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Indigenous Natural Dye Microlearning for Climate Education: An Indoor and Outdoor Learning Approach to Promote Students' Climate Action Intention

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Abstract: Climate change education requires pedagogical approaches that connect environmental knowledge with concrete sustainability practices. However, climate-related topics in schools are often delivered primarily through theoretical instruction, limiting students' opportunities to translate environmental concepts into practical action. One potential strategy to address this gap is the integration of Indigenous knowledge with experiential learning. Indigenous Natural Dye practices, which utilize plant-based pigments derived from local biodiversity, represent a contextual learning resource that can connect environmental science concepts with sustainable production practices. This study investigates how an Indigenous Natural Dye microlearning model implemented through a combination of indoor and outdoor learning environments can promote students' climate action intention.

The research employed a quasi-experimental mixed-methods design involving a group of secondary school students participating in a structured microlearning program. The learning model consisted of a sequence of short instructional modules that integrated classroom-based conceptual learning with field-based experiential activities. Indoor learning sessions focused on introducing key concepts related to climate change, sustainable consumption, and environmentally friendly production systems, as well as the ecological importance of plant-based resources. Outdoor learning activities involved direct engagement with local biodiversity, including plant identification, observation of natural pigment sources, extraction and processing of plant-based dyes, and small-scale dye application practices using locally available materials. Through these activities, students were encouraged to explore the environmental implications of synthetic dyes, the sustainability potential of plant-based alternatives, and the role of local ecological knowledge in sustainable resource use.

Quantitative data were collected using a climate action intention questionnaire consisting of eight behavioral indicators related to environmental awareness, sustainable consumption, support for indigenous environmental practices, participation in environmental activities, and long-term commitment to climate action. Descriptive statistics were used to compare the mean scores of students' responses in indoor and outdoor learning contexts. Inferential statistical analysis using independent t-tests was conducted to determine whether significant differences existed between the two learning environments. Qualitative data were obtained through field observations and structured student discussions during outdoor activities and were analyzed using thematic analysis to identify recurring patterns related to students' environmental perceptions, inquiry processes, and behavioral intentions.

The results indicate that both indoor and outdoor learning environments contributed to the development of students' climate action intention. However, outdoor learning consistently produced slightly higher mean scores across most indicators, suggesting that experiential engagement with environmental practices strengthened students' motivation to participate in climate-related actions. Significant differences were found in two indicators: *Support for Indigenous Natural Dye Utilization* ($t = 2.24$, $p = 0.026$) and *Environmental Participation in Indigenous Dye Activities* ($t = 2.05$, $p = 0.041$). These findings indicate that students who participated in outdoor experiential activities demonstrated stronger support for the use of indigenous plant-based dyes and greater willingness to engage in environmental practices related to sustainable resource use. Other indicators, including energy and resource conservation intention, sustainable consumption, and long-term environmental commitment, did not show statistically significant differences between the two learning contexts, although the outdoor learning condition still showed a positive trend.

Qualitative findings further support the quantitative results. Thematic analysis revealed several key patterns in students' learning experiences. First, direct interaction with plants increased students' ecological awareness by allowing them to observe the relationship between local biodiversity and sustainable material production. Second, hands-on experimentation during pigment extraction stimulated inquiry-based thinking, as students discussed differences in color intensity, plant characteristics, and dye stability. Third, the learning activities encouraged students to reconsider everyday consumption practices by recognizing that plant-based dyes represent an environmentally friendly alternative to synthetic chemical dyes. Finally, collaborative field activities fostered a sense of collective environmental responsibility, with students expressing interest in planting dye-producing plants and maintaining green areas within the school environment.

The findings of this study provide several practical implications for climate education. First, the integration of Indigenous Natural Dye practices into microlearning modules offers an operational framework for connecting climate education with local ecological knowledge. Second, combining indoor conceptual instruction with outdoor experiential learning can create a more balanced pedagogical approach that supports both cognitive understanding and practical engagement with environmental issues. Third, the structured microlearning format enables educators to implement climate-related activities in manageable segments that can be integrated into existing science or environmental education curricula.

Overall, the results demonstrate that Indigenous Natural Dye microlearning implemented through integrated indoor and outdoor learning environments can serve as an effective strategy to strengthen students' climate action intention. By linking climate change concepts with tangible sustainability practices based on local biodiversity, this approach can contribute to the development of environmentally responsible attitudes and behaviors among students. Future research should expand the study to larger and more diverse educational settings, incorporate longitudinal designs to evaluate long-term behavioral changes, and explore the integration of other indigenous ecological practices in climate education programs.

Keywords: Indigenous Natural Dye, Microlearning, Climate Education, Indoor Learning, Outdoor Learning, Climate Action Intention

Background

Climate change education has developed rapidly in recent years in response to growing global awareness of the impacts of climate change on the environment, the economy, and human well-being (Hannigan et al., 2025; Kırca & Daglı, 2025; Wahelo et al., 2025). Educational institutions have increasingly integrated climate change issues into their curricula as part of broader efforts to strengthen environmental literacy and foster a sense of responsibility among younger generations toward the sustainability of the planet (Catling et al., 2025; Ladhar et al., 2025). Climate change education does not merely focus on scientific concepts such as global warming, carbon emissions, and environmental degradation; it also aims to cultivate environmental awareness and encourage pro-environmental behaviors among students (Ahmed & Ahmed, 2026; Lee et al., 2025; Su et al., 2026). In this context, climate change education is expected to contribute to the development of a generation that not only understands environmental challenges but is also prepared to take meaningful actions in addressing climate-related issues (Mursyid et al., 2021; Saleh et al., 2026; Weathers et al., 2025). To achieve these goals, instructional approaches in climate change education must be designed to be contextual and participatory so that students can engage with environmental issues in a more meaningful way. Various pedagogical approaches such as experiential learning, project-based learning, and contextual learning have been widely implemented to connect climate change concepts with students' everyday experiences (Ahmed & Ahmed, 2026; Hannigan et al., 2025). One approach that has gained increasing attention is the integration of indoor and outdoor learning environments, which provides students with opportunities to explore environmental phenomena directly through field-based activities. This approach not only enhances students' theoretical understanding of climate change but also enables them to observe firsthand the relationships between human activities, natural resource utilization, and their environmental consequences.

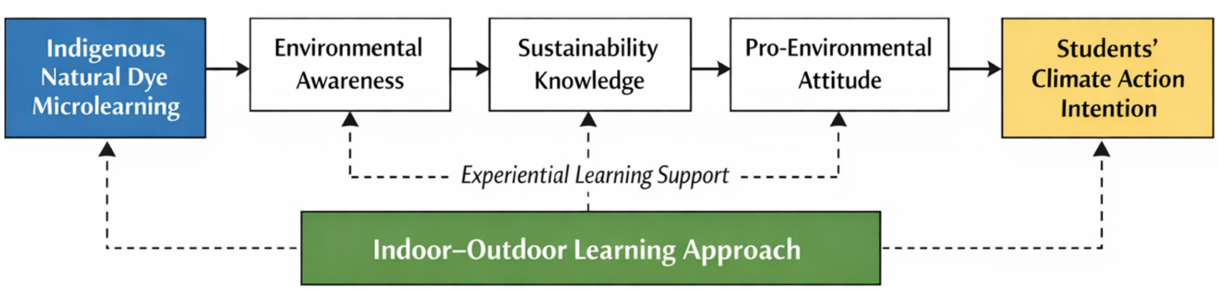
In line with this approach, the use of learning media that are closely connected to the local environment plays a crucial role in enhancing the effectiveness of climate change education (Kırca & Daglı, 2025; Ladhar et al., 2025; Mursyid et al., 2021). Learning media derived from local natural resources can help students understand sustainability concepts through more authentic and contextual learning experiences (Chen, 2025; Mayen et al., 2025). One potential medium that can be utilized is natural dyes derived from local plants, which have traditionally been used by local communities (Mayen et al., 2025; Mursyid et al., 2021). Through microlearning activities that incorporate local knowledge about natural dyes and combine indoor and outdoor learning experiences, students can explore the relationship between natural resource utilization, environmentally friendly practices, and climate change mitigation efforts. Although research on climate change education has expanded significantly in recent years, most studies have primarily focused on theory-based instructional approaches, digital technologies, or general environmental awareness campaigns (Hannigan et al., 2025; Lee et al., 2025; Saleh et al., 2026; Su et al., 2026; Wahelo et al., 2025). These approaches often fail to fully connect climate change concepts with students' real-life experiences within their local environmental and cultural contexts.

At the same time, studies on microlearning in environmental education remain largely limited to short digital content delivery, with minimal integration of hands-on or experiential learning components (Hamdani et al., 2026; Marlina et al., 2026). Furthermore, the use of indigenous knowledge particularly knowledge related to the traditional use of natural dyes from local plants has rarely been examined as a pedagogical medium for fostering awareness and action-oriented responses to climate change. Research that integrates microlearning, indigenous knowledge, and experiential learning through combined indoor–outdoor activities remains scarce within the sustainability education literature. Therefore, this study seeks to address this gap by developing a learning approach that integrates microlearning based on traditional natural dyes within an indoor–outdoor learning framework, in order to explore how such a strategy can enhance students' climate action intentions in a more contextual, participatory, and culturally grounded climate education setting.

Conceptual Framework

The conceptual framework of this study encompasses the integration of indigenous knowledge within microlearning, the indoor and outdoor learning approach in climate education, and students' climate action intention. Figure 1 presents the conceptual framework of the indoor and outdoor learning approach to promote students' climate action intention.

Figure 1: Conceptual Framework Indoor and Outdoor Learning Approach to Promote Students' Climate Action Intention



Integration of Indigenous Knowledge in Microlearning

The integration of indigenous knowledge into climate change education has increasingly gained attention as an approach to contextualize sustainability learning within local ecological and cultural practices (Filho et al., 2025;

Rudge, 2026). Indigenous knowledge systems encompass environmental understanding accumulated through long-term interactions between communities and their surrounding ecosystems. Such knowledge often reflects sustainable natural resource management practices, including the traditional use of plant-based materials, which can serve as meaningful entry points for environmental education (Bol & van Niekerk, 2024; Chapola et al., 2025; Sandilya & Goswami, 2025). In many traditional societies, natural dyes derived from local plants represent environmentally friendly alternatives to synthetic chemical dyes, illustrating how local practices embody principles of sustainability and ecological balance.

In the context of education, integrating indigenous knowledge into learning activities can enhance students' environmental awareness by linking scientific concepts with culturally relevant experiences (Çolak & Karakaya, 2026; Plohl et al., 2026; Spina et al., 2026). Rather than presenting climate change solely through abstract scientific explanations, contextual learning grounded in local practices allows students to directly observe the relationship between natural resources and sustainable livelihoods. For example, traditional knowledge regarding natural dyes derived from plants demonstrates how past communities utilized renewable biological resources without causing harmful environmental impacts (Bol & van Niekerk, 2024; Çolak & Karakaya, 2026; Mursyid et al., 2021; Rudge, 2026; Weathers et al., 2025). Such contextual examples can help students develop a deeper understanding of the ecological consequences of industrial practices and the importance of adopting more sustainable alternatives.

The emergence of microlearning as an instructional strategy has also created new opportunities for delivering culturally grounded environmental content in concise and engaging formats. Microlearning emphasizes short and focused learning units, thereby supporting more flexible and efficient knowledge acquisition (Alias & Razak, 2023; Chicué & García-Valcárcel, 2023; Hamdani et al., 2026). When local knowledge related to natural dyes is organized into microlearning modules, students can gradually explore key concepts such as plant identification, natural pigment extraction processes, and environmentally responsible material use. This approach aligns well with experiential learning processes, particularly when combined with indoor and outdoor learning activities that enable students to conduct direct observations, experiments, and reflections on ecological practices.

Furthermore, integrating plant-based natural dye knowledge into microlearning has the potential to contribute to the development of students' sustainability knowledge and pro-environmental attitudes (Mas-Normand et al., 2025). Through engagement with tangible examples of environmentally friendly practices rooted in local culture, students can develop a stronger appreciation for the sustainable use of natural resources. This process supports the broader objectives of climate change education, which extend beyond increasing knowledge about environmental issues to fostering behavioral intentions that support climate action. Therefore, the integration of local ecological knowledge within a microlearning framework offers a promising pedagogical approach for cultivating students' climate action intentions through enhanced environmental awareness, sustainability understanding, and positive environmental attitudes.

Indoor and Outdoor Learning Approach in Climate Education

Instructional approaches that integrate learning activities both inside and outside the classroom are increasingly applied in environmental education because they effectively connect theoretical concepts with real-world experiences (Arnberger et al., 2026; Proulx et al., 2026). This approach enables students to develop a deeper understanding of environmental phenomena through a combination of cognitive activities, direct observation, and exploratory experiences. In the context of climate change education, learning that focuses solely on the delivery of scientific concepts in the classroom often fails to foster strong emotional engagement and ecological awareness among students (Anjum et al., 2025; Arnberger et al., 2026; Delgado-Guerrero et al., 2025). Therefore, the integration of outdoor learning becomes an important strategy for enriching learning experiences and strengthening students' understanding of the relationship between human activities and environmental change. Outdoor learning provides students with opportunities to interact directly with the natural environment, allowing sustainability concepts to be understood through empirical experiences. Activities such as observing local plants, exploring natural resources, or conducting simple experiments enable students to connect scientific knowledge with the environmental conditions surrounding them. These direct experiences can strengthen environmental awareness and help students understand more sustainable practices in the use of natural resources. In the context of plant-based natural dye learning, environmental exploration activities allow students to identify natural dye sources, understand their utilization processes, and reflect on the ecological benefits of using natural materials compared to synthetic alternatives.

At the same time, indoor learning continues to play an essential role in developing conceptual frameworks and scientific reflection on students' field-based experiences (Kim et al., 2024; Li et al., 2023, 2023; Soomro et al., 2026). Through discussions, conceptual explanations, and reflective learning activities, students can relate their exploratory experiences to scientific knowledge about climate change, sustainability, and natural resource management. The integration of indoor and outdoor learning therefore creates a more comprehensive learning process, as students not only acquire theoretical knowledge but also directly experience practices related to environmental sustainability. When the indoor–outdoor learning approach is combined with microlearning, the learning process can become more structured and effective. Microlearning provides short and focused learning units that introduce key concepts before or after field exploration activities (Chicué & García-Valcárcel, 2023; Hamdani et al., 2026; Marlina, 2024). In this model, students first gain foundational understanding through microlearning materials in the classroom and then deepen that understanding through exploratory activities in their surrounding environment. The integration of microlearning with direct experiential learning results in a more authentic, contextual, and experience-based learning process. Such an approach remains relatively limited in climate change education research; therefore, the development of a learning model that integrates microlearning with indoor–outdoor learning activities has the potential to contribute new insights into enhancing students' environmental awareness, sustainability knowledge, and climate action intentions.

Students Climate Action Intention

Climate action intention refers to an individual's psychological readiness to engage in actions that contribute to both the mitigation of and adaptation to climate change (Geiger et al., 2021; Malecki et al., 2025; Pittaway et al., 2025; Stanley et al., 2025; Zinn et al., 2026). In the context of environmental education, this concept is often used to assess the extent to which learning processes encourage students not only to understand climate change issues cognitively but also to develop the intention to participate in behaviors that support environmental sustainability. Climate action intention is considered an important indicator because numerous behavioral studies have shown that intention is a key predictor of actual behavior across various social and environmental contexts (Geiger et al., 2021; Stanley et al., 2025). Within the framework of climate change education, the development of students' climate action intention is generally influenced by several psychological and cognitive factors, including environmental awareness, sustainability knowledge, and pro-environmental attitudes (Pittaway et al., 2025; Zinn et al., 2026). Environmental awareness helps students recognize the urgency of climate change problems and their impacts on ecosystems and human life. Sustainability knowledge provides an understanding of practices that support responsible natural resource management. Meanwhile, pro-environmental attitudes reflect individuals' tendencies to support actions aimed at protecting and preserving the environment. The interaction among these three factors plays a significant role in shaping students' willingness to participate in actions related to climate change solutions.

In the learning context, the development of climate action intention can be strengthened through learning experiences that are contextual and relevant to students' everyday lives. Learning that connects climate change concepts with local practices and direct experiences enables students to understand the relationship between human activities, natural resource utilization, and environmental sustainability (Hao et al., 2026; Jesse et al., 2026; Wiśniewski, 2020). This approach not only enhances conceptual understanding but also helps students develop an emotional connection with their surrounding environment, which can ultimately encourage the formation of intentions to engage in more environmentally responsible actions.

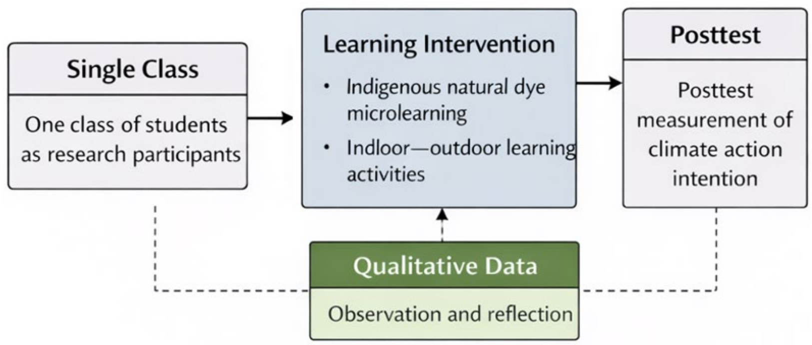
Research Method

Research Design

This study employs a quasi-experimental design with a mixed-methods approach (Pagliarino et al., 2026; Shannon-Baker et al., 2026) to evaluate the effectiveness of the Indigenous Natural Dye Microlearning model implemented through an indoor and outdoor learning approach in enhancing students' climate action intention. A quasi-experimental design was selected because the research was conducted in an authentic learning context both inside and outside the classroom without fully randomizing the participants (Brown et al., 2025; Han et al., 2026). The study adopts a one-shot case study design, in which a single class serves as the research group receiving the learning intervention (Şendur & Onursal Ayırır, 2025). In the initial stage, students participate in microlearning sessions introducing local natural dyes, implemented through both indoor and outdoor learning activities. After completing the entire learning sequence, students are given a posttest to measure changes in their climate action intention following the instructional intervention.

A mixed-methods approach is employed to obtain a more comprehensive understanding of the effectiveness of the learning model. Quantitative data are collected through posttest results that measure students' climate action intention. Meanwhile, qualitative data are obtained through observations of learning activities and students' reflections during indoor and outdoor learning sessions, aiming to capture students' learning experiences and engagement in the learning process based on indigenous knowledge related to natural dyes. The overall research design is illustrated in Figure 2.

Figure 2: Research Design



Research Participants

The total number of participants in this study was 36 students**.** Based on gender characteristics, the majority of participants were female (26 students; 72.2%), while 10 students (27.8%) were male. In terms of age, the participants ranged from 7 to 12 years old. The largest proportion was in the 9–10-year-old group (36.1%), followed by the 7–9-year-old group (33.3%), and the 10–12-year-old group (30.6%). The ethnic composition of the participants reflects the cultural diversity of West Kalimantan, with the largest groups being Dayak (33.3%) and Malay (25.0%), followed by Javanese (16.7%), Madurese (11.1%), Chinese (8.3%), and Buginese (5.6%). The detailed characteristics of the research participants are presented in Table 1.

Table 1: Research Participants (n = 36)

Characteristics	Category	Number (n=36)	Percentage (%)	Total
Gender	Male	10	27.8	100
	Female	26	72.2	
Age Range	7–9 tahun	11	33.3	100
	9–10 tahun	13	36.1	
	10–12 tahun	12	30.6	
Ethnicity	Dayak	12	33.3	100
	Malay	9	25.0	
	Javanese	6	16.7	
	Madurese	4	11.1	
	Chinese	3	8,3	
	Buginese	2	5,6	

Rationale for Sample Size

The sample size of 36 students was determined using purposive sampling based on the objectives of this field-based educational intervention study. The participants represented one intact classroom, allowing the implementation of indoor and outdoor learning activities in authentic educational settings without disrupting regular instruction. This sample size is considered adequate for exploratory and mixed-method educational research, where participant numbers between 30 and 50 are commonly used to identify educational trends and intervention effects. Furthermore, the participants represented diverse gender, age, and ethnic backgrounds, reflecting the multicultural context of West Kalimantan and strengthening the contextual relevance and applicability of the findings to climate education and sustainable.

Ethical approval for this study was formally granted by the Research Ethics Committee of Universitas Tanjungpura prior to data collection and analysis (Reference No. 4490/DST/UN22.10/AL.04/2026). The study adhered to established ethical principles for research involving human participants, including respect for autonomy, confidentiality, voluntary participation, and responsible data management. Data were collected from multiple sources, including observation sheets, publicly accessible YouTube media, and interview protocols. Before participation, all individuals were informed about the objectives, procedures, and intended use of the study. Participation was entirely voluntary, and participants had the right to decline or withdraw from the study at any stage without any negative consequences. To protect participants' privacy, all responses and collected information were anonymized during the data processing stage. No personally identifiable information was recorded, and individual statements were not linked to participants' names or other identifying characteristics. Data obtained from interviews and observations were used exclusively for academic and research purposes. Furthermore, all research data were securely stored and accessed only by authorized researchers. Data handling, storage, and analysis procedures followed institutional data protection guidelines to ensure confidentiality, integrity, and responsible use of information. These measures were implemented to maintain compliance with ethical standards and to safeguard the rights, dignity, and well-being of all participants throughout the research process.

Climate Action Intention of Indigenous Natural Dye Instrument

Students' climate action intention was measured using an instrument adapted and modified from previous studies (Malecki et al., 2025; Stanley et al., 2025; Zinn et al., 2026). The instrument development process resulted in eight final indicators, with each indicator consisting of four statements. These indicators were designed to capture various dimensions of students' intentions to engage in behaviors that support climate action and environmental sustainability. The indicators of the students' climate action intention instrument are presented in Table 2.

Table 2: Indicators of the Climate Action Intention Instrument

No	Indicator	Item Code
1	Energy and Resource Conservation Intention in Natural Dye Practices	CAI1–CAI4
2	Sustainable Consumption Intention toward Natural Dye Products	CAI5–CAI8
3	Waste Reduction and Eco-friendly Dyeing Practices	CAI9–CAI12
4	Support for Indigenous Natural Dye Utilization	CAI13–CAI16
5	Environmental Participation in Indigenous Dye Activities	CAI17–CAI20
6	Advocacy and Promotion of Indigenous Natural Dye for Climate Action	CAI21–CAI24
7	Knowledge Application and Responsible Production Behavior	CAI25–CAI28
8	Long-term Commitment to Climate-friendly Indigenous Dye Practices	CAI29–CAI32

Data Analysis

The level of students' climate action intention was analyzed using descriptive statistical categorization (Abdullahi, 2025). The mean score of students' climate action intention was calculated based on the ideal mean and ideal standard deviation approach. The instrument used in this study consisted of 32 statement items, each measured using a five-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree). Since the instrument contained 32 items, the minimum possible score was 32, while the maximum possible score was 160. Based on the calculation of the ideal mean and ideal standard deviation, the level of students' climate action intention was classified into five categories, namely: very high (>131), high (112–131), moderate (93–111), low (74–92), and very low (≤73). Inferential statistical analysis was conducted using a one-sample t-test. In addition, an independent samples t-test was applied with a significance level of $p < 0.05$ (Brown et al., 2025). A significant t-value with $p < 0.05$ indicates that the level of students' climate action intention in indoor learning and outdoor learning is statistically different. Qualitative data were analyzed using thematic analysis, with the stages of analysis presented sequentially in Table 3.

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Table 3: Stages of Thematic Analysis in Qualitative Data ((Bueno & Niess, 2023)

Analysis Stage	Brief Description of the Process	Analytical Output	Initial Code	Category	Theme
Reviewing Themes	Themes are reviewed to ensure alignment with the data and to avoid overlap between themes.	Consistent thematic structure	environmental action; inquiry	environmental protection; scientific exploration	environmental awareness; inquiry thinking
Defining and Naming Themes	The researcher defines and assigns clear names and meanings to each theme.	Research final theme	plant benefits; sustainable dye	Environmental learning; sustainable practice	Recognition of natural resources; sustainable practice awareness
Producing the Analytical Narrative	Themes are connected to students' climate action intentions dengan niat aksi iklim.	Result narration and explanation	environmental responsibility	environmental action	Producing the Analytical Narrative

Results and Discussion

Indoor Learning

The indoor learning session successfully identified five local plant species that can be used as sources of (A), namely *Curcuma longa*, *Melastoma malabathricum*, *Elaeis guineensis*, *Pandanus amaryllifolius*, and *Pterocarpus indicus*. Each plant produced different pigments through simple processing methods such as pounding, grating, soaking, burning, and boiling (Rathnayake et al., 2025). Beyond the diversity of colors produced, these findings demonstrate how the biochemical properties of plants can serve as meaningful learning experiences. Direct observation of the pigment extraction process provided an important entry point for introducing basic scientific concepts, including plant secondary metabolites, pigment chemistry, and material transformation. This experiential learning approach helps students connect abstract concepts with observable phenomena that they can directly see and experience, thereby strengthening their conceptual understanding (Chen, 2025; Marlina et al., 2023; Mayen et al., 2025). Qualitative observations during the implementation indicated that student engagement was very high, particularly when they directly performed the extraction process and observed the emergence of colors. One student expressed:

"I enjoyed making colors myself from plants around the school. The yellow color from turmeric was very bright and different from the colors of ordinary pencils." (StuD4)

The accompanying teacher also noted that the activity stimulated students' curiosity:

"Some students asked why the color produced from pandan leaves was different from the color of the leaves they usually see. They began to think about how the soaking process could change the color." (Teacher C)

This indicates that direct experiential learning not only activates students' visual senses but also stimulates deeper scientific inquiry. In addition, the use of local resources enhances the ecological relevance of the learning process. By utilizing the surrounding biodiversity, the learning activities do not rely on commercial laboratory materials, while simultaneously fostering environmental awareness and appreciation of local wisdom (Anjum et al., 2025; Pagliarino et al., 2026). In this context, natural dyes function not merely as a teaching technique but also as a strategy for integrating sustainability perspectives into learning practices. To facilitate students' understanding, the results of the plant identification were subsequently packaged into a microlearning medium in the form of BioCards (B). Each card contains key information such as the scientific name, local name, plant parts used, processing methods, and the color produced. This microlearning format functions as a cognitive support tool that simplifies complex information into concise and easily digestible learning units. Beyond functioning merely as an instructional medium, the BioCard acts as a mediating artifact that connects three domains: botanical knowledge, processing techniques, and the resulting colors. By explicitly mapping these relationships, students are supported in developing deeper causal understanding rather than simply memorizing plant names or colors. Qualitative feedback from students indicated that the cards helped them remember the dye-making steps and associate scientific names with local names. For example, one student stated:

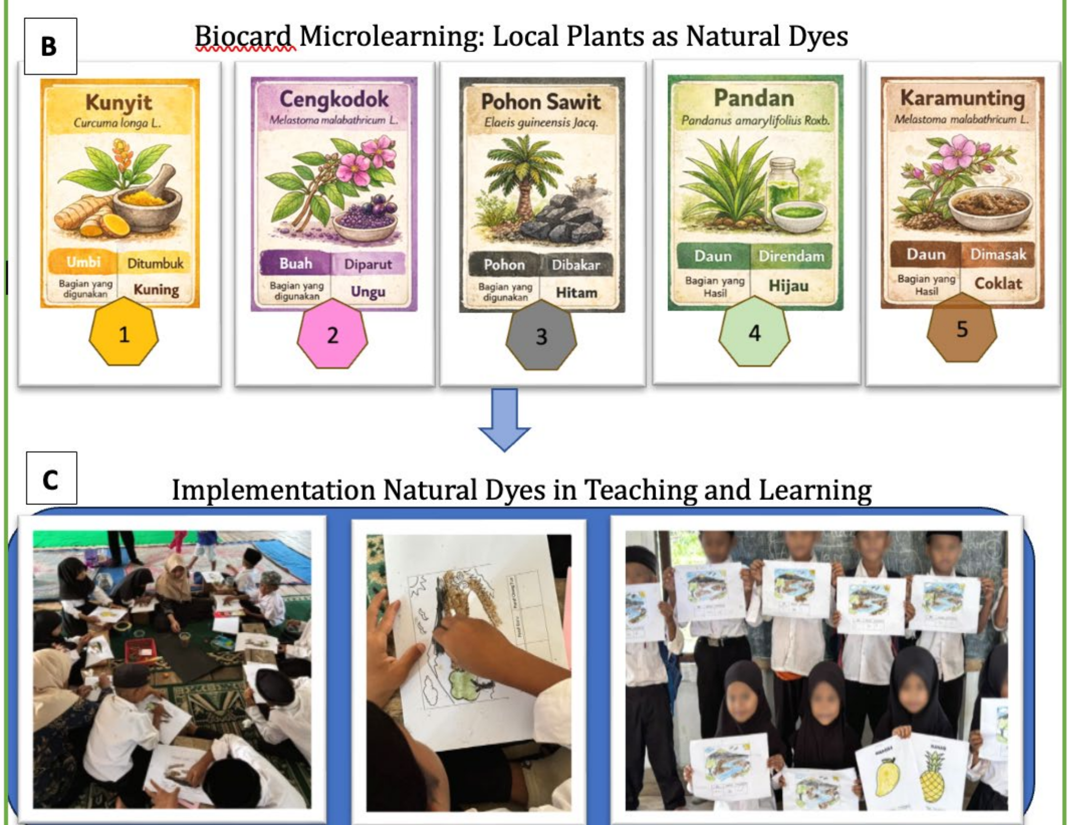
"With this card, I learned that turmeric is *Curcuma longa*, and if we want a yellow color, the part used is the rhizome." (StuM32

Figure 3: illustrates the indoor learning process.

A

Sharing session on the Benefits of Local Plants

No	Scientific Name	Local Name	Section	Processing	Natural Dye
1	*Curcuma longa* L	Kunyit	Roots	Pounded	Yellow
2	*Melastoma malabathricum* L	Cengkodok	Fruit	Grated	Purple
3	*Elaeis guineensis* Jacq.	Pohon Sawit	Burned	Burned	Black
4	*Pandanus amaryllifolius* Roxb	Pandan	Leaves	Soaked	Green
5	*Pterocarpus indicus*	Angsana	Leaves	Cooked	Brown

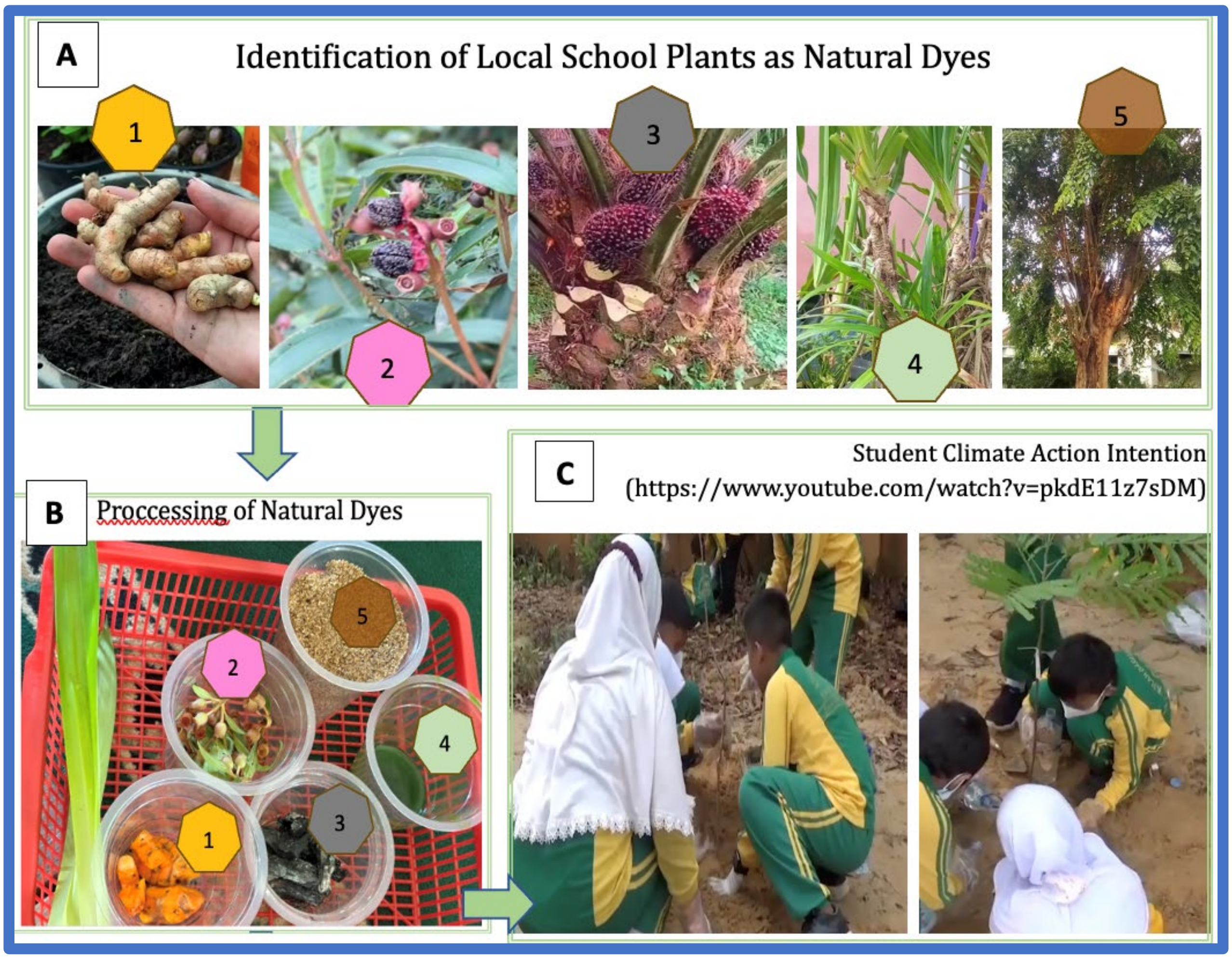


Classroom implementation (C) showed that the natural dye activities fostered a participatory learning environment. Students worked in groups to apply the extracted pigments to worksheets and drawings, allowing them to directly observe the practical results of the extraction process. From a pedagogical perspective, the primary value of this activity lies in its experiential learning structure (Abidin et al., 2020; Alias & Razak, 2023; Aydin et al., 2015; Marlina et al., 2023). Students did not merely receive information passively; instead, they actively participated in the production and application of pigments. Such active engagement is essential for deepening conceptual understanding because it enables students to connect procedural knowledge (how to produce natural dyes) with observable outcomes (the colors produced). The collaborative nature of the activity also supported the development of social learning dynamics (Hao et al., 2026; Soomro et al., 2026; Wiśniewski, 2020). Discussions and exchanges of experiences within groups helped students compare results and collaboratively solve problems when the colors produced differed from expectations. This form of social interaction is particularly important in primary education, as it encourages the development of inquiry attitudes and collective thinking (Delgado-Guerrero et al., 2025; Marlina, 2024).

Ourdoor Learning

Students worked in small groups to observe plant morphology, identify plant parts that could be utilized, and discuss their potential as natural dyes. Field notes from the observations indicated that students demonstrated a high level of curiosity when they discovered that plants commonly found in the school garden could produce a variety of colors.

Figure 4: illustrates students' activities during the outdoor learning session.



During the observation activity, one student expressed surprise after crushing the fruit of *Melastoma malabathricum*:

"I didn't know this fruit could produce a purple color. We usually just see it in the garden, but we have never used it."

Further qualitative observation notes revealed that students frequently compared the plants they found with materials commonly used in their daily lives. This suggests that the outdoor learning process facilitated contextual understanding by connecting scientific concepts with environmental resources that are familiar to students (Chicué & García-Valcárcel, 2023; Wahelo et al., 2025).

After identifying the plant sources, students then processed the collected materials to extract natural pigments. The processing stage included cleaning, cutting, crushing, soaking, and filtering the plant materials to obtain dye solutions. Students actively participated in each step of the extraction process. Observation notes indicated that students frequently discussed differences in color intensity and possible applications of the dyes they produced. Students also proposed ideas regarding the practical use of natural dyes. One student commented:

"We could use these colors for fabric or art projects so we don't have to use chemical dyes." (StuF12)

This statement suggests that students began to perceive the production of natural dyes not only as a classroom activity but also as a sustainable alternative to synthetic materials. Students further demonstrated enthusiasm when engaging in collaborative environmental activities. They worked together to dig the soil, plant seedlings, and water the newly planted plants. This collaborative engagement appeared to strengthen a shared sense of environmental responsibility (Charalambous et al., 2021; Li et al., 2023). The findings indicate that environmental actions at the local level can shape students' perceptions of sustainability (Ladhar et al., 2025; Lee et al., 2025). By directly participating in environmental practices, students developed a stronger sense of ownership and connection to their surrounding environment.

Qualitative findings indicate that outdoor learning activities integrating plant identification, natural dye processing, and environmental action can effectively support the development of climate awareness among students. Three main patterns emerged from the qualitative data. First, students demonstrated increased curiosity about local biodiversity. The discovery that commonly found plants could produce natural dyes encouraged exploration and discussions about the functions and potential uses of these plants. Second, hands-on experimentation fostered inquiry-based thinking. Students compared pigment intensity, formulated hypotheses, and explored possible applications of natural dyes. Third, experiential environmental activities promoted the development of climate action intentions. Students expressed motivations related to environmental protection, such as reducing pollution and increasing green spaces. These findings support the perspective that experiential learning environments provide meaningful contexts for connecting scientific knowledge with environmental responsibility (Law et al., 2023). When students directly engage with ecological resources and sustainable practices, they are more likely to internalize environmental values and develop intentions to take action on climate-related issues.

Implications for Contextual and Sustainability Based Education

The use of local plants as sources of natural dyes has significant implications for the development of contextual science learning. First, this approach demonstrates that meaningful science learning can be developed from everyday ecological resources rather than relying solely on high-technology laboratory materials (Arif & Changxiao, 2022; Pagliarino et al., 2026; Soomro et al., 2026). This challenges the conventional assumption that scientific experiments must be conducted using sophisticated equipment. Second, this approach strengthens the connection between environmental literacy and classroom learning. By interacting directly with plant-based materials, students develop a concrete understanding of biodiversity and the sustainable use of natural resources. Such experiences can foster environmental awareness from an early age and encourage a sense of responsibility toward nature. Third, the combination of microlearning media and experiential activities creates a learning model with strong potential for broader application. The BioCard format ensures the efficient delivery of knowledge, while the direct application of natural dyes reinforces the experiential dimension of learning. This dual strategy balances conceptual clarity with practical engagement, making it particularly suitable for the context of primary school education (Kumar et al., 2024).

Thematic Analysis of Students' Climate Action Intention

Qualitative data obtained from field observations and student discussions during the outdoor learning activities were analyzed using thematic analysis. Several key themes emerged from students' conversations and reflections during the activities of plant identification, natural dye processing, and tree planting. The grouping of themes based on students' conversation data is presented in Table 4.

Table 4: Emergent themes from students' conversations during outdoor learning activities

Theme	Description	Representative Student Quotations
Environmental awareness	Students demonstrated increasing awareness of the relationship between plants and environmental sustainability. They recognized the importance of plants in maintaining ecological balance and reducing environmental pollution.	"Planting trees helps make the air cleaner." ; "If there are more trees around the school, the environment will feel cooler."
Recognition of natural resources	Students realized that plants commonly found in the school environment could be used as useful natural resources, such as natural dyes.	"I didn't know this fruit could make purple color." ; "Usually we see this plant every day but never use it."
Inquiry and exploratory thinking	Students engaged in exploratory discussions, comparing pigments from different plants and proposing ideas about mixing or modifying colors.	"The turmeric color is stronger than pandan leaves." ; "If we mix them, maybe we can get another color."
Sustainable practice awareness	Students began to associate natural dyes with environmentally friendly alternatives to synthetic materials.	"Using plant colors might be better than chemical dyes." ; "Natural colors are safer for the environment."
Collective environmental responsibility	Students expressed willingness to participate in environmental actions, particularly through collaborative activities such as planting and maintaining vegetation.	"If we take care of the plants here, our school will be greener." ; "We should plant more trees around the school."

Thematic analysis indicates that outdoor learning experiences can facilitate the development of environmental awareness and climate action intentions among students. The theme of environmental awareness suggests that direct interaction with plants enables students to understand ecological functions in a more concrete manner. Rather than learning environmental concepts solely through classroom instruction, students experience them directly through observation and active participation. The theme of recognition of natural resources reflects an important shift in students' perceptions of their local environment. Plants that were previously regarded as ordinary elements in the school garden are now understood as valuable resources because they can produce natural dyes. This awareness supports the development of contextual environmental literacy.

The theme of inquiry and exploratory thinking demonstrates that hands-on experimentation can stimulate students' scientific reasoning. Discussions about pigment intensity and color mixing indicate the emergence of informal hypothesis formation and collaborative problem-solving processes. Furthermore, the theme of sustainable practice awareness shows that students are able to connect the use of plant-based dyes with broader issues of environmental sustainability. These findings suggest that experiential learning can help translate abstract sustainability concepts into practical understanding. Finally, the theme of collective environmental responsibility reflects the development of climate action intentions among students. Students' statements regarding tree planting and maintenance indicate the emergence of a sense of responsibility to preserve and improve the environmental quality around their school. Overall, these qualitative findings confirm the role of outdoor learning as an effective pedagogical strategy for integrating environmental science education with climate action awareness. Through direct engagement with local biodiversity and sustainable practices, students begin to develop both ecological understanding and motivation to participate in environmental protection efforts.

Inferential Statistical Analysis of Climate Action Intention

The analysis results indicate that, in general, students' climate action intention scores during outdoor learning activities tended to be higher than during indoor learning activities across most indicators. Statistically significant differences were found in the indicators Support for Indigenous Natural Dye Utilization *(t = 2.24, p = 0.026)* and Environmental Participation in Indigenous Dye Activities *(t = 2.05, p = 0.041)*. Table 5 presents the results of the descriptive and inferential statistical analysis.

Table 5: Results of Descriptive and Inferential Statistical Analysis

No	Indicator	Indoor		Outdoor		Min	Max	t	p
		Mean	SD	Mean	SD				
1	Energy and Resource Conservation Intention in Natural Dye Practices	3.55	0.60	3.67	0.64	2	5	1.42	0.157
2	Sustainable Consumption Intention toward Natural Dye Products	3.69	0.56	3.78	0.52	2	5	1.21	0.227
3	Waste Reduction and Eco-friendly Dyeing Practices	3.63	0.61	3.74	0.58	2	5	1.39	0.166
4	Support for Indigenous Natural Dye Utilization	3.21	0.73	3.43	0.69	1	5	2.24	0.026*
5	Environmental Participation in Indigenous Dye Activities	3.47	0.66	3.69	0.63	2	5	2.05	0.041*
6	Advocacy and Promotion of Indigenous Natural Dye for Climate Action	3.71	0.59	3.82	0.55	2	5	1.36	0.175
7	Knowledge Application and Responsible Production Behavior	3.57	0.64	3.70	0.61	2	5	1.48	0.141
8	Long-term Commitment to Climate-friendly Indigenous Dye Practices	3.66	0.60	3.76	0.57	2	5	1.19	0.236

Note:
Significant differences between the two groups are marked with an asterisk (*).
$p < 0.05$ indicates a statistically significant difference between the indoor and outdoor learning conditions.

Overall, the mean scores for outdoor learning were slightly higher than those for indoor learning across all indicators, suggesting that direct experiences outside the classroom tend to enhance students' motivation and participation in natural dye practices. The indicators "Support for Indigenous Natural Dye Utilization" *(t = 2.24; p = 0.026)* and "Environmental Participation in Indigenous Dye Activities" *(t = 2.05; p = 0.041)* showed statistically significant differences, indicating that outdoor learning is particularly more effective in encouraging support for the use of local natural dyes and promoting environmental participation. Meanwhile, other indicators such as Energy and Resource Conservation Intention, Sustainable Consumption, and Long-term Commitment did not show statistically significant differences *(p > 0.05)*, although they still demonstrated a trend of higher scores during the outdoor session. These findings highlight that experiential learning through outdoor activities not only strengthens student engagement but also enhances practical awareness regarding the use of local resources and sustainable behaviors. In other words, outdoor learning shows particular advantages for indicators related to social interaction and support for local practices, whereas cognitive indicators and long-term intentions tend to remain relatively stable across both learning methods.

Climate Action Intention in Indoor and Outdoor Learning

The analysis of the two learning contexts, indoor learning and outdoor learning, indicates that each approach highlights different indicators in shaping students' climate action intention within the practice of Indigenous Natural Dye. These differences illustrate how the characteristics of the learning environment influence specific dimensions of students' climate action intentions. In indoor learning, the most prominent indicators are sustainable consumption and advocacy and promotion, both reaching 74%, which represents the highest values among all indicators within the classroom learning context. These findings suggest that theoretically and conceptually oriented classroom instruction tends to be more effective in strengthening students' cognitive understanding of sustainable consumption and the importance of promoting environmentally friendly practices (Arif & Changxiao, 2022; Kim et al., 2024; Law et al., 2023; Marlina et al., 2025). Through activities such as discussions, content explanations, case analyses, and the presentation of climate change concepts, students acquire substantial knowledge about how consumption patterns can influence environmental sustainability. Furthermore, the classroom environment facilitates reflection and argumentation processes that can encourage students to develop supportive attitudes and promote environmentally responsible practices to others.

In contrast, the lowest indicator in indoor learning is support for indigenous natural dye utilization, with a value of 64%. This finding suggests that without direct experience, students' understanding of the use of natural dyes based on indigenous knowledge remains relatively limited, as they receive the information primarily at a conceptual level. Table 6 presents the achievement of indicators in Indoor Learning and Outdoor Learning.

Table 6: Indoor Learning and Outdoor Learning

Indicator	Outdoor	Indoor
Energy & Resource Conservation	73%	72%
Sustainable Consumption	76%	75%
Waste Reduction	75%	74%
Support Indigenous Dye	69%	66%
Environmental Participation	74%	72%
Advocacy & Promotion	76%	75%
Knowledge Application	74%	72%
Long-term Commitment	75%	74%

In Outdoor learning, the most prominent indicators are also sustainable consumption and advocacy and promotion, both reaching the highest value of 76%. This represents the highest score among all indicators across the learning contexts. These findings suggest that learning conducted outside the classroom provides direct experiences that strengthen students' understanding of sustainable consumption and encourage them to be more active in promoting environmentally friendly practices (Arif & Changxiao, 2022; Kim et al., 2024; Law et al., 2023). Through activities such as observation, exploration of natural materials, and dyeing practices using local resources, students can directly observe how natural materials can serve as more environmentally friendly alternatives to synthetic substances. These hands-on experiences not only enhance understanding but also reinforce students' motivation to support and disseminate sustainable practices (Delgado-Guerrero et al., 2025; Su et al., 2026). In addition, several other indicators such as waste reduction, long-term commitment, and environmental participation also show relatively high values in outdoor learning, ranging from 74% to 75%. This indicates that experiential learning activities are capable of increasing students' awareness of waste management, environmental participation, and long-term commitment to environmentally responsible actions. Other indicators, including approach supports multiple dimensions of pro-environmental behavior more comprehensively.

When compared overall, sustainable consumption and advocacy and promotion emerge as the two most prominent indicators across the learning contexts. This finding indicates that students demonstrate a strong tendency to understand the importance of sustainable consumption and possess motivation to promote environmentally friendly practices within their communities. Furthermore, these results highlight that integrating indigenous natural dye practices into learning activities can strengthen students' awareness of environmentally friendly production alternatives while encouraging them to take an active role in supporting climate action. Overall, outdoor learning produces the highest indicator levels, particularly in aspects related to direct experience and environmental participation, while indoor learning is more prominent in strengthening conceptual understanding. The combination of these two approaches therefore has strong potential to create a more comprehensive learning model for developing students' climate action intentions through the integration of knowledge, experiential engagement, and sustainability values.

Sustainable Development Contributions and Challenges

The findings demonstrate that Indigenous Natural Dye Microlearning contributes directly to several dimensions of sustainable development. First, the use of locally available plant-based dyes promotes environmentally responsible consumption by introducing renewable and biodegradable alternatives to synthetic dyes, which are often associated with chemical pollution and environmental degradation. Through both indoor and outdoor learning experiences, students developed awareness of sustainable resource utilization, waste reduction, and environmentally friendly production practices. These outcomes support Sustainable Development Goal (SDG) 12 concerning Responsible Consumption and Production. Second, the integration of indigenous knowledge into science learning contributes to the preservation of local cultural heritage while simultaneously promoting environmental stewardship. Students recognized that plants commonly found in their surroundings possess ecological and economic value, strengthening their appreciation of local biodiversity and traditional ecological knowledge. This finding aligns with SDG 15 (Life on Land), which emphasizes biodiversity conservation and sustainable use of terrestrial ecosystems.

Third, the development of climate action intention among students reflects the contribution of this learning approach to SDG 13 (Climate Action). Through direct participation in plant identification, natural dye production, and environmental activities such as tree planting, students developed greater environmental responsibility and willingness to engage in climate-friendly behaviors (Arif & Changxiao, 2022; Pagliarino et al., 2026; Soomro et al., 2026). The qualitative findings revealed increased environmental awareness, sustainable practice orientation, and collective responsibility, indicating that experiential learning can serve as an effective pathway for fostering climate-conscious citizens. Despite these contributions, several challenges remain. Students' support for indigenous natural dye utilization showed only moderate levels, indicating that traditional ecological knowledge is still not fully integrated into students' daily practices (Pagliarino et al., 2026; Soomro et al., 2026). Furthermore, the absence of significant differences in several indicators suggests that short-term interventions may not be sufficient to produce substantial behavioral transformation. Additional challenges include limited access to outdoor learning facilities, variations in local biodiversity resources, and the need for teacher preparation to effectively integrate sustainability concepts into classroom practice. Addressing these challenges is essential for maximizing the long-term contribution of indigenous natural dye education to sustainable development.

Strengths and Limitations of the Research Method

Strengths of the Research Method

The research method employed in this study offers several important strengths for investigating the contributions of Indigenous Natural Dye Microlearning to sustainable development education and students' climate action intention. First, the study was conducted in authentic educational settings through both indoor and outdoor learning activities, allowing students to interact directly with local biodiversity and indigenous natural dye resources. This field-based approach enhances ecological validity because the learning experiences closely reflect real-world environmental contexts rather than artificial laboratory conditions. As a result, the findings provide meaningful insights into how sustainability education can be implemented within actual school environments. Second, the integration of quantitative and qualitative data provides a comprehensive understanding of students' learning experiences. Quantitative findings reveal measurable patterns in climate action intention, while qualitative observations, student reflections, and teacher comments provide deeper explanations regarding how and why these changes occur. Such methodological triangulation strengthens the credibility of the findings and enables a richer interpretation of sustainability-related learning outcomes. Furthermore, the use of local plant resources and simple learning materials makes the intervention relatively inexpensive and feasible for implementation in resource-limited educational settings. This practical nature increases the potential scalability of the approach across different schools and communities. The findings therefore contribute to sustainable development education by demonstrating how indigenous knowledge, experiential learning, and environmental action can be integrated into science education to foster environmental awareness, responsible resource use, and climate-conscious behaviors among students.

Limitations of the Research Method

Despite its strengths, the research method also presents several limitations that should be considered when interpreting the findings. The study employed a non-randomized educational intervention conducted within a natural school setting. Consequently, it is difficult to completely eliminate the influence of selection bias and external confounding variables, such as students' prior environmental attitudes, differences in classroom dynamics, teacher facilitation styles, or previous exposure to sustainability-related activities. These factors may have influenced students' climate action intentions independently of the intervention itself. Additionally, while the mixed-methods approach provides rich contextual information, the qualitative findings are inherently dependent on participants' responses, observations, and interpretations of experiences. Although triangulation, observation notes, and participant quotations were used to enhance trustworthiness, qualitative interpretations may still be influenced by contextual factors and cannot be generalized universally. Furthermore, the relatively short duration of the intervention limits the ability to determine whether the observed changes in climate action intention will be sustained over time. The findings therefore demonstrate associations between Indigenous Natural Dye Microlearning and sustainability-related outcomes rather than definitive cause-and-effect relationships. Nevertheless, these limitations do not diminish the value of the study. Instead, they highlight important challenges in sustainable development research, particularly the complexity of measuring behavioral change in authentic educational environments. Future studies employing longitudinal designs, larger samples, and randomized or quasi-experimental approaches are recommended to strengthen causal inferences and further examine the long-term contributions of indigenous knowledge-based learning to sustainable development and climate action.

Conclusion, Limitations and Directions for Future Research

In this study, several strategies were implemented to minimize internal bias and ensure that the conclusions accurately reflected students' climate action intentions following participation in the Indigenous Natural Dye Microlearning program. First, data were collected using multiple sources, including classroom observations, student interviews, reflective responses, and climate action intention questionnaires. The use of these different data sources enabled methodological triangulation, allowing findings from one source to be verified against evidence from other sources. Second, qualitative data were analyzed inductively, meaning that themes and interpretations emerged directly from participants' responses rather than being predetermined by the researchers. This approach reduced the possibility of imposing subjective expectations on the findings. Third, observation records were documented systematically during both indoor and outdoor learning activities to capture authentic student behaviors, interactions, and engagement with indigenous natural dye practices. Fourth, students' verbal statements from interviews and reflections were analyzed alongside observational evidence to ensure that interpretations were grounded in participants' actual experiences. Consistent patterns across different participants and learning contexts strengthened the credibility of the findings. Furthermore, all data were anonymized and reviewed carefully to avoid selective interpretation. By relying on multiple sources of evidence, systematic documentation, and inductive qualitative analysis, this study was able to draw conclusions that reflect students' genuine experiences and climate action intentions rather than researcher assumptions or personal judgments.

This study has several limitations. First, the sample was limited to a single location, which restricts the generalizability of the findings. Future studies are recommended to involve larger samples from various schools or regions in order to enhance external validity. Second, the relatively short duration of the learning intervention limits the ability to assess long-term changes in sustainability attitudes and behaviors. A longitudinal research design could provide a more comprehensive understanding of the long-term impacts of the learning approach. Third, perception-based methods such as questionnaires may not fully reflect students' actual behaviors. Future research should therefore combine questionnaires with additional data sources, such as direct observation, environmental projects, or student portfolios, to obtain more valid and comprehensive data. Fourth, variations in the implementation of learning activities and limitations in facilities—particularly for outdoor activities—may influence the research outcomes. Adaptive approaches that utilize school gardens, green spaces, or community-based projects may expand access to field-based experiences and improve the quality of outdoor learning.

From a sustainable development perspective, the study highlights how indigenous natural dye practices can support responsible consumption, biodiversity appreciation, and climate action by encouraging students to utilize environmentally friendly local resources and engage in sustainable behaviors. The integration of indigenous knowledge with science learning provides meaningful opportunities to connect environmental conservation with cultural preservation. However, several challenges remain, including the moderate level of support for indigenous natural dye utilization, the limited duration of intervention, and contextual constraints related to learning facilities and environmental resources. These findings advance the understanding of sustainable development by demonstrating that experiential and context-based learning can strengthen students' environmental responsibility while simultaneously preserving local ecological knowledge. Future research should explore long-term interventions and broader implementation contexts to further examine the potential of indigenous knowledge-based learning in promoting sustainable development goals and climate-responsible citizenship.

Research ethics

Author contributions

Reni Marlina: Conceptualized the study, designed the research framework, and led the writing process. She also contributed to data analysis and the interpretation of findings related to the use of local plants as sources of natural dyes and their influence on students' climate action intention.

Hamdani: Conducted a comprehensive literature review and contributed to the qualitative synthesis of the selected studies. She also assisted in data analysis and drafted the section discussing microlearning.

Lerato Kim Ndlovu: Provided expertise in educational methodologies and contributed to the evaluation of pedagogical outcomes using both qualitative and quantitative approaches. He focused on integrating local wisdom into science education and collaborated in analyzing climate change–based learning models.

Thokozani Isaac Mtshali: Contributed insights from an international perspective on educational practices and science learning based on local potential and indigenous knowledge. He provided critical feedback throughout the writing process to ensure clarity and coherence in the manuscript.

Tri Ervina: Conducted participant sampling and analyzed the climate action intention questionnaire data.

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Conflicts of Interest

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