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Exploring the Need for Ethno-STEM-Based Physics Module Development and Differentiation to Improve Critical Thinking Among High School Students in the Context of Global Warming in South Sumatera

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Abstract: This study aims to identify the empirical needs for developing an Ethno-STEM-based and differentiated physics module to improve critical thinking skills among high school students in South Sumatra, within the context of global warming. A mixed-methods exploratory sequential design was employed, with qualitative data from open-ended questions informing the development of a quantitative Likert-scale questionnaire administered to 81 physics teachers and 1,118 Grade 10 students across five vulnerable districts. Results show that while 100% of teachers express interest in Ethno-STEM, only 24.7% have implemented it, primarily due to the lack of ready-to-use modules (32.4%) and curriculum time constraints (27.0%). Students exhibit diverse learning preferences, with 74.6% favoring hands-on experiments. Furthermore, 83.5% demonstrate analytical skills by identifying causes of environmental problems, but only 61% can compare solutions effectively. These findings reveal a significant gap between awareness and practice, underscoring the urgent need for contextual, culturally responsive, and differentiated learning materials. The study provides a strong empirical foundation for designing a project-based physics module aligned with the Merdeka Curriculum, integrating local wisdom, STEM principles, and learning style differentiation to enhance critical thinking.

Keywords: Critical thinking; Differentiated learning; Ethno-STEM; Global warming; Needs assessment

Introduction

Global warming is one of the most crucial environmental challenges of the 21st century. The latest report by IPCC (2023) shows that the global average temperature has increased by 1.1°C since the pre-industrial era, triggering extreme climate changes such as droughts, floods, forest fires, and ecosystem disturbances that directly impact human life and the sustainability of natural resources. In Indonesia, these impacts are increasingly evident, including in South Sumatera, which has extensive peatlands. This region is prone to forest and land fires (karhutla) every dry season. This not only produces cross-border haze, but also damages public health, food security, and the sustainability of local wisdom (Adil & Hadi, 2018; Mahendra et al., 2023).

Within the educational context, global warming offers a strategic entry point for fostering scientific literacy, environmental awareness, and critical thinking—core competencies of the 21st-century 4C framework (Critical Thinking, Creativity,

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Collaboration, Communication) embedded in Indonesia's Merdeka Curriculum (Kementerian Pendidikian, Kebudayaan, Riset, dan Teknologi (Kemendikbudristek, 2022). However, physics instruction in Indonesian senior high schools remains largely conventional, relying on rote memorization and abstract explanations disconnected from local realities (Akhsan & Wiyono, 2020). Concepts like the greenhouse effect and thermal radiation are often taught without linking them to tangible phenomena such as peatland degradation or traditional fire prevention practices in South Sumatra.

Contemporary pedagogical approaches like STEM (Science, Technology, Engineering, Mathematics) have proven effective in enhancing cognitive engagement and problem-solving skills through multidisciplinary, real-world projects (Astuti et al., 2021; Othman et al., 2022; Anggraini et al., 2023). Yet, their application in Indonesia often lacks cultural contextualization. Integrating ethnoscience—local knowledge and cultural wisdom—into science education (known as Ethno-STEM) can increase relevance, meaning, and student motivation (Rochman et al., 2018; Nurhasnah et al., 2022). For instance, the local adat principle "*Do not burn the forest, otherwise your children and grandchildren will have nowhere to play*" embodies ecological foresight aligned with climate change mitigation. Despite this potential, no study has yet combined Ethno-STEM, learning differentiation, and critical thinking within the context of global warming in fire-prone regions like South Sumatra.

Furthermore, Akhsan et al. (2023) showed that Furthermore, students exhibit diverse learning styles (visual, auditory, kinesthetic), necessitating differentiated instruction (Tomlinson, 2014). Research indicates that tailored learning strategies improve outcomes on complex topics like climate change (Lestari et al., 2023; Minangkabau et al., 2024; Putra & Suryadi, 2024). While project-based learning with a STEM approach has been shown to significantly enhance environmental literacy (Aji et al., 2024), its implementation is hindered by limited resources and teacher training. This study addresses the research gap by investigating the empirical needs of teachers and students for a differentiated, Ethno-STEM-based physics module focused on global warming, with the explicit goal of improving critical thinking skills in alignment with the Merdeka Curriculum. The novelty lies in the integration of three key dimensions—cultural relevance, pedagogical differentiation, and higher-order thinking—within a localized, real-world context.

Method

This study employed a mixed-methods exploratory sequential design (QUAL → QUAN), where qualitative insights informed the development of a quantitative instrument. This approach allows for a deeper understanding of contextual needs before scaling up to broader survey data (Creswell & Creswell, 2018).

The population consisted of physics teachers and Grade 10 students from five districts in South Sumatra most vulnerable to global warming impacts: Palembang City, Ogan Komering Ilir (OKI), Ogan Ilir, Musi Banyuasin, and Banyuasin. Participants were selected using purposive sampling based on geographic representation, exposure to peatland fires, and access to educational infrastructure.

Data collection occurred in two phases. First, semi-structured interviews were conducted with 15 teachers to explore their experiences, challenges, and expectations regarding contextual physics teaching. Thematic analysis (Braun & Clarke, 2006) identified key barriers (e.g., lack of modules, time constraints) and opportunities (e.g., local wisdom integration). These findings informed the development of a structured online questionnaire.

The final instrument, administered via Google Form in October 2024, included: Likert-scale items (1 = strongly disagree to 5 = strongly agree) assessing teachers' awareness, interest, and obstacles related to Ethno-STEM and critical thinking; and open-ended questions exploring student expectations and learning preferences. The instrument underwent content validity review by three experts in physics education and environmental science. Reliability testing using Cronbach's Alpha yielded $\alpha = 0.87$ for the Likert scale, indicating high internal consistency (DeVellis, 2016).

Quantitative data were analyzed using descriptive statistics (percentages, means, standard deviations) in Microsoft Excel. Qualitative responses were coded and thematically analyzed. Data triangulation was performed by comparing teacher and student narratives to ensure convergence of findings.

Result and Discussion

This study involved 81 physics teachers and 1,118 Grade 10 high school students from five districts in South Sumatra—Palembang City, Ogan Komering Ilir (OKI), Ogan Ilir, Musi Banyuasin, and Banyuasin—regions frequently affected by peatland fires and haze due to global warming. The demographic profiles of respondents are presented in Figures 1 to 4. Figure 1 shows that teacher respondents were predominantly male (80.25%), which reflects the gender imbalance

commonly observed in STEM teaching at the secondary level in Indonesia. Figure 2 reveals that the largest proportions of teachers came from OKI (29.63%) and Banyuasin (27.16%), areas with extensive peatlands and recurring fire hazards, ensuring the sample's relevance to the study context. Meanwhile, student respondents were mostly female (70.57%) as shown in Figure 3, a pattern consistent with national enrollment trends in science classes. Figure 4 indicates that 35.60% of students were from OKI and 27.91% from Banyuasin, reinforcing the geographic focus on environmentally vulnerable zones.

Figure 1 shows that teacher respondents were predominantly male (80.25%), which reflects the gender imbalance commonly observed in STEM teaching at the secondary level in Indonesia.

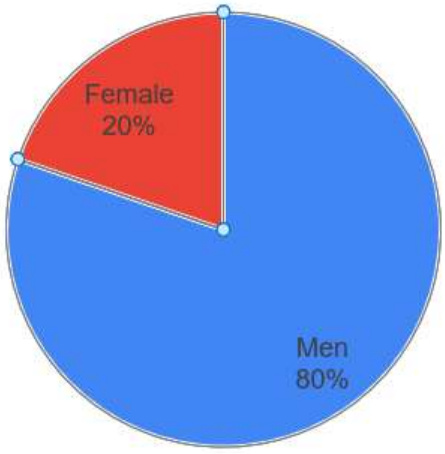

Figure 1. Distribution of physics teacher respondents by gender across five districts in South Sumatra (N = 81). The majority were male (80.25%), reflecting the gender distribution commonly observed in STEM teaching at the secondary level in Indonesia

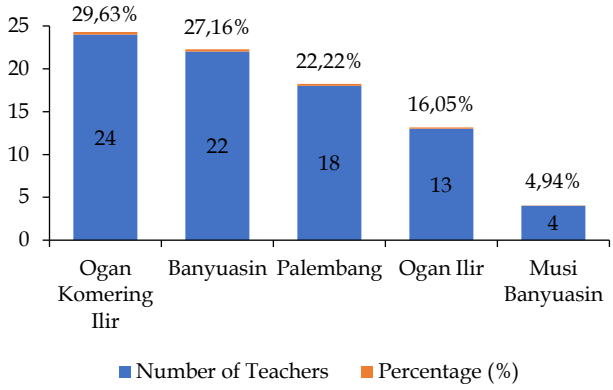

Figure 2. Regional distribution of physics teacher respondents in South Sumatra (N = 81). The largest proportions were from Ogan Komering Ilir (29.63%) and Banyuasin (27.16%), areas frequently affected by peatland fires and haze

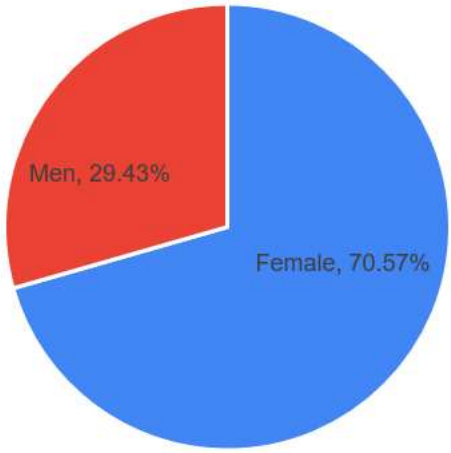

Figure 3. Gender distribution of high school student respondents (N = 1,118). Female students constituted the majority (70.57%), consistent with enrollment patterns in science classes in public senior high schools in the region

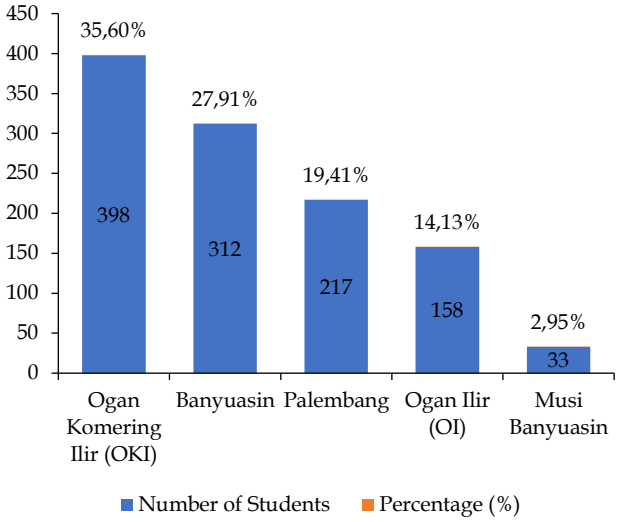

Figure 4. Geographical distribution of high school student respondents across five vulnerable districts in South Sumatra (N = 1,118). Most students were from Ogan Komering Ilir (35.60%) and Banyuasin (27.91%), regions with extensive peatlands and recurring fire hazards

Teacher perspectives on environmental education and Ethno-STEM are detailed in Figures 5 and 6. Figure 5 demonstrates that 92.6% of teachers reported a good understanding of global warming, 100% acknowledged its local impacts (e.g., haze, land fires), and 96.3% were aware of relevant local wisdom such as the customary prohibition against burning forests. Crucially, 100% expressed interest in integrating Ethno-STEM into their teaching, yet Figure 6 reveals a stark implementation gap: only 24.7% have ever used it. The primary barriers were the lack of ready-to-use modules (32.4%) and limited curriculum time (27.0%). Only 5.9% reported using local wisdom-based projects. As one teacher

stated: *"We need valid, accessible modules. Creating them from scratch takes too much time."* This confirms a critical disconnect between awareness and practice, echoing Akhsan et al. (2023), who found that teacher readiness is constrained by insufficient instructional tools. These findings underscore the urgent need for pre-designed, curriculum-aligned modules that integrate local ecological knowledge—such as the adat principle "Do not burn the forest, otherwise your children and grandchildren will have nowhere to play"—into physics concepts like heat transfer and greenhouse effect.

Student learning preferences and cognitive engagement are illustrated in Figures 7 and 8. Figure 7 shows that 88.4% of high school students are interested in learning physics through environmental issues, and 74.6% prefer hands-on experiments, supporting the feasibility of project-based learning. Their learning styles were diverse: 42% visual, 31% auditory, and 27% kinesthetic learners, reinforcing the necessity of differentiated instruction (Tomlinson, 2014; Marlina et al., 2024). For example, visual learners benefit from infographics on fire mechanisms; auditory learners from discussions on local customs; and kinesthetic learners from building simple smoke detectors using local materials. Figure 8 highlights critical thinking indicators: 83.5% attempted to identify causes of environmental problems, and 77.6% proposed personal solutions, demonstrating analysis and evaluation skills (Ennis, 1987). However, only 61% could compare solutions effectively, indicating a need for structured debate and evidence-based tasks. Students explicitly requested more practical work (70%) and clearer theory explanations (65%), with one stating: *"More practice and real applications, please."* This aligns with Astuti et al. (2021), who emphasize inquiry-based STEM for fostering systems thinking.

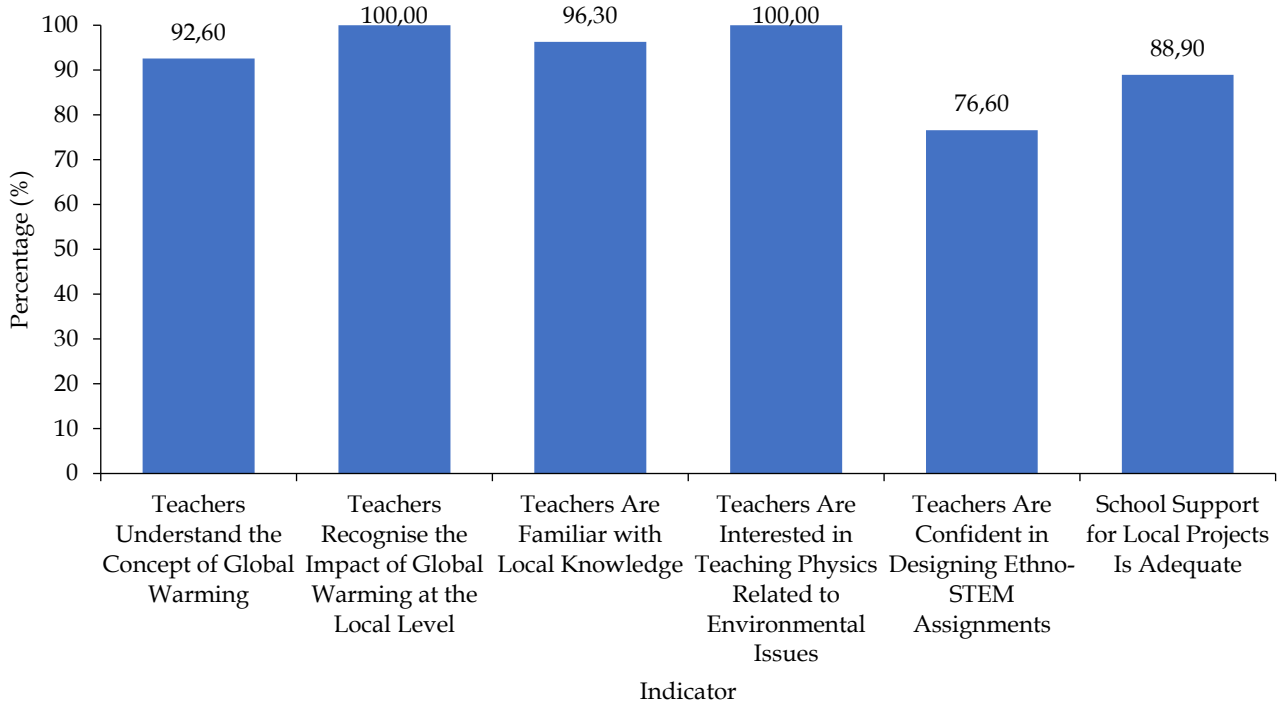

Figure 5. Teachers' understanding of global warming and awareness of local wisdom (N = 81). Nearly all teachers acknowledged local impacts (100%) and were aware of customary prohibitions against forest burning (96.3%), indicating strong potential for Ethno-STEM integration

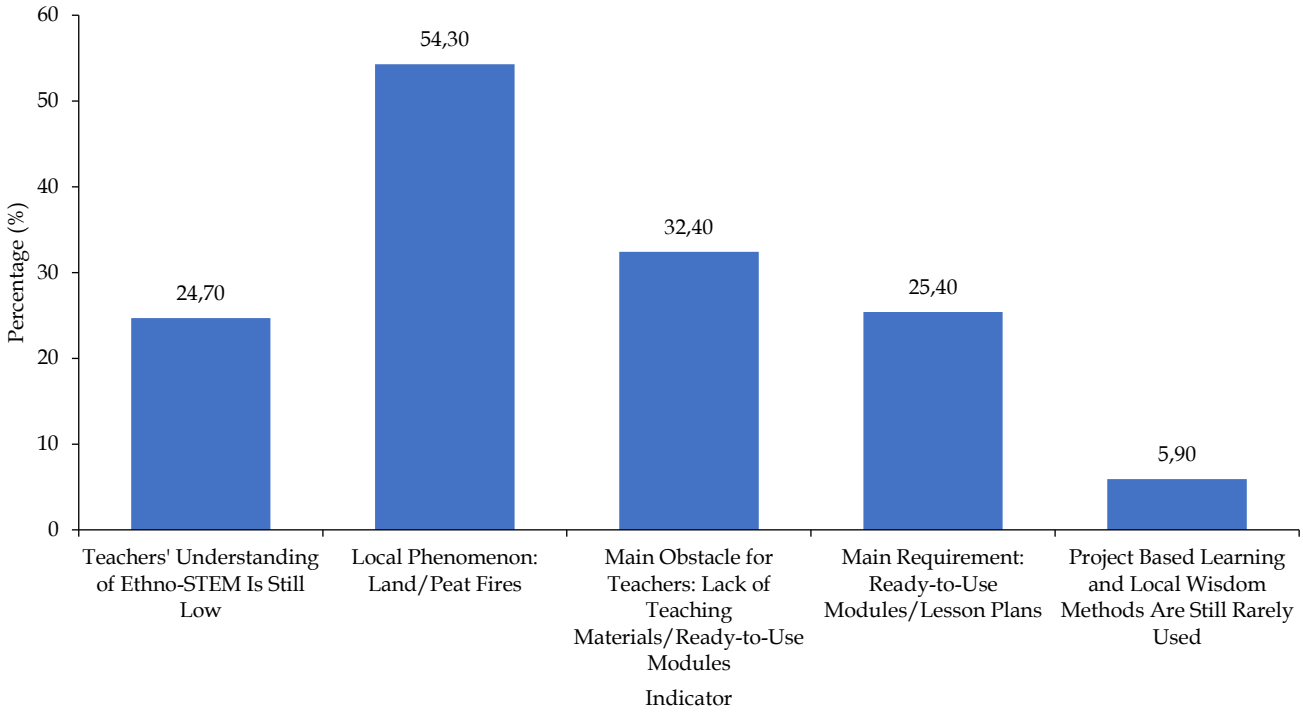

Figure 6. Barriers to implementing Ethno-STEM among physics teachers (N = 81). Despite universal interest (100%), only 24.7% had implemented it. The main obstacles were lack of ready-to-use modules (32.4%) and limited curriculum time (27.0%)

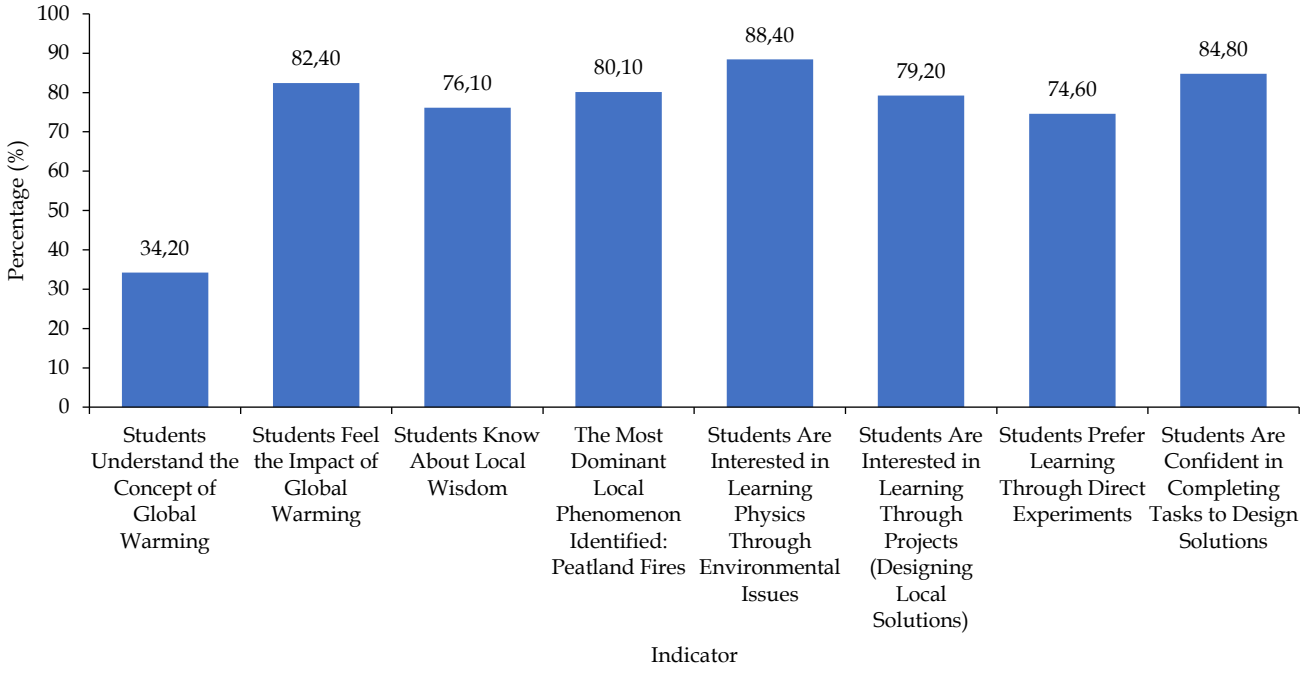

Figure 7. Learning preferences and styles of high school students (N = 1,118). A large majority preferred hands-on experiments (74.6%). Learning styles were diverse: 42% visual, 31% auditory, and 27% kinesthetic, supporting the need for differentiated instruction

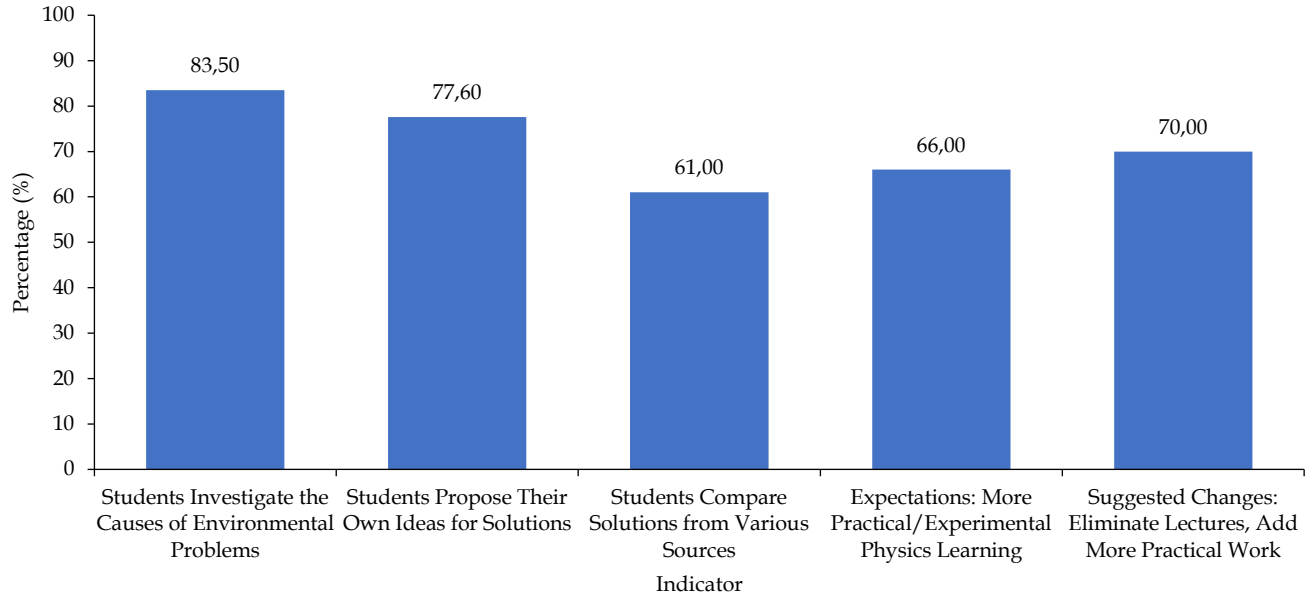

Figure 8. Critical thinking indicators and learning expectations of high school students (N = 1,118). Most students could identify causes (83.5%) and propose solutions (77.6%) to environmental problems, but only 61% could compare solutions effectively. Additionally, 70% requested more practical work and fewer lectures

These findings collectively reveal a strong demand for a differentiated, project-based, Ethno-STEM physics module on global warming. Teachers possess cultural capital and motivation but lack resources; students show high interest and confidence in designing solutions but need scaffolded activities to enhance higher-order thinking. The integration of local projects (e.g., simulating peatland water conservation), multiple learning pathways, and critical thinking assessments would directly address the identified needs across all figures. Such a design aligns with the Merdeka Curriculum's emphasis on authenticity, student agency, and contextual learning (Kemendikbudristek, 2022). Moreover, it responds to recent calls for culturally responsive science education that bridges formal knowledge and local wisdom (Setiawan et al., 2021; Nurhasnah et al., 2022; Rochman et al., 2018; Fitriani et al., 2023; Nugroho et al., 2023; Prasetyo et al., 2023). The proposed module also reflects best practices in STEM education, where project-based approaches have been shown to significantly improve environmental literacy and systems thinking (Aji et al., 2024; Halawa et al., 2024). Furthermore, differentiation based on learning styles is essential for equitable access to complex scientific concepts, as demonstrated by Winarto et al. (2025) in Indonesian senior high schools. Future module development should therefore adopt a Design-Based Research framework to ensure validity, practicality, and effectiveness in real classroom settings (Afriana et al., 2016; Akhsan et al., 2024).

Conclusion

This study reveals a significant gap between the high awareness of global warming and the current practice of physics teaching in South Sumatra's senior high schools. While 100% of teachers express interest in Ethno-STEM and 88.4% of students are interested in learning through environmental issues, only 24.7% of teachers have implemented it, primarily due to the lack of ready-to-use modules (32.4%) and limited curriculum time (27.0%). Students exhibit diverse learning preferences, with 74.6% favoring hands-on experiments, and demonstrate promising critical thinking skills—83.5% can identify causes of environmental problems—but only 61% can compare solutions effectively. These findings provide strong empirical justification for developing a differentiated, project-based, Ethno-STEM physics module that integrates local wisdom (e.g., forest fire prohibitions), responds to varied learning styles (visual, auditory, kinesthetic), and scaffolds higher-order thinking. Such a module would align with the Merdeka Curriculum and bridge the gap between contextual relevance and pedagogical practice.

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Author Contributions
Conceptualization and methodology, formal analysis and data curation, writing–original draft preparation, H.A.; software and validation, I. and K.; writing–review, K.; supervision, I.

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Conflicts of Interest
The authors declare that there is no conflict of interest in this article.

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