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EXPLORING THE ESD-INTEGRATED PHYSICS E-MODULES NEEDS OF CULTIVATING HIGH SCHOOL STUDENTS' SUSTAINABILITY AWARENESS ABOUT GLOBAL WARMING IN WETLAND ECOSYSTEMS

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ABSTRACT

The rapid advancement of technology and the pressing challenges of global warming demand innovative approaches in physics education to foster students' sustainability awareness. However, current learning practices often fail to integrate these aspects effectively, creating a critical gap that must be addressed. The aim of this research is to identify the gaps in technology integration, sustainability awareness, and teaching materials in the context of physics education. This study employed a descriptive quantitative method involving 45 high school students and 3 physics teachers from a state high school in Ogan Komering Ulu Timur, as well as relevant teaching documents. Data were collected through questionnaires, document studies, and sustainability awareness assessments, and analyzed using descriptive statistics. The results revealed low integration of technology in physics learning, limited sustainability awareness among students, and insufficient alignment of teaching materials with sustainability topics. These findings underscore the urgent need for the development of ESD-integrated physics e-modules that bridge these gaps. It is concluded that such e-modules could significantly enhance students' understanding of global warming and its impact on wetland ecosystems, and the study recommends further development of technology-based teaching tools, teacher training programs, and the creation of relevant educational materials to improve sustainability awareness among students.

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1. INTRODUCTION

Global warming has emerged as one of the most pressing environmental challenges of the 21st century, significantly impacting ecosystems and human livelihoods worldwide (Upadhyay 2020; Bandh et al. 2021; Abbass et al. 2022). Among the ecosystems most vulnerable to climate change are wetlands, which play a critical role in carbon sequestration, flood regulation, and biodiversity conservation (Taillardat et al. 2020; Eller et al. 2021; Ye et al. 2022). However, these vital ecosystems are increasingly threatened by rising temperatures, changes in precipitation

patterns, and human activities such as deforestation and urbanization. Wetlands' degradation leads to the release of stored carbon, contributing further to global warming, as highlighted by Yang et al. (2022), who documented significant carbon loss from disturbed wetlands. Despite their ecological significance, awareness of wetlands' role in mitigating climate change remains low, particularly among younger generations (Alikhani et al. 2021). Addressing this gap requires targeted educational interventions that emphasize sustainability and the interconnectedness of global environmental issues.

Education for Sustainable Development (ESD) provides a holistic and integrative approach to equip learners with the knowledge, skills, and attitudes necessary to address complex sustainability challenges (Glavič 2020; Kjellgren & Richter 2021; Ferguson et al. 2022; Kougias et al. 2023). By linking global phenomena such as climate change with local environmental contexts, ESD fosters critical thinking and problem-solving skills among students (Shutaleva 2023). However, integrating ESD into subject-specific curricula, particularly physics, remains underexplored. Rahmawati et al. (2020) demonstrated that incorporating local environmental examples in physics education enhances students' engagement and conceptual understanding. Nevertheless, current physics curricula often fail to connect theoretical concepts to real-world environmental issues because sustainability topics are rarely integrated into lesson plans, teaching materials remain focused on abstract formulas rather than contextual applications, and teachers lack sufficient training to embed ESD principles (Irving et al. 2020). This disconnection underscores the need for innovative teaching resources, such as ESD-integrated physics e-modules, that bridge the gap between theoretical learning and practical application.

Traditional physics education often struggles to relate abstract scientific concepts to tangible environmental issues like global warming (Prayogi & Verawati 2024). Research conducted by Mahardika (2022) indicates that students frequently experience difficulties in understanding the connections between physics concepts and real-world environmental phenomena, particularly in ecosystems such as wetlands. E-modules, or digital learning materials, have shown significant potential in addressing these challenges. Studies by Lestari & Atun (2021) emphasize the effectiveness of e-modules in promoting self-regulated learning, while Serevina et al. (2022) highlight their role in improving accessibility and engagement, particularly during distance learning scenarios. These digital tools, when aligned with ESD principles, can contextualize physics concepts within global and local environmental challenges, such as the role of greenhouse gases in global warming, enabling students to better understand their relevance and implications (Malavoloneque & Costa 2022).

Developing effective ESD-integrated e-modules requires a thorough understanding of the needs of both students and teachers. Variability in students' awareness and preparedness regarding sustainability issues often stems from differences in socio-economic, cultural, and geographical contexts (Urbańska et al. 2022). Teachers, on the other hand, frequently lack access to resources and training necessary to integrate ESD effectively into their teaching practices. Lowell & Moore (2020) underscores the importance of participatory approaches in designing educational materials, ensuring alignment with the real-world challenges and contexts of learners. This study, therefore, seeks to explore these needs, particularly in regions like wetlands where students and educators face unique environmental challenges. Understanding these perspectives will inform the design of e-modules that are not only scientifically accurate but also culturally and contextually relevant.

This study seeks to explore the needs for ESD-integrated physics e-modules designed to cultivate high school students' sustainability awareness regarding global warming and wetland ecosystems. Previous research by Wamsler (2020) highlights the transformative potential of integrating sustainability principles into science education, which this study aims to build upon. By addressing gaps in existing teaching resources and methodologies, this research contributes to the development of localized, participatory, and context-sensitive educational materials. These resources empower students to connect theoretical knowledge with practical applications, fostering proactive behaviors and collective resilience. Furthermore, this study emphasizes the importance of collaboration between educators, policymakers, and community stakeholders to ensure scalable and sustainable impacts. By equipping students with the knowledge and skills necessary to understand and protect critical ecosystems like wetlands, this research aligns with global sustainability goals and supports the development of future generations capable of navigating complex environmental challenges.

2. METHOD

The research undertaken is a quantitative descriptive study with a focus on product development. This method was chosen because it allows researchers to obtain a systematic description of existing conditions and educational practices, making it appropriate for identifying gaps between curriculum, student awareness, and technology use (Creswell & Creswell 2017). In the initial phase, a comprehensive needs analysis was conducted involving three primary objects of investigation: three high school physics teachers from a state high school in Ogan Komering Ulu Timur Regency, 45 tenth-grade students, and a collection of teacher-related documents, including teaching modules and records measuring students' sustainability awareness levels. The sample was selected purposively to include teachers as implementers of the curriculum, students as primary beneficiaries, and teaching documents as the instructional foundation. Although relatively limited in size, the combination of teachers, students, and curriculum materials is considered sufficient for exploratory studies because it provides a holistic snapshot of current learning practices and sustainability awareness within the studied context.

Data collection was carried out utilizing carefully selected instruments and analyzed through established analytical techniques. The data collection methods employed in this study included a needs questionnaire administered to both teachers and students, document analysis, and a sustainability awareness questionnaire. The teacher and student needs questionnaires aimed to identify the integration and utilization of technology in physics education. The document analysis was used to evaluate the sustainability awareness levels of students as well as to examine the instructional modules implemented by teachers. Furthermore, the sustainability awareness questionnaire served to quantitatively measure the extent of students' awareness of sustainability, particularly in the context of the peatland ecosystem's contribution to global warming phenomena.

The data analysis process involved the application of descriptive statistical techniques. Descriptive statistics are utilized to systematically present the characteristics of the research objects based on the sample or population data, reflecting the data as it is, without performing in-depth inferential analysis or drawing generalized conclusions. The analysis involved quantitative evaluation of sustainability awareness questionnaire data.

$$\text{Mean} = \frac{\text{Total Score Obtained}}{\text{Total Score}} \text{ x } 4 \quad (1)$$

The percentage of values received during data processing is examined using the categories in Table 1 (Zulkarnaen et al., 2023).

Table 1. Categories of Students' Sustainability Awareness

Mean	Category
1,00-2,00	Low
2,01-3,00	Medium
3,01-4,00	High

3. RESULTS AND DISCUSSION

3.1 Analysis Results of Technology Integration in Physics Learning

The integration of technology into physics learning has become a pivotal component in enhancing educational outcomes, particularly in addressing sustainability awareness among students. This results provide insight into the current state of technology adoption and its alignment with Education for Sustainable Development (ESD) principles in cultivating awareness about global warming and wetland ecosystems. To evaluate the current state of technology use in physics learning, data were collected on various aspects, including digital tools, online resources, simulations, and the incorporation of sustainability themes. The findings indicate that the level of technology integration is significantly low, highlighting the need for innovative, technology-based educational solutions in Figure 1.

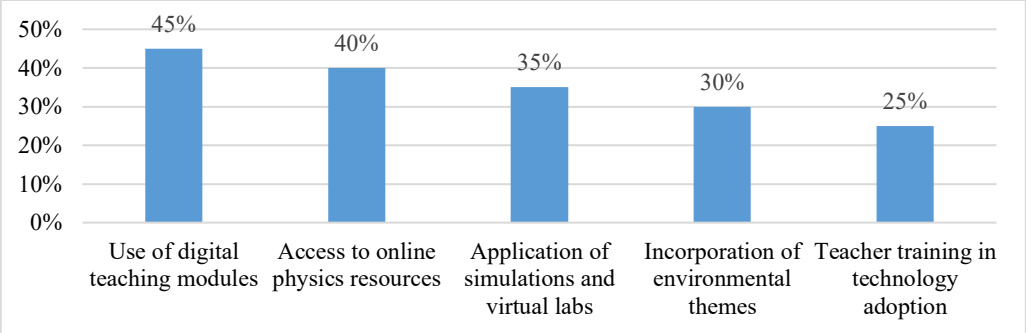

Figure 1. Technology Use in Physics Learning

Figure 1 reveals alarmingly low levels of technology integration across all evaluated aspects, indicating significant barriers to achieving effective and modern physics instruction. With only 45.0% of teachers utilizing digital modules, the potential of these tools to facilitate flexible and engaging learning remains largely untapped, likely due to limited digital literacy or inadequate access to relevant resources. Access to online materials stands at just 40.0%, suggesting that internet-based platforms have not yet been fully leveraged to enrich classroom teaching. The adoption of interactive simulations and virtual labs, which are critical for fostering experiential and inquiry-based physics learning, is even lower at 35.0%, potentially restricting students'

opportunities to visualize abstract concepts. Despite the growing urgency of sustainability education, only 30.0% of lessons incorporate environmental themes, reflecting a gap between physics content and pressing real-world issues such as global warming. The lowest indicator, professional development for teachers (25.0%), points to insufficient institutional support and targeted training for educators. These findings collectively suggest that without systematic interventions such as capacity-building programs, curriculum redesign to embed sustainability, and improved infrastructure, the integration of technology and sustainability themes into physics learning will remain limited, thereby reducing the subject's relevance and impact on students' future competencies.

3.2 Analysis Results of Students' Sustainability Awareness

The analysis of students' sustainability awareness evaluates three key categories: Sustainability Practice Awareness, Behavioral and Attitude Awareness, and Emotional Awareness based on Hassan et al. (2010). The findings (figure 2) reveal varied levels of awareness, with most students scoring in the low to medium range, highlighting the need for targeted educational interventions in Table 2.

Table 2. Students' Sustainability Awareness Evaluation

Categories	Average Score	Awareness Level
Sustainability Practice Awareness	2,10	Medium
Behavioral and Attitude Awareness	1,80	Low
Emotional Awareness	2,50	Medium

Table 2 shows that students demonstrate moderate awareness of sustainable practices such as conserving energy or managing waste, yet they lack deeper understanding of how these actions connect to global environmental challenges. On behavioral and attittude awareness category highlights a significant gap in students' commitment to sustainability, reflecting a lack of actionable behaviors and attitudes that support sustainable practices. Emotional awareness, including empathy toward environmental issues and concern for future generations, scored slightly higher. However, this does not translate into consistent practices or attitudes.

3.3 Analysis Results of Teaching Materials

This section presents an analysis of the teaching materials currently used in high school physics learning. The evaluation covers various criteria, including the relevance to environmental sustainability, alignment with learning objectives, interactivity, digital accessibility, and the inclusion of real-world applications. The findings highlight significant gaps in these teaching materials, indicating the need for innovative, ESD-integrated physics e-modules in Figue 2.

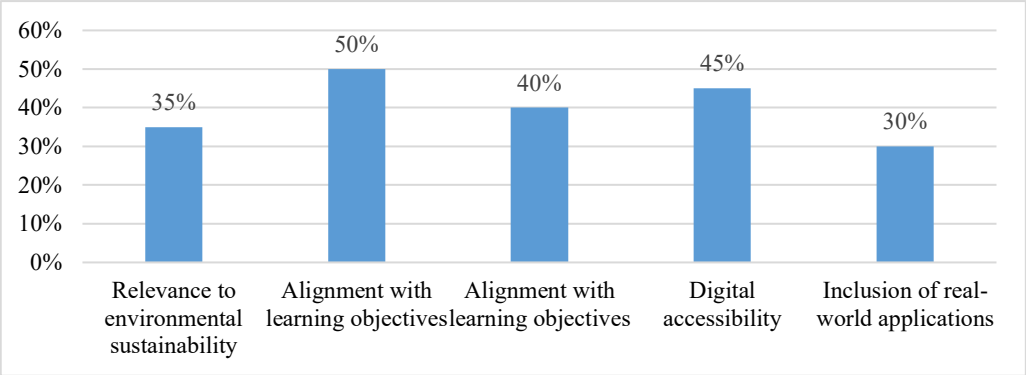

Figure 2. Evaluation of Teaching Materials

Figure 2 shows that a lack of integration between physics concepts and sustainability topics like global warming and wetland ecosystems is evident, limiting students' contextual understanding. While half of the teaching materials align with curriculum goals, the lack of depth and contextual relevance hinders effective learning. Low interactivity highlights the need for more engaging and student-centered approaches, such as simulations and multimedia content. Limited digital accessibility restricts students from leveraging learning materials anytime and anywhere, particularly in rural or under-resourced areas. Teaching materials lack real-world scenarios to help students relate physics concepts to their daily lives and environmental challenges.

3.4 Discussion

The findings of this study, as presented in Figure 1, reveal alarmingly low levels of technology integration across all evaluated aspects, indicating significant barriers to effective physics instruction. Only 45.0% of teachers reported using digital modules, and just 40.0% accessed online resources, suggesting that the potential of digital platforms to enrich and diversify learning experiences remains underutilized. Even more concerning, the adoption of interactive simulations and virtual laboratories stands at 35.0%, limiting opportunities for students to engage in experiential and inquiry-based learning. The minimal inclusion of environmental themes in lessons (30.0%) and the lowest score for professional development (25.0%) underscore systemic gaps in teacher capacity and institutional support. This corroborates findings by Chiu (2023). who asserted that inadequate technological integration diminishes the potential for creating dynamic and engaging learning environments. Furthermore, research by (Adeoye et al. (2024) emphasized that technological literacy is a cornerstone of 21st-century skills, critical for addressing global challenges like climate change. Therefore, the current findings reinforce the urgency of providing innovative and technology-based learning solutions, such as ESD-integrated physics e-modules, to bridge these gaps and enhance both student engagement and understanding.

In terms of students' sustainability awareness, Table 2 indicates that while emotional awareness scores are moderate (2.50), behavioral and attitudinal awareness is notably low (1.80), and sustainability practice awareness remains at a medium level (2.10). This pattern suggests that although students express empathy and concern for environmental issues, these sentiments are not translating into consistent pro-sustainability behaviors. This result is consistent with findings by Howell (2021), who reported that while students often express concern for environmental issues, their actions and attitudes towards sustainable practices remain underdeveloped. Such gaps are

particularly concerning in the context of climate change and wetland ecosystems, where immediate and informed action is critical. Previous research by Algurén (2021) supports this observation, highlighting that integrating sustainability themes into the curriculum fosters not only cognitive understanding but also behavioral transformation. The findings of this study underscore the need for an educational intervention that connects theoretical physics concepts to actionable knowledge and attitudes, promoting sustainability as a practical and relevant aspect of students' lives.

The evaluation of teaching materials, summarized in Figure 2, further confirms the disconnect between physics content and sustainability contexts. Although around half of the materials align with curriculum objectives, they remain largely theoretical, with low interactivity and limited digital accessibility, especially for rural or under-resourced students. The near absence of contextual links to global warming or wetland ecosystems represents a missed opportunity to connect physics learning with real-world environmental challenges. This aligns with Subramaniam (2020), who emphasized the importance of place-based education in making learning more meaningful by linking academic content to students' local and cultural contexts. In the case of this study, the absence of materials addressing the interconnection between physics and global warming in wetland ecosystems demonstrates a missed opportunity to integrate sustainability concepts effectively. Prior studies, such as those by Nguyen et al. (2020), have shown that localized teaching materials not only enhance understanding but also inspire students to address environmental issues in their own communities. The findings of this study further highlight the need for teaching materials that incorporate sustainability themes, empowering students to view physics not just as an academic subject but as a tool for addressing real-world environmental challenges.

Taken together, the results presented in Figure 1, Table 2, and Figure 2 highlight intersecting gaps in technology usage, sustainability awareness, and teaching material design. Addressing these gaps through the development of ESD-integrated physics e-modules could simultaneously improve digital engagement, foster actionable sustainability competencies, and provide contextualized learning experiences. As shown by Haleem et al. (2022) demonstrated that digital resources specifically designed for sustainability education significantly enhance students' engagement and understanding of environmental issues. Similarly, research by Shrivastava et al. (2020) found that integrating sustainability into science education positively impacts students' cognitive and emotional connection to global issues. Building on these insights, this study suggests that the development of ESD-integrated e-modules tailored to the unique challenges of wetland ecosystems can play a pivotal role in fostering sustainability awareness, bridging the gap between theoretical knowledge and practical application.

In conclusion, this study strongly supports the integration of ESD principles into physics education as an essential innovation for addressing the multifaceted challenges of sustainability. By improving technology utilization, enhancing sustainability awareness, and enriching teaching materials, ESD-integrated physics e-modules have the potential to transform learning environments. They offer a pathway for equipping students with the skills, attitudes, and knowledge required to address pressing environmental issues, particularly those linked to vulnerable ecosystems like wetlands. Prioritizing the development and implementation of such modules aligns with global educational priorities and ensures that future generations are better prepared to navigate and mitigate the complex challenges posed by climate change.

4. CONCLUSION

The findings show that technology use in physics learning remains low, with limited application of digital modules, online resources, and interactive simulations, compounded by minimal teacher training for effective implementation. Students demonstrate moderate levels of emotional and practice-based sustainability awareness, but their behavioral and attitudinal awareness is still lacking, indicating that concern for environmental issues has not yet translated into consistent action. Current teaching materials are heavily theoretical, offer low interactivity, have limited digital accessibility, and provide little connection between physics concepts and real-world environmental challenges such as global warming and wetland conservation.

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