Contextual Socio-Scientific Issues and Education for Sustainable Development (SSI-ESD) Climate Change Module: Improving Chemical Literacy and Environmental Awareness among High School Students in Ketapang, Indonesia

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Abstract: This study investigates the effectiveness of a contextual Socio-Scientific Issues and Education for Sustainable Development (SSI-ESD) learning module on climate change in enhancing students' chemical literacy and environmental awareness. A quantitative quasi-experimental design was employed, involving 143 tenth-grade students from public secondary schools in Ketapang Regency, Indonesia, assigned to experimental and control groups through class-based random sampling. Data were collected using a validated chemical literacy test and an environmental awareness questionnaire, and analyzed using Multivariate Analysis of Variance (MANOVA). The results revealed significant multivariate and univariate differences between the two groups, favoring the experimental group. The intervention produced a moderate effect size ($\eta^2 = 0.127$), indicating that contextual SSI-ESD learning improved students' conceptual understanding and pro-environmental attitudes. The module created meaningful connections between abstract chemistry concepts and students' real-world experiences by integrating local environmental issues such as forest fires and haze. This study provides novel evidence that locally contextualized SSI-ESD modules can strengthen chemistry education in Indonesia while embedding sustainability values, offering implications for curriculum development, teacher training, and education policy.

Introduction

Education in the Indonesian context, particularly through the implementation of the Merdeka Curriculum, emphasizes the development of competencies relevant to contemporary challenges (Lubis et al., 2023; Saa, 2024). In chemistry education, these competencies translate into the need for strengthened scientific and chemical literacy, as students are expected to analyse environmental phenomena, interpret data, and apply chemical reasoning to real-world problems such as climate change and pollution (Turiman et al., 2012). Chemical literacy enables students to apply chemical knowledge and reasoning in real-life contexts, particularly in addressing global and local environmental challenges (Wei & Chen, 2017).

However, various studies reveal that Indonesian students often demonstrate only nominal literacy in basic chemical concepts and struggle with higher-order literacies such as conceptual, functional, and multidimensional chemical literacy (Celik, 2014; Fahmina et al., 2019; Raub et al., 2017). Previous studies have also highlighted that chemistry instruction prioritizes cognitive achievement over affective and behavioral domains, resulting in limited development of students' environmental awareness (Ridha et al., 2020). This gap is critical, as environmental awareness, defined as individual attitudes and actions toward maintaining a

clean, healthy, and sustainable environment, is increasingly necessary to address contemporary issues such as climate change and resource degradation (Cahyani & Utami, 2025). This limitation has been attributed to traditional instructional methods prioritizing rote memorization over conceptual understanding, contextual relevance, and problem-solving skills (Anugrah et al., 2017; Fuadi et al., 2020).

Conventional instruction in chemistry, which often emphasizes rote learning and isolated experiments, has proven insufficient in fostering meaningful connections between scientific concepts and socio-environmental contexts (Ahmad et al., 2023; Musengimana et al., 2021). While innovative approaches such as inquiry-based and discussion-based learning can increase engagement, they frequently lack explicit connections to socio-scientific issues (SSI) and sustainability principles (Sanchez et al., 2024; Shulla et al., 2020). This highlights the need for contextual learning frameworks that directly integrate scientific content with real-world issues.

Socio-Scientific Issues (SSI) and Education for Sustainable Development (ESD) offer a promising pathway to address this gap. SSI introduces students to controversial and socially relevant issues, strengthening their scientific reasoning, ethical evaluation, and decision-making skills (Rahayu, 2019; Suparman et al., 2022). Meanwhile, ESD emphasizes sustainability values across environmental, economic, and social dimensions, encouraging learners to become responsible citizens (Juntunen & Aksela, 2014). Studies indicate that integrating SSI and ESD can enhance both scientific understanding and environmental awareness (Dina et al., 2024; Hanifha et al., 2023).

The local context of Ketapang Regency, West Kalimantan, illustrates the urgency of such integration. The region faces recurring forest fires, haze, and land degradation, which provide authentic entry points for contextualizing chemistry topics such as combustion reactions and climate change. Ketapang is therefore a particularly appropriate and meaningful research site because the region regularly experiences forest fires and haze pollution, which have substantial impacts on air quality and public health. The occurrence of haze is directly linked to key chemistry concepts, particularly complete and incomplete combustion reactions that generate CO_2, CO, and particulate matter, contributing to greenhouse gas emissions and atmospheric degradation.

Contextualising instruction using real cases of forest fires in Ketapang, students are able to observe firsthand how combustion processes relate to the environmental issues they encounter on a yearly basis. This contextual integration enhances the meaningfulness of chemistry learning, strengthens the relevance of instructional content to students' daily lives, and deepens their understanding of the connection between chemical processes and environmental consequences. For these reasons, Ketapang provides a highly suitable setting for implementing SSI–ESD–based instruction, especially for teaching climate change concepts and combustion reactions. Embedding these issues in a structured learning module allows students to connect abstract concepts with tangible local problems while fostering responsibility for environmental sustainability (Aubrecht et al., 2019; Karpudewan, 2020). Despite this potential, research examining the combined influence of SSI and ESD-based modules on chemical literacy and environmental awareness in Indonesian high schools remains limited.

This study addresses this gap by implementing a contextual learning module based on SSI and ESD, focusing on climate change and environmental issues specific to Ketapang Regency. This study investigates the effectiveness of a contextual SSI-ESD-based learning module on climate change in improving students' chemical literacy and environmental awareness. By contextualising chemical concepts such as combustion and climate change

within issues that students directly experience, the study provides a locally relevant and place-based instructional model. Furthermore, the dual measurement of chemical literacy and environmental awareness represents a novel approach, offering a more comprehensive understanding of how contextualised SSI–ESD learning influences both cognitive and affective dimensions of student development. Together, these elements highlight the study's originality and its potential to inform future curriculum design in regions facing similar environmental challenges.

Research Method

The study used a quantitative approach with a quasi-experimental design with a non-equivalent pre-test post-test control group. Conducted at SMA Negeri 3 Ketapang, West Kalimantan, during the even semester of the 2024/2025 academic year, the research involved four tenth-grade classes (X-D, X-F, X-I, and X-J) selected through a random sampling technique (Creswell, 2009). Initial equivalence of the classes was established using ANOVA tests on students' midterm chemistry scores, with normality and homogeneity confirmed via Shapiro-Wilk and Levene's tests before assigning two classes as the control and experimental groups.

Data collection involved both test and non-test methods: chemical literacy was assessed using a problem-based essay test contextualized to real-life climate-related issues such as deforestation, emissions, and microplastics, while environmental awareness was measured through a Likert-scale questionnaire evaluating knowledge, attitude, and behavior. Both instruments were validated using Rasch modeling via Winsteps 3.73, with reliability confirmed through Cronbach's alpha and person-item separation indices. The experimental group was taught using a self-instructional module integrating SSI-ESD, contextualizing local issues like forest fires, waste management, and mining pollution in Ketapang. In contrast, the control group used a module based on the scientific approach that was aligned with the Merdeka Curriculum.

Instruction occurred over five meetings for both groups. Data analysis employed descriptive and inferential statistics, with normalized gain (N-gain) calculated to assess learning improvement. In this study, normalized gains (N-gain) were calculated at the individual level to capture the extent of improvement for each student between the pre-test and post-test. The individual N-gain values were then used not only for descriptive interpretation but also for inferential analysis. Specifically, the distribution of N-gain scores was subjected to a normality test to determine the appropriate subsequent statistical procedures. This approach ensures that the analysis reflects both the magnitude of learning improvement and the statistical robustness required for comparing learning outcomes across groups.

Multivariate Analysis of Variance (MANOVA) was used to evaluate the intervention's effect on chemical literacy and environmental awareness, followed by univariate tests for individual outcomes. Effect sizes were assessed using partial eta squared (η^2), with interpretations guided by the criteria proposed by Richardson (2011). According to these thresholds, η^2 values of approximately 0.0099 indicate a small effect, values around 0.0588 represent a medium effect, and values near 0.1379 reflect a large effect. These benchmarks were used to categorize the magnitude of the observed effects and to complement the statistical significance of the findings. Before analysis, MANOVA assumptions, including normality, homogeneity, linearity, multicollinearity, and the absence of outliers, were rigorously tested to ensure the validity of the findings.

Result and Discussion
Assumption Testing MANOVA

This study utilised a MANOVA (Multivariate Analysis of Variance) to examine the effect of the independent variable, namely, implementing a contextual SSI-ESD-based learning module, on the dependent variables, namely, chemical literacy and environmental awareness. Before conducting the hypothesis testing, several statistical assumptions required for MANOVA were tested. The dependent variables (chemical literacy and environmental awareness) were measured on an interval scale and classified as continuous data. The independent variable consisted of two categorical groups: an experimental group that received a contextual SSI-ESD-based climate change module and a control group that used a scientific approach-based module. The data were collected independently, meaning participants in each group were mutually exclusive and not involved in both interventions. The sample size was adequate, consisting of 72 students in the control group and 71 in the experimental group. Furthermore, no extreme values were found for univariate and multivariate outlier analysis, as confirmed by the box plots in Figure 1.
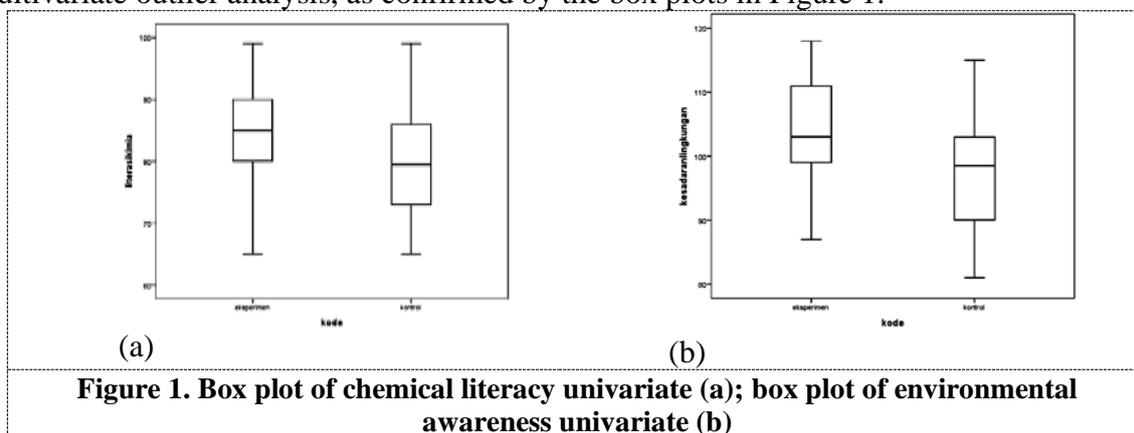

(a)   (b)

Figure 1. Box plot of chemical literacy univariate (a); box plot of environmental awareness univariate (b)

Table 1. Normality Test Using Shapiro-Wilk

Shapiro-wilk test		Sig.
Chemical Literacy	Control group	0.338
	Experimental group	0.136
Environmental Awareness	Control group	0.122
	Experimental group	0.356

Normality for univariate data was tested by using the Shapiro-Wilk test. The results are shown in Table 1. Table 1 indicates that the data are normally distributed (p > 0.05). The multivariate test is supported by a Mahalanobis distance vs. chi-square plot with an R2 value of 0.969, showing strong linearity and the absence of multivariate outliers, as presented in Figure 2. Based on Figure 2, a test was conducted to assess the normality of the data. The analysis showed an R^2 value of 0.969, suggesting that the data can be considered normally distributed as multivariate. The next one for the assumption of homogeneity of the variance-covariance matrix is shown in Table 2.
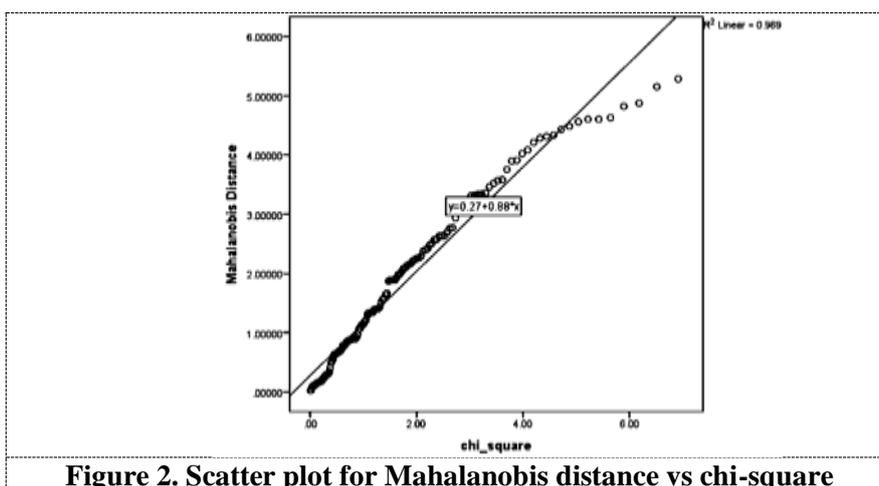
Figure 2. Scatter plot for Mahalanobis distance vs chi-square

Table 2. Box's M test

Box's M	F	df1	df2	Sig.
3.216	1.055	3	3594626,589	0,367

Based on Table 2, it was concluded that the data come from populations with a homogeneous variance-covariance matrix, as indicated by the significance value of Box's Test, which was 0.367 (greater than 0.05). Other assumptions were also verified, such as linearity between the dependent variables, which was confirmed through scatterplot visualization, which revealed a linear relationship suitable for multivariate testing. Multicollinearity was examined through a correlation matrix, which showed moderate correlations between variables, indicating no risk of redundancy. The study's design ensured the independence of observations, where participants were randomly assigned to non-overlapping experimental and control groups. While not all assumptions are discussed in detail, these checks collectively support the appropriateness of using MANOVA in this study.

Differences in Chemical Literacy and Environmental Awareness

This analysis examines whether implementing a contextual SSI-ESD-based learning module significantly affects students' chemical literacy and environmental awareness compared to conventional instruction. The null hypothesis posits no significant difference between groups. Based on MANOVA results, as shown in Table 3, the learning module has a significant multivariate effect on the combined dependent variables. These results suggest the intervention.

Table 3. MANOVA test Hotelling's Trace & Roy's Largest Root

Effect	Value	Sig.	Partial eta squared	Decision
Hotelling's Trace	0,167	0,000	0,127	H_0 rejected
Roy's Largest Root	0,167	0,000	0,127	

Table 1 shows a statistically significant multivariate effect in favor of the experimental group by Hotelling's Trace, with partial eta squared 0,127, indicating a moderate effect size.

N-gain Scores of Chemical Literacy and Environmental Awareness

The descriptive statistics (Tables 4 and 5) show that the experimental group achieved a greater mean score increase than the control group.

Table 4. Chemical Literacy Mean Score

Group	N	Mean Score	Category
Control	72	0.359	Medium
Experiemental	71	0.505	Medium

Table 5. Environmental Awareness Mean Score

Group	N	Mean score	Category
Control	72	0.301	Medium
Experiemental	71	0.404	Medium

These gains indicate that the SSI-ESD-based module improved chemical literacy and environmental awareness more than the conventional scientific approach. The contextual integration of local environmental issues related to climate change likely increased student engagement and facilitated deeper understanding.

Discussion

The present study provides empirical evidence that contextual learning modules based on Socio-Scientific Issues (SSI) and Education for Sustainable Development (ESD) significantly improved students' chemical literacy and environmental awareness in climate change contexts. The MANOVA results indicated a significant simultaneous effect of the SSI-ESD-based module on students' chemical literacy and environmental awareness ($p < 0.05$). Students in the experimental group achieved higher N-gain scores in both chemical literacy (M = 0.505, medium category) and environmental awareness (M = 0.404, medium category) compared to the control group (M = 0.359 and M = 0.301, respectively). These findings demonstrate that contextual SSI-ESD learning effectively enhances both cognitive and affective domains, consistent with prior studies reporting that SSI and ESD integration promotes deeper scientific reasoning and pro-environmental attitudes (Hanifha et al., 2023; Sari & Wiyarsi, 2021; Taha et al., 2019). The partial eta squared value ($\eta^2 = 0.127$) indicates a moderate effect size, confirming that the intervention contributed meaningfully to students' outcomes. While external factors such as time allocation and students' prior experiences may also influence learning gains, the module provided a balanced integration of conceptual understanding, contextual issues, and sustainability-oriented decision-making.

Post-test scores revealed that students in the experimental group significantly outperformed their peers in the control group, confirming the positive impact of SSI-ESD contextualization on chemical literacy. The module introduced local environmental issues such as forest fires, haze, and mining activities in Ketapang Regency, which were linked to chemical concepts including combustion reactions, greenhouse gas emissions, and the carbon cycle. These local contexts supported students' argumentation, data analysis, and application of scientific reasoning. This aligns with earlier studies indicating that SSI-based instruction develops higher-order learning skills and argumentation abilities (Mamlok-Naaman & Mandler, 2020; Zidny et al., 2021). However, this study's lack of hands-on experiments limited opportunities to triangulate conceptual learning with practical evidence. Future research should consider incorporating simple laboratory activities (e.g., CO_2 emission analysis from combustion) to reinforce theoretical discussions.

The SSI-ESD-based module also significantly improved students' environmental awareness. Post-test results showed that experimental group students reported stronger pro-environmental attitudes, behaviors, and care than their peers. Discussion of local sustainability dilemmas, such as the trade-offs between the economic benefits of palm oil expansion and its ecological consequences, encouraged reflection on ethical, social, and environmental dimensions. These findings corroborate the role of ESD in embedding sustainability values into science education (Juntunen & Aksela, 2014; UNESCO, 2017). The integration of local issues was particularly impactful. It enabled students to connect abstract chemical knowledge with their realities, reinforcing scientific understanding and environmental responsibility.
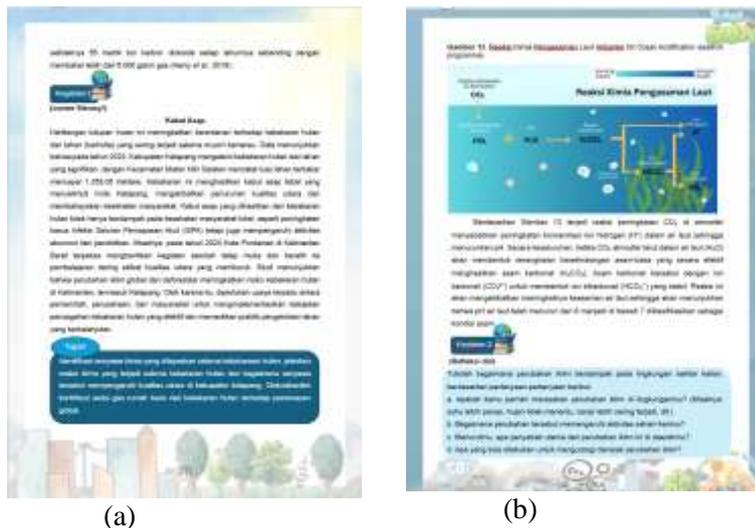
(a)　　　　(b)

Figure 3. **Differences in instructional context between the experimental group (a) local contextualization and the control group (b) general context**

The study's reliance on contextualized local content is a critical factor. Recent reviews highlight that climate change is by far the most common environmental socioscientific issue in science education research (Kumar et al., 2024). By contrast, our intervention centered on issues very salient to Ketapang (Borneo) residents, e.g., peatland and forest fires that cause transboundary haze, and the local impacts of mining. Embedding learning in these authentic contexts made the chemistry content more meaningful and engaging. Indeed, the educational literature emphasizes that connecting science topics to students' daily lives and community issues boosts motivation and relevance. For instance, a case study of Indonesian science teachers found that using daily-life contexts (especially societal and environmental problems) is a common way to engage students, even if teachers often under-utilize these contexts for deeper discussion. Broader research also argues that curriculum should be tied to socially relevant questions and SSIs to enhance students' interests and civic scientific literacy (Nida et al., 2021). Our results support this view by leveraging the local haze/fire crisis as a socio-scientific context; students could see the direct application of chemistry (atmospheric reactions, combustion) to real environmental crises. This approach is also explicitly endorsed by Indonesia's new curriculum guidelines; for example, the national Merdeka Curriculum mandates that chemistry teaching "establish connections between chemistry concepts and global warming." (Tang, 2024). In Ketapang, discussing local peat burning adds an even stronger contextual hook to the global concept of climate change.

Considering the sustainability education theory, including local case studies, is of particular value. Socio-scientific reasoning and environmental literacy both benefit from culturally relevant cases. As the review by Kumar et al. (2024) suggests, examining SSIs through the lens of local cultural and value systems remains underexplored. Our study fills this gap by showing that place-based SSIs can improve science understanding. It implies that environmental awareness gains are cognitive and affective. Students confronted with familiar smoke and polluted air scenes may become emotionally invested in learning the underlying chemistry.

Finally, our findings clearly affect Indonesian chemistry education policy and curriculum design, especially under the Kurikulum Merdeka (Independent Curriculum). The Merdeka Curriculum explicitly emphasizes "sustainable future-oriented learning" as a core pedagogical principle. Educators directly address this principle and the broader goals of

Education for Sustainable Development (ESD) that the Indonesian Ministry of Education endorses by integrating SSIs on climate and local environment into chemistry lessons. In practice, chemistry teachers can develop Merdeka-style modules (such as the forest-fire/haze unit) that link existing chemistry standards to Sustainable Development Goals. For example, our approach resonates with calls for green chemistry and ESD materials in Indonesian high schools (Widyawati et al., 2025). Similarly, ESD frameworks note that students trained in sustainability-oriented curricula show marked improvement in problem-solving and ethical reasoning on environmental issues.

The findings of this study carry important conceptual and practical implications for chemistry education and sustainability-oriented pedagogy. Conceptually, the results demonstrate that SSI–ESD-based modules grounded in local environmental issues can strengthen the theoretical link between chemical literacy and environmental awareness. This reinforces the notion that scientific understanding cannot be separated from socio-environmental contexts and that contextualized learning promotes deeper conceptual integration across cognitive and affective domains. The study provides empirical support for models arguing that students construct more coherent and meaningful knowledge when chemistry concepts—such as combustion and climate change—are embedded in real-world sustainability challenges that they directly experience.

Practically, the outcomes highlight the value of designing curriculum and instructional materials that explicitly incorporate local environmental problems as learning contexts. Teachers can adopt SSI–ESD modules to enhance student engagement, promote relevance, and foster environmentally responsible decision-making. The module developed in this study offers a replicable instructional model that schools in regions facing similar environmental issues can implement to improve both scientific understanding and environmental consciousness. Additionally, the positive learning outcomes suggest that policymakers and curriculum designers should consider integrating contextualized SSI–ESD approaches more systematically within national chemistry curricula, particularly in areas vulnerable to ecological hazards such as forest fires and haze.

Conclusion

The conclusions obtained from the findings of this study are as follows. First, the findings revealed a significant difference in chemical literacy and environmental awareness between students taught with the contextual SSI-ESD-based module and those who were not. Students in the experimental group consistently achieved higher post-test scores and N-gain values, indicating that contextual integration of socio-scientific issues and sustainability principles provided meaningful improvements in cognitive and affective domains. Second, the effectiveness test showed a moderate effect size (partial eta squared = 0.127), confirming that the SSI-ESD-based module had a substantial and educationally relevant impact on students' outcomes. These findings demonstrate that contextual SSI-ESD learning is an effective strategy for enhancing scientific understanding and promoting pro-environmental attitudes in chemistry education, particularly within local issues such as those faced in Ketapang Regency.

A key strength of this research lies in its contextualization of local environmental issues in Ketapang Regency, such as forest fires, haze, and mining activities, into chemistry learning. This approach improved students' comprehension of abstract scientific concepts like combustion and greenhouse gases and encouraged them to engage in socio-scientific reasoning, ethical reflection, and sustainability-oriented decision-making. Such outcomes

align with the objectives of the *Merdeka Curriculum* and global agendas for sustainability education, reinforcing the importance of localised SSI-ESD modules in science classrooms.

Recommendation

Future research should extend the implementation period to examine long-term impacts on students' knowledge, attitudes, and behaviour related to sustainability. Inquiry-based laboratory activities would also strengthen the connection between theoretical knowledge and practical experience. Comparative studies across different regions in Indonesia could provide broader insights into how local contexts shape the effectiveness of SSI-ESD learning. Additionally, teacher professional development programs are recommended to support the wider adoption of SSI-ESD modules in chemistry classrooms and align them with the objectives of the *Merdeka Curriculum*. For teachers, follow-up actions include receiving training on designing SSI-ESD-oriented lesson plans, integrating local environmental issues into chemistry topics, and conducting classroom assessments that emphasise real-world problem-solving. Teachers are also encouraged to collaborate through professional learning communities to share best practices, adapt SSI-ESD materials to diverse school contexts, and continuously reflect on instructional strategies to improve students' literacy and environmental awareness.

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