire responses, and interviews were analyzed using the Miles and Huberman (1994) framework, which includes data reduction, data display, and conclusion drawing. The open-ended items in the questionnaire were designed to capture students' perceptions of the learning process, including their experiences, challenges, and levels of interest in the ethno STEM approach. In addition, semi-structured interviews were conducted with a selected sample of students and one science teacher to gain deeper insights into their learning experiences and instructional practices. Not all participants were interviewed; instead, participants were purposively selected to represent varying levels of academic performance and engagement. The validity of qualitative findings was enhanced through data triangulation and member checking. This methodological approach ensured that the study not only measured cognitive improvements but also captured students' emotional and behavioral responses to a culturally contextualized learning environment. The validity of qualitative findings was enhanced through data triangulation and member checking. In this study, member checking was conducted by returning summarized interview results to the selected participants, including students and the science teacher, to verify the accuracy and credibility of the interpretations. Participants were given the opportunity to review, clarify, and confirm whether the findings accurately reflected their experiences and perspectives. This methodological approach ensured that the study not only measured cognitive improvements but also captured students' emotional and behavioral responses to a culturally contextualized learning environment. By grounding STEM learning in local culture and lived experiences, the model offers a viable solution for educational equity in remote and culturally rich regions.

RESULTS AND DISCUSSION

Results

This study aimed to examine the effectiveness of a STEM learning model grounded in local wisdom (ethno-STEM) in improving students' scientific literacy. The findings are presented in two main sections: (1) quantitative analysis of the scientific literacy test results, and (2) qualitative analysis of student engagement and responses to the learning model.

1. Quantitative Analysis: Scientific Literacy Test Results

The scientific literacy test was administered before (pretest) and after (posttest) the implementation of the learning model to both the experimental and control groups. Data were analyzed using t-tests and N-Gain calculations to determine the effectiveness of the ethno STEM model.

Table 1. Mean Scores of Pretest and Posttest Scientific Literacy

Group	N	Pretest (Mean $\pm$ SD)	Posttest (Mean $\pm$ SD)	N-Gain	Category
Experimental	28	54.6 $\pm$ 8.7	82.3 $\pm$ 7.4	0.72	High
Control	28	55.1 $\pm$ 9.2	67.8 $\pm$ 8.3	0.41	Medium

The results presented in Table 1 indicate that both the experimental and control groups showed improvement in students' scientific literacy after the intervention. However, the magnitude of improvement differs significantly between the two groups. The experimental group, which was taught using the ethno-STEM learning model, demonstrated a substantial increase in mean scores from 54.6 (SD = 8.7) in the pretest to 82.3 (SD = 7.4) in the posttest. This improvement corresponds to an N-gain score of 0.72, which falls into the high category, indicating a strong effectiveness of the intervention. In contrast, the control group, which received conventional instruction, showed a more modest improvement, with mean scores increasing from 55.1 (SD = 9.2) to 67.8 (SD = 8.3). The N-gain score of 0.41 is categorized as medium, suggesting a moderate level of improvement. These findings suggest that the ethno-STEM learning model is more effective than conventional teaching methods in enhancing students' scientific literacy. The higher N-gain in the experimental group indicates that integrating local wisdom into STEM learning provides a more meaningful, contextual learning experience that facilitates deeper understanding and knowledge retention.

Table 2. Results of Paired Sample t-Test (Within Groups)

Group	t-value	Df	Sig. (2-tailed)	Interpretation
Experimental	14.21	27	0.000	Significant improvement
Control	6.93	27	0.000	Significant improvement

The results of the paired sample t-test used to examine the differences between pretest and posttest scores within each group are presented in Table 2. As shown in Table 2, both the experimental and control groups demonstrated statistically significant improvements in students' scientific literacy after the intervention. The experimental group obtained a t-value of 14.21 (df = 27, $p < 0.001$), indicating a highly significant increase in posttest scores compared to pretest scores. Similarly, the control group also showed a significant improvement, with a t-value of 6.93 (df = 27, $p < 0.001$). However, the magnitude of improvement in the experimental group was considerably higher than that of the control group, as reflected by the larger t-value. This finding suggests that the ethno STEM learning model more effectively enhanced students' scientific literacy than conventional instruction. Both groups experienced statistically significant improvements ($p < 0.05$); however, the increase in the experimental group was greater in terms of mean score and effect size. The paired-sample t-test results are presented in Table 02, indicating significant improvements in both groups.

Table 3. Results of Independent Sample t-Test (Between Groups)

Aspect	t-value	df	Sig. (2-tailed)	Interpretation
Posttest	6.01	54	0.000	Significant difference between groups
N-Gain	5.73	54	0.000	Significant difference in improvement

The results of the independent-samples t-test examining differences between the



experimental and control groups are presented in Table 3. As shown in Table 3, there is a statistically significant difference between the two groups in both posttest scores and N-gain values. The posttest results indicate a t-value of 6.01 ($df = 54$, $p < 0.001$), demonstrating that students in the experimental group achieved significantly higher scientific literacy scores compared to those in the control group. Similarly, the N-gain analysis yields a t-value of 5.73 ($df = 54$, $p < 0.001$), indicating a significant difference in improvement between the two groups. This finding confirms that the experimental group experienced a greater increase in scientific literacy than the control group. The t-test results show a significant difference between the experimental and control groups in both posttest scores and N-Gain values, indicating that the ethno-STEM learning model is effective in enhancing scientific literacy. This result is consistent with the findings in Table 1 and Table 2, which also indicate that the experimental group outperformed the control group.

2. Qualitative Analysis: Student Engagement and Responses

Qualitative analysis was conducted to complement the quantitative data and gain deeper insights into students' perceptions of the ethno-STEM learning experience.

Table 4. Quantitative Summary of Student Responses to the Ethno-STEM Learning Model (N = 28)

Statement	Agree (%)	Disagree (%)
The learning was easier to understand because it was connected to local culture	92.9	7.1
I felt more motivated to learn science through this approach	89.3	10.7
I was more active during the learning process	85.7	14.3
Culture-based practical activities were very interesting	96.4	3.6
I would like this type of learning to be applied in other subjects	90.0	10.0

The results of students' responses toward the implementation of the ethno-STEM learning model are presented in Table 4. As shown in Table 4, the majority of students expressed highly positive perceptions of the ethno-STEM learning model. A significant proportion of students (92.9%) agreed that the learning process was easier to understand when connected to local culture. Additionally, 89.3% of students reported increased motivation to learn science, while 85.7% indicated that they became more active during the learning process. Furthermore, culture-based practical activities were perceived as highly engaging, with 96.4% of students expressing agreement. Notably, 90.0% of students stated their preference for applying this type of learning approach in other subjects. The majority of students responded positively to the ethno-STEM learning model, particularly in terms of comprehension, engagement, and learning motivation. During the learning sessions in the experimental group, student engagement was monitored using observation sheets. Results showed that 82% of students actively participated in discussions, 79% were involved in hands-on activities using local practices (e.g., creating traditional irrigation models), and 88% asked questions or gave responses related to local phenomena linked to science concepts. This result supports previous findings that culturally responsive learning approaches can foster positive student attitudes and meaningful engagement in science learning.

Table 4 presents students' responses to the implementation of the Ethno STEM learning model, collected via a structured questionnaire with dichotomous (agree/disagree) items. While the quantitative results indicate a high level of agreement across all statements, additional qualitative data from open-ended responses were analyzed to provide deeper insights into students' perceptions. The qualitative analysis revealed that students found the integration of local culture particularly helpful in understanding scientific concepts. For example, one student stated, "I understand science better because it relates to what we do in daily life." Another student mentioned, "Learning through local activities makes science more interesting and easier to follow." These responses suggest that the Ethno STEM approach not only enhances cognitive understanding but also positively influences students' motivation and engagement. Therefore, the combination of quantitative and qualitative data provides a more comprehensive understanding of students' learning experiences.

Discussion

This study was conducted to address three core research questions: (1) the effectiveness of



integrating local wisdom into a STEM learning model (ethno STEM) in enhancing students' scientific literacy in remote and underserved regions, (2) the influence of the ethno STEM model on student engagement in science learning, and (3) students' responses toward the implementation of the ethno STEM approach.

1. Effectiveness of Ethno STEM in Enhancing Scientific Literacy

The findings of this study revealed a substantial improvement in students' scientific literacy in the experimental group. The mean score increased significantly from 54.6 in the pretest to 82.3 in the posttest, with an N-Gain of 0.72, which falls into the high category. In contrast, the control group demonstrated a lower level of improvement, with an N-Gain of 0.41, categorized as moderate. This difference clearly indicates that the ethno STEM learning model is more effective than conventional teaching approaches in enhancing students' scientific literacy, particularly in the context of remote and underserved regions. This result is further strengthened by inferential statistical analysis, which confirmed that the differences between the experimental and control groups were statistically significant. The higher level of improvement in the experimental group suggests that embedding scientific concepts within culturally relevant contexts enables students to engage more deeply with the learning material. Rather than perceiving science as abstract and disconnected from their lives, students were able to relate scientific ideas to familiar practices and environments, thereby facilitating meaningful learning experiences.

From a theoretical perspective, these findings strongly align with the framework of scientific literacy proposed by [Holbrook and Rannikmäe \(2009\)](#), which emphasizes not only the mastery of scientific concepts but also the ability to apply scientific knowledge in real life situations. The ethno-STEM model supports this by bridging the gap between formal scientific knowledge and students' everyday experiences. For example, local agricultural practices, traditional ecological knowledge, and indigenous resource management systems were utilized as contextual entry points to explain scientific concepts such as ecosystems, sustainability, and environmental balance ([Haka et al., 2020](#)). This approach enables students to see science as relevant and applicable, rather than distant and theoretical. Furthermore, these findings are consistent with constructivist learning theory, which posits that knowledge is actively constructed by learners through interaction with their environment and prior experiences. In this study, students were not passive recipients of information; instead, they actively engaged in the learning process by connecting new scientific knowledge with their existing cultural understanding ([Yetti, 2024](#)). This active construction of knowledge not only enhances conceptual understanding but also improves long-term retention and transferability of learning.

The results of this study are also in line with previous empirical research. [Khotimah et al. \(2024\)](#) reported that culturally integrated STEM learning significantly improves students' critical thinking skills and scientific literacy. Similarly, [Hikmawati et al. \(2021\)](#) demonstrated that incorporating local cultural elements into STEM instruction enhances both cognitive outcomes and students' cultural awareness. These studies collectively highlight the importance of contextual and culturally responsive approaches in science education. However, this study offers a distinct contribution by adopting a more systematic and structured approach through the use of the 4-D development model (Define, Design, Develop, Disseminate) combined with a quasi experimental research design. Unlike previous studies that often focus on isolated instructional strategies, this research provides a validated and comprehensive learning model that is both theoretically grounded and empirically tested. This strengthens the reliability, scalability, and practical applicability of the ethno STEM model, particularly for implementation in similar educational contexts. Overall, the findings demonstrate that the ethno STEM approach is not only effective in improving students' scientific literacy but also capable of transforming science learning into a more meaningful, contextual, and culturally relevant experience.

2. Student Engagement in Ethno STEM Learning

In relation to the second research question, the findings indicate that the ethno STEM model significantly enhances student engagement in science learning. Observational data revealed that 82% of students actively participated in classroom discussions, 79% were involved in hands on activities, and 88% demonstrated curiosity by asking questions or providing feedback related to



the learning content. These figures suggest a high level of behavioral and cognitive engagement, indicating that students were not only physically involved but also mentally invested in the learning process. These results highlight that the integration of local wisdom into STEM learning can transform the classroom environment from passive to active. In conventional settings, students often assume the role of passive recipients of information, relying heavily on teacher explanations and textbook-based instruction. However, in the ethno STEM learning model, students are positioned as active participants who engage in inquiry based learning processes. They explore, question, and construct knowledge through interactions with real-life contexts that are familiar to them. The use of local materials, cultural practices, and community based examples makes abstract scientific concepts more concrete, thereby increasing students' willingness and enthusiasm to engage in learning activities.

This shift toward active learning is particularly important in the context of remote and underserved regions, where students frequently experience a disconnect between school knowledge and their everyday lives. By incorporating local wisdom, the ethno STEM model reduces this gap and creates a more meaningful learning experience. Students are able to see the relevance of science in their own environments, which fosters a sense of ownership and relevance in the learning process. As a result, engagement is not externally imposed but emerges naturally from students' intrinsic interest and curiosity. From a theoretical standpoint, these findings can be explained through the lens of Contextual Teaching and Learning (CTL) theory (Johnson, 2007), which emphasizes that learning becomes meaningful when students can relate academic content to real life situations. The ethno STEM approach aligns well with this principle by embedding scientific concepts within socio cultural and environmental contexts familiar to students. This contextualization allows students to build connections between prior knowledge and new information, thereby enhancing both understanding and engagement.

Furthermore, the increased engagement observed in this study can also be interpreted through self determination theory, particularly in terms of intrinsic motivation. When students perceive learning as relevant, authentic, and connected to their lives, their psychological needs for autonomy, competence, and relatedness are more likely to be fulfilled. In this study, students were given opportunities to explore their own cultural contexts, work collaboratively, and apply their knowledge in meaningful ways. These conditions foster intrinsic motivation, which in turn leads to sustained engagement and persistence in learning tasks. Additionally, the hands on and collaborative nature of the ethno STEM model supports social engagement among students (Syiafuddin, 2020). Group discussions, collaborative problem solving, and shared exploration of local phenomena encourage interaction and communication, which are essential components of active learning. This social dimension further strengthens engagement by creating a supportive and interactive learning environment. Overall, the findings suggest that the ethno STEM model is highly effective in promoting multidimensional student engagement, encompassing behavioral, cognitive, and social aspects. By connecting science learning to students' lived experiences and cultural backgrounds, the model not only enhances participation but also fosters deeper interest and meaningful involvement in the learning process (Alawiah., 2023).

3. Students' Responses toward the Ethno STEM Model

Regarding the third research question, the findings demonstrate overwhelmingly positive student responses toward the implementation of the ethno STEM learning model. More than 90% of students agreed that integrating local wisdom into STEM learning made the learning process more engaging, understandable, and enjoyable. In addition, a large proportion of students expressed a strong preference for applying similar approaches in other subjects, indicating not only satisfaction with the current learning experience but also a desire for broader pedagogical transformation. These responses suggest that the ethno STEM model has a significant impact not only on cognitive outcomes but also on the affective domain of learning. In educational contexts, affective factors such as motivation, interest, attitude, and emotional engagement play a crucial role in determining students' learning success. Science, in particular, is often perceived by students as a difficult and abstract subject, which can lead to low motivation and disengagement. However, the findings of this study indicate that when science learning is contextualized through



culturally relevant content, students' perceptions of the subject can shift from being intimidating to being accessible and meaningful. The increased motivation and positive attitudes observed in this study can be attributed to the relevance of the learning content to students' daily lives. When students recognize that what they are learning reflects their own cultural practices and environmental contexts, they are more likely to develop a sense of connection and ownership toward the learning process. This sense of relevance fosters intrinsic interest, which is a key driver of sustained engagement and deeper learning.

Research shows that when students connect course material to their personal lives, especially those with low expectations of success, their interest and performance in science increases (Hulleman & Harackiewicz, 2009), who emphasized that culturally responsive pedagogy can enhance students' confidence, strengthen their identity, and foster a positive emotional connection to learning. By integrating local wisdom into the learning process, the ethno STEM model acknowledges and values students' cultural backgrounds, thereby creating an inclusive learning environment. Students feel that their knowledge, traditions, and experiences are respected, which contributes to increased self-esteem and a stronger sense of belonging in the classroom. Furthermore, the validation of local knowledge within formal education serves an important role in bridging the gap between school-based learning and community practices. In many remote and underserved regions, local knowledge systems are often overlooked or undervalued within national curricula, leading to a disconnect between students' cultural identities and their academic experiences. The ethno STEM model addresses this issue by positioning local wisdom as a legitimate and valuable source of knowledge that can coexist with scientific concepts (Syaifuddin., 2020). This integration not only enhances learning outcomes but also contributes to cultural sustainability. By incorporating indigenous knowledge into science education, students are encouraged to appreciate and preserve their cultural heritage while simultaneously developing scientific competencies. This dual benefit is particularly important in the context of globalization, where local cultures are increasingly at risk of being marginalized. In addition, positive student responses toward the ethno STEM model may also indicate a shift in students' epistemological beliefs about science. Rather than viewing science as a rigid, universal body of knowledge detached from culture, students begin to understand it as dynamic, contextual, and relevant to their own lives. This shift in perspective is essential for developing a more inclusive and holistic understanding of science (Le Busque & Litchfield, 2025). Overall, the findings suggest that the ethno STEM learning model is highly effective in fostering positive affective responses among students. By creating a learning environment that is engaging, culturally relevant, and emotionally supportive, the model not only enhances students' attitudes toward science but also promotes deeper, more meaningful learning (Wahyuni et al., 2024).

4. Integration of Cognitive, Affective, and Contextual Dimensions

One of the key contributions of this study is its demonstration of how cognitive, affective, and contextual dimensions of learning can be effectively integrated into a single instructional model. The ethno STEM approach does not merely aim to improve students' academic performance or test scores; rather, it promotes a holistic learning experience that connects knowledge acquisition with students' cultural identity and real-life applications. This multidimensional integration is essential in developing meaningful and sustainable learning, particularly in science education. From a cognitive perspective, the ethno STEM model enhances students' understanding of scientific concepts by linking abstract ideas to concrete experiences rooted in local culture. Students are not only introduced to scientific theories but are also guided to explore how these concepts manifest in their daily lives, such as in traditional agricultural practices, local ecological systems, or indigenous technologies. This approach facilitates deeper conceptual understanding and supports knowledge retention by allowing students to anchor new information in familiar contexts. In terms of the affective dimension, the model fosters positive attitudes toward learning by increasing students' motivation, interest, and emotional engagement. When students see their cultural background reflected in the learning process, they are more likely to feel valued and included. This sense of recognition enhances their confidence and encourages active participation in classroom activities. As a result, learning becomes not only an intellectual



process but also an emotionally meaningful experience. The contextual dimension further strengthens this integration by situating learning within students' socio-cultural and environmental realities. In many cases, traditional science instruction relies on standardized curricula that may not be relevant to students in diverse or remote settings. The ethno STEM model addresses this limitation by incorporating local wisdom as a core component of instruction. This contextualization ensures that learning is grounded in real-life situations, making it more applicable and meaningful for students.

This integrative approach is particularly relevant in addressing educational inequality, especially in remote and underserved regions. In such contexts, challenges are not limited to inadequate infrastructure or limited access to educational resources, but also include a fundamental mismatch between curriculum content and students' lived experiences. When learning materials do not reflect students' realities, it can lead to disengagement, low achievement, and a diminished sense of relevance in education (Noris et al., 2024). By aligning science learning with local contexts, the ethno STEM model offers a more inclusive and equitable approach to education. It recognizes that students from different backgrounds bring diverse knowledge systems and experiences that can enrich the learning process. Rather than imposing a one-size-fits-all curriculum, this model adapts instruction to learners' cultural and environmental contexts, thereby reducing barriers to understanding and participation. Moreover, this approach contributes to the broader goal of educational equity by empowering students in marginalized regions. It provides them with opportunities to succeed academically while maintaining a strong connection to their cultural heritage. In this sense, the ethno STEM model not only addresses disparities in learning outcomes but also promotes cultural sustainability and social inclusion (Setianingrum et al., 2023). Overall, the integration of cognitive, affective, and contextual dimensions in the ethno STEM model represents a comprehensive and transformative approach to science education. It demonstrates that effective learning is not solely about mastering content, but also about connecting knowledge with identity, experience, and real-world application.

5. Implications for Theory and Practice

The findings of this study have several important implications, both theoretically and practically, for the advancement of science education, particularly in culturally diverse and geographically marginalized contexts. From a theoretical perspective, this research reinforces the significance of culturally responsive pedagogy and contextual learning as essential foundations for effective science instruction. It provides empirical support for the argument that learning becomes more meaningful when it is connected to students' sociocultural backgrounds and lived experiences. In this regard, the study strengthens existing theoretical frameworks that emphasize the role of culture in shaping knowledge construction, such as constructivist learning theory and culturally responsive teaching. Moreover, this research extends the current body of literature by providing empirical evidence from remote and underserved regions, which are often underrepresented in educational research. Most previous studies on STEM education and culturally responsive pedagogy have been conducted in urban or relatively well-resourced settings. As a result, there has been limited understanding of how these approaches function in areas characterized by geographical isolation, limited infrastructure, and strong adherence to local traditions. By situating the study in such a context, this research contributes to a more inclusive and comprehensive understanding of how STEM education can be adapted to meet the needs of diverse learners.

In addition, the study makes a conceptual contribution by demonstrating how integrating local wisdom into STEM education through the ethnoSTEM approach can serve as a bridge between formal scientific knowledge and indigenous knowledge systems. This highlights the importance of viewing science not as a culturally neutral discipline, but as a dynamic body of knowledge that can be enriched through interaction with local contexts. Such a perspective challenges conventional assumptions about science education and opens new avenues for developing more inclusive and context-sensitive pedagogical models. From a practical standpoint, this study offers a validated instructional model that educators, curriculum developers, and policymakers can implement. The ethno STEM model developed in this research is grounded in



a systematic Research and Development (R&D) process using the 4-D framework (Define, Design, Develop, Disseminate), which ensures that the model is not only theoretically sound but also practically feasible. Each stage of the development process contributes to the model's refinement and validation, making it adaptable to different educational contexts. The scalability of the model is particularly important for its broader application. Given that many regions in Indonesia and other developing countries face similar challenges, such as limited resources, cultural diversity, and geographical constraints, the ethno STEM approach can be adapted to suit diverse local contexts. Teachers can modify learning materials by incorporating locally relevant examples, while policymakers can integrate this approach into curriculum guidelines to promote more inclusive and context-based education. Furthermore, implementing the ethno STEM model has the potential to enhance teacher professional development. Educators are encouraged to become more reflective and innovative in designing learning experiences that are responsive to students' cultural backgrounds. This shift from a teacher-centered to a learner-centered approach requires not only pedagogical competence but also cultural awareness and sensitivity (Lyesmaya et al., 2020). Overall, the implications of this study highlight the need for a paradigm shift in science education, one that moves beyond standardized, one-size-fits-all approaches toward more flexible, inclusive, and culturally grounded practices. By bridging theory and practice, this research provides a meaningful contribution to the development of science education that is both equitable and contextually relevant.

Overall, the results of this study indicate that the ethno STEM learning model is a highly effective approach for enhancing students' scientific literacy, increasing engagement, and fostering positive learning attitudes. The integration of local wisdom into STEM learning enables students to connect abstract scientific concepts with their everyday experiences, thereby making learning more meaningful and relevant. This approach not only improves cognitive outcomes but also supports the development of affective and contextual dimensions of learning, which are essential for holistic education. More importantly, the findings demonstrate that integrating local wisdom into STEM education is not merely a pedagogical strategy, but also a culturally meaningful practice (Mukaromah, et al., 2022). By incorporating local knowledge systems, traditions, and environmental practices into the learning process, education becomes a space where students' identities and cultural backgrounds are acknowledged and valued. This contributes to a more inclusive learning environment in which students feel a sense of belonging and ownership over their learning. This study reinforces the notion that science education should not be viewed as culturally neutral or universally detached from context. Instead, science learning should reflect the values, knowledge systems, and lived experiences of learners, particularly in diverse and underserved regions. When education is aligned with students' socio-cultural realities, it becomes more accessible and impactful, allowing learners to engage more deeply with the content. Furthermore, this approach has broader implications for educational transformation. By bridging the gap between formal scientific knowledge and indigenous knowledge systems, the ethno STEM model promotes not only academic achievement but also cultural sustainability. In doing so, it supports the development of learners who are not only scientifically literate but also culturally grounded and socially aware (Darling et al., 2019).

CONCLUSIONS AND SUGGESTIONS

This study aimed to investigate the effectiveness of integrating local wisdom into a STEM learning model, known as ethno STEM, in enhancing students' scientific literacy in remote and underserved regions. It also examined how this approach influences student engagement and students' perceptions of the learning experience. The findings indicate that the ethno STEM model is an effective approach for improving students' scientific literacy. By embedding scientific concepts in culturally relevant contexts, the model enables students to develop a deeper, more meaningful understanding of science. This confirms that culturally contextualized STEM learning is not only relevant to students' backgrounds but also capable of significantly improving learning outcomes. In addition to its impact on cognitive achievement, the ethno STEM model also positively influences student engagement. The learning process encourages active participation,



inquiry, and interaction by connecting science with students' real-life experiences. As a result, students become more involved in the learning process and demonstrate greater curiosity and participation.

Furthermore, students' responses toward the ethno STEM approach are highly positive. The integration of local wisdom creates a more engaging and enjoyable learning environment, which enhances students' motivation and interest in science. It also fosters a sense of relevance and connection between academic content and students' cultural identities. Overall, this study concludes that the ethno STEM learning model provides a holistic and effective approach to science education by addressing cognitive, affective, and contextual dimensions simultaneously. The model not only improves scientific literacy but also promotes meaningful, inclusive, and culturally responsive learning experiences. These findings highlight the importance of integrating local wisdom into STEM education to improve educational quality and equity in diverse learning contexts.

Based on these findings, several practical suggestions can be articulated for stakeholders:

1. For educators and school administrators, the ethno STEM model offers a viable and scalable approach to improving science education outcomes. Teachers should be supported in developing and implementing lesson plans that connect scientific concepts to students' cultural and environmental realities. Professional development programs should prioritize building teachers' capacity to research, integrate, and facilitate ethno-STEM activities, including the development of culturally relevant teaching media such as local materials, community stories, and environment-based experiments.
2. For curriculum developers and policymakers, the findings highlight a critical opportunity to operationalize the Kurikulum Merdeka mandate for flexible, student-centered, and context-based learning. Ethno STEM can serve as a model framework for embedding local wisdom into formal science curricula, particularly for remote, underserved regions. Policymakers should consider allocating resources to develop regional ethno STEM modules, train teachers to apply them, and evaluate their impact systematically across diverse geographical and cultural settings.
3. For educational researchers, this study demonstrates that combining R&D methodology (using the 4-D model) with quasi-experimental design yields both practical pedagogical resources and robust evidence of effectiveness. Future research may expand on this by adapting the ethno STEM approach to different educational levels (e.g., lower secondary, upper secondary, or informal learning contexts), different cultural contexts, or additional STEM sub-disciplines. Longitudinal studies could assess the retention of scientific literacy gains, the development of cultural identity, and students' future engagement with STEM careers.
4. For local communities and cultural institutions, active involvement in education can reinforce cultural preservation while enhancing learning. Collaborations between schools, elders, traditional practitioners, and cultural organizations can help document and validate local knowledge, co-create learning materials, and enrich classroom practice. This participatory approach fosters mutual respect between formal education and community knowledge systems, promoting educational equity and cultural continuity.

In conclusion, the ethno STEM learning model effectively enhances students' scientific literacy, engagement, and motivation contexts while fostering cultural identity and educational relevance. It offers a blueprint for inclusive, context-sensitive science education that bridges the gap between formal academic content and students' lived experiences. Implementing and scaling this model can contribute significantly to closing educational disparities, honoring cultural heritage, and equipping students in marginalized regions with the scientific competencies and cultural pride needed for their future development.

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