



# Integrating Environment-Based Mathematics Learning into the Indonesian Curriculum: A Comparative Study with Singapore's Sustainable Education Model

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## Abstract

**Background:** Integrating environment-based mathematics learning offers a strategic pathway toward contextual and sustainable education in the 21st century. It addresses global concerns of environmental degradation and declining numeracy levels reflected in international assessments.

**Aims :** This study explores the implementation, strategies, challenges, and policy support for environment-based mathematics learning within Indonesia's curriculum, and compares it with Singapore's sustainable education model. The aim is to generate conceptual insights and policy recommendations to inform cross-national educational reforms.

**Methods:** A qualitative approach was employed through a literature-based and comparative study design. This approach is appropriate given the study's reliance on secondary sources rather than empirical field data. Data were purposively collected from education policy documents, curricula, academic publications, and international reports. Thematic analysis was used to interpret patterns in curriculum integration, pedagogical strategies, and institutional support mechanisms.

**Results:** Nature-based schools in Indonesia demonstrate full implementation of this learning model, while conventional schools show limited adoption, often relying on individual teacher initiatives. In contrast, Singapore has systemically embedded this model through inquiry-based curricula, centralized teacher training, and structured policy frameworks.

**Conclusion:** Environment-based mathematics learning can enhance both environmental literacy and numeracy skills. However, broader implementation in Indonesia is constrained by uneven teacher certification, limited training access, and lack of systemic support. The study proposes a framework for future implementation and highlights the need for further research to strengthen interdisciplinary curriculum design, expand model school networks, and improve professional development structures.

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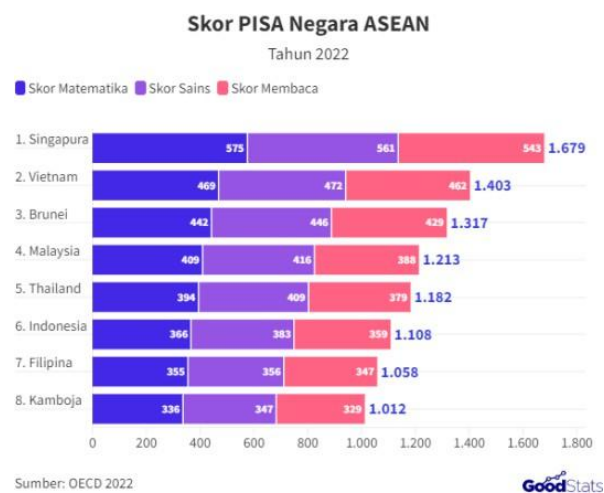
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## Introduction

Environment-based mathematics learning is part of a growing global agenda in sustainable education, positioning the environment as an authentic and contextual foundation for fostering meaningful mathematical understanding. This approach aligns with international efforts to integrate environmental awareness into core disciplines as a response to sustainability challenges in education (Wasil & Muizudin, 2023; Olawale et al., 2025; Karrow, 2016; Leal Filho, 2020; Khanum, 2019; Olsen et al., 2020; Sondergeld et al., 2014). Its implementation in Indonesia

reflects distinct patterns between nature-based schools and conventional schools. Nature-based schools tend to implement this approach holistically through exploratory activities, including environmental expeditions for teaching addition, the use of straw waste to introduce multiplication, and contextual measurement using objects found in the surrounding environment (Handiyati et al., 2022; Robianti et al., 2024; Gaffney, 2016). These strategies help concretize abstract mathematical concepts while simultaneously fostering early ecological awareness.

Conversely, the integration of environment-based mathematics learning in conventional schools remains fragmented and largely reliant on individual teacher initiative (Wijayanto et al., 2024; Istance, 2013; Segal et al., 2025; Bodzin et al., 2010). This limited integration is considered a contributing factor to the persistently low performance of Indonesian students in international assessments. Data from the GoodStats (2023) indicate that Indonesia's PISA score in 2022 ranked among the bottom three ASEAN countries. As illustrated in Figure 1 below:

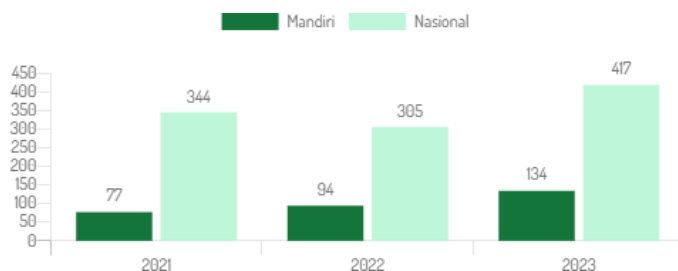


**Figure 1.** Indonesia's PISA Score in 2022

As illustrated in Figure 1, Indonesia's mathematics PISA score lags 209 points behind Singapore, the top-performing country. This substantial gap not only signals the urgency of curriculum reform but also reflects the limited integration of interdisciplinary and contextual learning approaches within the national education system. The data imply that conventional instructional methods have yet to effectively cultivate students' mathematical literacy in real-world contexts. Therefore, this performance disparity reinforces the study's argument that embedding environment-based mathematics learning into the curriculum could offer a strategic response to improving students' understanding and application of mathematics in meaningful, sustainable ways.

Indonesia's national curriculum provides avenues for contextual integration, particularly through the *Pancasila Student Profile Strengthening Project (P5)*, which includes environmental sustainability as a core theme. A more detailed discussion of this policy, along with the *Adiwiyata* school program, is presented in the policy framework section (Zaliyanti & Azani, 2024). However, its implementation faces several challenges, including limited teaching resources, low teacher competency in integrative pedagogy, and administrative pressure to meet academic targets. On the other hand, the curriculum also offers flexibility in lesson planning, especially for schools with a culture of innovation and adequate managerial support (Santosa & Supadi, 2024).

The Indonesian government has demonstrated its commitment to environmental education through the *Adiwiyata* program, as reported by the Ministry of Environment and Forestry (2023), which promotes the transformation of both nature-based and conventional schools into environmentally cultured institutions. As illustrated in Figure 2 below:



**Figure 2.** Number of Adiwiyata Awardee Schools in Indonesia

Figure 2 illustrates the government's increasing commitment to environmental education, as reflected in the growing number of Adiwiyata awardee schools over the past three years totaling 130 at national and independent levels. While this trend signifies institutional acknowledgment of sustainability efforts, a closer examination reveals that such recognition remains largely focused on ecological practices rather than on curricular transformation. The data suggest that environmental initiatives like Adiwiyata have yet to systematically embed interdisciplinary learning particularly in subjects like mathematics. This gap reinforces the study's finding that environment-based mathematics learning remains peripheral within current environmental education programs, signaling the need for stronger curricular integration aligned with sustainability goals.

In contrast to Indonesia, Singapore has developed a comprehensive model of environment-based sustainable education that is embedded in its national education policy (Bustari & Putri, 2023). Beyond dedicated green schools such as Greendale Secondary and Northland Primary, environment-based learning is also implemented in mainstream schools through the Applied Learning Programme (ALP). The ALP facilitates the contextual application of mathematical concepts within environmental sustainability projects, including energy efficiency and wastewater management (Nursianda et al., 2025).

This consistent interdisciplinary integration of environmental education aligns with Singapore's high performance in international assessments, particularly in mathematics and science. According to GoodStats (2023), Singapore topped the global rankings in the 2022 PISA assessment. Figure 3 presents Singapore's top performance in the 2022 PISA assessment.



**Figure 3.** Singapore's PISA Score in 2022

Figure 3 illustrates that Singapore's PISA score reflects the effectiveness of a national curriculum grounded in experiential, inquiry-based, and real-world learning. Furthermore, the Ministry of Education in Singapore provides robust support through teacher training, the development of instructional materials, and funding for inter-school collaborative projects (Timur & Prasetyo, 2023).

The comparative analysis between Indonesia and Singapore underscores fundamental differences in the implementation of environment-based mathematics learning. Whereas Indonesia remains in the experimental phase, Singapore has fully institutionalized this educational approach (Alissa et al., 2022). Accordingly, this study seeks to examine the modes of integration, implementation strategies, encountered challenges, and policy support mechanisms for environment-based mathematics learning in both countries. The findings aim to provide practical recommendations for schools yet to optimally implement this approach and to contribute meaningfully to academic discourse and policy development in the context of global educational challenges.

## **Method**

### *Research Design*

This study adopted a qualitative comparative research design, grounded in a thematic literature review approach to explore how environment-based mathematics learning is integrated into the national curricula of Indonesia and Singapore. The research design was selected to allow for an in-depth examination of conceptual frameworks, pedagogical practices, and policy orientations across both national contexts. To ensure transparency and academic rigor, the research process was guided by the Standards for Reporting Qualitative Research (SRQR), which provides a structured framework for reporting qualitative data in a credible and consistent manner. This design enabled the researchers to synthesize diverse sources and draw meaningful comparisons that reflect both convergence and divergence in educational practices related to sustainability and mathematics instruction.

### *Participant*

This study did not involve human participants, as the research did not employ field-based data collection or involve primary sources such as interviews or surveys. Instead, the unit of analysis consisted entirely of secondary data sources, including official policy documents, curriculum guidelines, school-based program reports, and peer-reviewed academic publications. The focus on non-human data sources was strategic, allowing the researchers to map the evolution and structure of environment-based mathematics education without the ethical and logistical constraints of human subject research. The absence of participants, therefore, reflects the nature of the study as a document-based comparative inquiry.

### *Population and Sampling*

The population of this study included a comprehensive set of 38 carefully selected sources published between 2012 and 2025. These sources were drawn from both national and international repositories, including educational journals, government websites, institutional reports, and curriculum documents. The selection process employed purposive sampling techniques, aimed at identifying sources that were highly relevant to the research objectives. Three key criteria were applied during the sampling process: (1) content relevance to environment-based mathematics learning, (2) credibility of the source, particularly peer-reviewed or government-endorsed materials, and (3) contextual significance, ensuring that the documents provided insight into the education systems of Indonesia and Singapore. This selective approach ensured that the data analyzed would be robust, focused, and aligned with the comparative goals of the study.

### *Instrument*

The primary research instrument used in this study was a document analysis matrix, developed to systematically extract and categorize information across all selected sources. The analysis employed both open coding, which allowed for the identification of emergent concepts and patterns, and axial coding, which facilitated the organization of these codes into broader thematic categories. This matrix functioned as an analytical scaffold, guiding the researchers in aligning identified themes with the study's core focus areas: pedagogical integration, policy alignment, and curricular coherence. The coding process was conducted manually to ensure

reflexivity and contextual interpretation, which are essential in qualitative research involving textual analysis.

#### *Procedures and Time Frame*

The data collection and analysis process was carried out over a period of four months, from January to April 2025. The research procedures followed a sequential approach beginning with the identification of relevant sources through targeted database searches and reference tracking. This was followed by the systematic analysis of documents, where each source was reviewed in depth and coded for thematic elements. The identified codes were then grouped into categories based on their conceptual similarities and subsequently synthesized across cases, allowing for meaningful comparisons between the Indonesian and Singaporean contexts. Each step was carefully documented to maintain methodological transparency and replicability.

#### *Analysis Plan*

Data analysis was conducted using a thematic analysis framework, which enabled the researchers to capture complex patterns and meanings embedded in the textual data. The process involved manual coding, which was conducted iteratively to refine theme accuracy and reduce researcher bias. Through this analysis, five major analytical themes emerged: (1) instructional practices, highlighting pedagogical approaches and strategies used in the classroom; (2) policy frameworks, examining national directives and educational mandates; (3) institutional support, exploring the role of school leadership and teacher training; (4) assessment methods, focusing on how environmental and mathematical competencies are evaluated; and (5) comparative outcomes, addressing the broader impacts and implications of integration efforts in both countries. These themes formed the basis for cross-contextual comparisons and interpretation.

#### *Scope and Limitations*

This study is scoped to examine the integration of environment-based mathematics learning within the primary and secondary education levels in Indonesia and Singapore. The analysis is limited to secondary data, and thus does not incorporate empirical findings from classroom observations or stakeholder interviews. As such, while the study offers a strong conceptual and policy-oriented foundation, it is constrained in its ability to assess real-time implementation or learner outcomes directly. The findings are best understood as indicative of systemic trends and theoretical alignments rather than definitive claims about classroom efficacy. Consequently, further field-based studies, involving qualitative interviews with educators or case studies of specific school programs, are recommended to validate and enrich the insights derived from this research.

## **Results and discussion**

### **Result:**

The results of this study were derived from a comprehensive thematic synthesis of document analysis, curriculum reviews, and policy comparisons. The findings highlight key differences and innovations in the integration of environment-based mathematics learning across Indonesia and Singapore. The results are presented in four major themes and are supported by three tables and two figures, each of which is preceded and followed by detailed explanations.

#### ***Theme 1: Implementation Differences Between Nature-Based and Conventional Schools in Indonesia***

This theme explores how different school models in Indonesia adopt environment-based mathematics learning. In particular, a comparison between a nature-based institution Bandung Nature School Kindergarten and a conventional institution Al-Falah Integrated Islamic Elementary School Jepara demonstrates the diversity of pedagogical approaches and contextual practices. These schools embody distinct educational philosophies, influencing how mathematics instruction is delivered and linked with sustainability. The contrast between these two models is summarized in Table 1.

**Table 1.** Comparison between Nature School and Non-Nature School

<b>Aspect</b>	<b>Bandung Nature School Kindergarten</b>	<b>Al Falah Integrated Islamic Elementary School</b>	<b>Analytical Interpretation</b>
<b>Curriculum Characteristics</b>	Thematic-integrative, nature exploration-based	Thematic contextual, but still classically structured	Nature-based curriculum allows seamless integration of environmental and mathematical concepts; conventional structure limits contextual depth
<b>Learning Media</b>	Stones, water, leaves, soil, direct natural objects	Discarded straws, recycled measuring tape, food from home	Nature schools utilize authentic, in-situ materials; non-nature schools rely on repurposed items, indicating creativity amid limited access to natural resources
<b>Learning Methods</b>	Nature exploration, observation, exploratory games	Environmental observation, simple educational games	Both apply experiential strategies, but nature schools embed learning more deeply in natural interactions
<b>Assessment Methods</b>	Observation, daily narrative reports, mid-term and comprehensive narratives	Personal tests, educational game evaluations, task product assessments	Narrative-based assessments in nature schools support holistic development; non-nature schools emphasize task outcomes and individual performance
<b>Challenges</b>	Weather, children's adaptation to open environment	Limited teacher training, teaching media, and systemic support	Nature schools face logistical and environmental constraints; non-nature schools struggle more with structural and pedagogical limitations
<b>Curriculum Flexibility</b>	Very high, integrated with nature	Limited, dependent on teacher creativity	Flexibility in nature schools enhances interdisciplinary integration; conventional settings rely heavily on teacher initiative for innovation
<b>Student Engagement</b>	High, based on direct activities	Moderate, varying among teachers	Active, embodied learning in nature schools increases engagement; in non-nature schools, engagement is inconsistent and teacher-dependent

Table 1 illustrates contrasting instructional strategies and learning environments. Bandung Nature School promotes experiential learning through natural materials and outdoor activities. Its curriculum emphasizes exploration and narrative-based assessment. In contrast, Al-Falah Integrated Islamic Elementary School Jepara utilizes classroom-based strategies that still incorporate environmental elements, though more constrained by resources and reliant on

individual teacher innovation. These differences influence the depth and consistency of student engagement and learning outcomes.

**Theme 2: Curricular and Policy Frameworks in Indonesia**

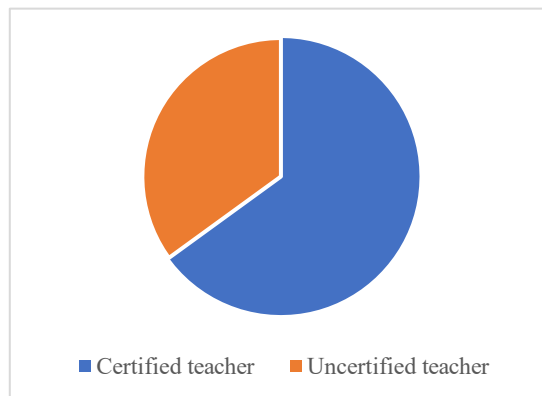
This theme delves into how the Indonesian national education system supports sustainability integration through its curriculum and teacher development programs. The Pancasila Student Profile (P5) project is a foundational component of the Merdeka Curriculum and introduces nine thematic areas for interdisciplinary instruction, including sustainability.

**Table 2.** Nine P5 Themes

No.	P5 Theme
1	Sustainable Lifestyle
2	Local Wisdom
3	Unity in Diversity (Bhinneka Tunggal Ika)
4	Build the Soul and Body
5	Voice of Democracy
6	Engineering and Technology for Building the Republic of Indonesia
7	Entrepreneurship
8	Employment (Mandatory for Vocational High Schools)
9	Work Culture (Mandatory for Vocational High Schools)

Table 2 lists the nine P5 themes, with the "Sustainable Lifestyle" theme being most relevant for integrating environmental content into mathematics instruction. These themes provide structured entry points for contextual learning but rely heavily on the readiness and creativity of teachers for successful implementation.

To further support environmental integration, the Indonesian government implements complementary programs such as Adiwiyata (green school recognition), Merdeka Mengajar (teacher resources platform), and teacher certification initiatives.



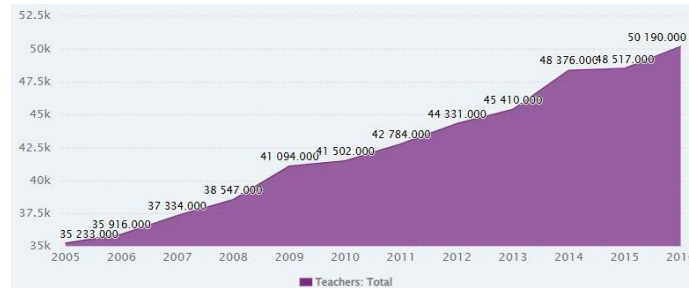
**Figure 4.** Percentage of Certified Teachers

Figure 5 highlights a significant challenge: only about 65% of teachers in Indonesia are certified. The remaining 35% face institutional and geographic barriers to professional development, which limits their capacity to carry out innovative, sustainability-integrated instruction. This directly impacts the scalability and consistency of environment-based mathematics teaching across schools.

**Theme 3: Systemic Integration of Sustainability in Singaporean Schools**

This theme highlights how Singapore has institutionalized sustainability education through national programs and infrastructure. Sustainability is embedded into school curricula via project-based learning, teacher training, and policy frameworks such as the 21st Century Competencies Framework and the Applied Learning Programme (ALP).

Green schools, such as Greendale Secondary, incorporate energy audits, waste tracking, and environmental modeling into daily instruction. Even non-green schools are mandated to conduct real-world sustainability projects through ALP, ensuring equitable exposure.



**Figure 5.** Total Teachers in Singapore

Figure 6 shows an upward trajectory in teacher participation in environmental professional development. By 2024, more than 85% of mathematics teachers had undergone sustainability oriented training, a result of coordinated efforts between the Ministry of Education and the National Institute of Education (NIE). This robust support system ensures that environmental concepts are seamlessly integrated into mathematics instruction across schools.

**Theme 4: Comparative Analysis Between Indonesia and Singapore**

This final theme synthesizes findings by comparing the structural and pedagogical aspects of environment-based mathematics learning between Indonesia and Singapore. It evaluates curriculum integration, government support, teacher training, instructional strategies, and key implementation challenges.

**Table 3.** Comparison of Environmental-Based Mathematics Learning in Indonesia and Singapore

Aspect	Indonesia	Singapura	Analytical Interpretation
<b>School Context</b>	Nature schools (explorative, nature-based) and non-nature schools (limited contextual)	Green schools and non-green schools with systemic approach	Singapore ensures system-wide integration, while Indonesia's efforts are school-dependent and fragmented.
<b>Curriculum Approach</b>	National Curriculum, integration through P5 (Sustainable Lifestyle)	National curriculum based on inquiry and experiential learning	Singapore's curriculum structurally supports sustainability; Indonesia's integration remains thematic and non-compulsory.
<b>Curriculum Strengthening Programs</b>	Pancasila Student Profile Strengthening Project (P5)	21st Century Competencies Framework	Singapore connects sustainability with broader competencies; Indonesia isolates it within P5.
<b>Government Support</b>	Adiwiyata program, P5 modules, Merdeka Mengajar platform, teacher competency development and training	Green school awards, green project funding, school collaboration	Singapore's support is more strategic and project-based; Indonesia's support is diverse but lacks integration and long-term continuity.
<b>Teacher Training</b>	65% certified teachers, limited quota and access for training	>85% teachers trained in sustainability by NIE	Singapore prioritizes sustainability training systemically; Indonesia faces access and coverage limitations.
<b>Aspect Aspect</b>	Indonesia <b>Indonesia</b>	Singapura <b>Singapura</b>	Analytical Interpretation <b>Analytical Interpretation</b>

<b>Learning Methods</b>	Observation, exploration, contextual games	Project-based learning, real-world problem solving	Singapore emphasizes active, real-world engagement; Indonesian practices remain more exploratory and less structured.
<b>Assessment Methods</b>	Observation reports, recycled material models, or contextual math problem-solving tasks	Process and project-based product assessment	Assessment in Singapore aligns with sustainability goals; Indonesia still emphasizes conventional evaluation.
<b>Main Challenges</b>	Limited training, systemic support, limited teacher initiatives	Administrative burden, project theme adaptation	Indonesia's challenges are structural and capacity-related; Singapore's are mostly technical and implementation-focused.

Table 3 underscores significant differences between the two countries. While Indonesia has made promising innovations, particularly in schools with nature-based models, the absence of widespread institutional alignment and uneven teacher training remains a barrier. Conversely, Singapore's top-down policy coherence ensures that sustainability is embedded across school types and that mathematics instruction consistently reflects real-world environmental issues. This comparison reveals the importance of both grassroots innovation and systemic policy alignment in advancing sustainability education through mathematics.

### Discussion:

This section interprets the findings by examining how environmental-based mathematics learning is implemented within differing educational models in Indonesia and Singapore. By comparing nature-based and conventional schools in Indonesia with the systemic approach in Singapore, the discussion identifies contextual conditions, resource inputs, pedagogical processes, and educational outcomes that influence the integration of sustainability into mathematics instruction. The analysis is structured thematically through six interconnected components: Context, Input, Process, Product, Research Contribution, Limitations, and Suggestions.

#### *Context*

The implementation of environment-based mathematics learning is shaped by each country's educational philosophy and school typology. In Indonesia, a dual model exists. Nature-based schools such as Bandung Nature School provide a highly contextual and exploratory environment where students learn mathematical concepts through direct interaction with nature (Eva Yulia Herawati et al., 2024). These schools typically emphasize flexible and narrative forms of assessment, reflecting a holistic pedagogical orientation.

For example, students explore measurement by calculating water flow rates in nearby streams, apply geometry by comparing leaf shapes and sizes, and practice counting and number operations using natural objects like stones or seeds. In some activities, students also engage with fractions and proportions when analyzing plant growth stages or dividing harvested produce. These experiences foster a deeper understanding of mathematics as embedded in real-world ecological contexts (Chang & Kidman, 2025).

In contrast, conventional schools such as Al-Falah Integrated Islamic Elementary School Jepara operate under more rigid classroom-based systems. Although efforts are made to incorporate environmental materials such as using recycled objects for arithmetic tasks this integration largely depends on individual teacher initiative and creativity. These schools often face structural challenges such as limited time allocation, inflexible curriculum mandates, and insufficient resources for environmental instruction (Agustiani et al., 2019).

Meanwhile, Singapore applies a unified and systemic approach. Through the Applied Learning Programme (ALP), environmental themes are embedded across subjects, including mathematics, regardless of a school's formal designation as "green." National frameworks such as the 21st Century Competencies guide this integration, ensuring alignment between sustainability values and academic standards. Unlike Indonesia's dual-track implementation, Singapore's strategy is policy-driven and standardized across schools, reflecting a whole-system commitment.

#### *Input*

Successful integration of environmental themes into mathematics depends on foundational inputs such as teacher qualifications, curriculum flexibility, and access to professional development. In Indonesia, the government has introduced several supporting mechanisms including the Pancasila Student Profile (P5) Project, Adiwiyata program, and the Merdeka Curriculum (Mutiaru, 2020). However, implementation remains inconsistent. As shown in Figure 5, approximately 65% of teachers were certified as of 2024, while 35% remained uncertified—highlighting disparities in access to training and institutional support.

In comparison, Singapore demonstrates significantly higher preparedness. Figure 6 indicates that over 85% of mathematics teachers have completed structured annual training in sustainability-integrated pedagogy. This is facilitated by the National Institute of Education (NIE), coupled with sustained funding and policy mandates. These differences in input conditions contribute to the uneven quality of environment-based mathematics learning observed between the two systems (Nopitasari & Juandi, 2020).

#### *Process*

Instructional practices further differentiate the two countries' approaches. In Indonesia, nature-based schools utilize outdoor and experiential learning techniques that allow students to explore mathematical concepts through real-life environmental contexts. Activities such as estimating plant growth or classifying waste types are designed to enhance both numeracy and ecological awareness. Conventional schools, on the other hand, often rely on games or observation-based exercises using recycled materials, constrained by the formal structure of the classroom (Hidayati et al., 2012).

In Singapore, instruction is more systematically aligned with real-world environmental issues. Students engage in inquiry-based projects such as analyzing energy consumption, interpreting data from waste audits, or modeling sustainable practices all grounded in authentic, interdisciplinary contexts. These pedagogical strategies are supported by national curricula and teacher development frameworks, ensuring consistency and coherence in implementation (Goi, C. L., 2024; Bărbulescu, 2025; Seprie et al., 2025; Pryor, 2024; Mäki-Kuutti et al., 2025). The comparative instructional pathways shown in Tables 1 and 3 confirm that while Indonesian schools exhibit localized innovation, Singapore's integration benefits from top-down alignment between curriculum, pedagogy, and institutional readiness.

#### *Product*

The outcomes of integrating environmental themes into mathematics education span both cognitive and affective domains. In Indonesian nature-based schools, students exhibit enhanced skills in measurement, volume calculation, and basic data processing, alongside stronger environmental awareness and participatory behaviors. In conventional schools, while similar outcomes are observed, the depth of learning is often limited by the availability of resources and teacher autonomy (Indriyanti et al., 2022).

Singaporean students demonstrate advanced mathematical reasoning through interdisciplinary projects. Their ability to connect data interpretation with sustainability themes reflects deeper conceptual understanding. Moreover, Singapore's assessment methods include reflective journals, process-based rubrics, and group presentations enabling a more comprehensive evaluation of student growth beyond academic achievement (Pahru et al., 2021). These differences underscore the argument made by UNESCO (2017) that sustainability competencies such as

systems thinking, problem-solving, and ethical reasoning are most effectively cultivated through interdisciplinary, contextual learning environments.

#### *Research Contribution*

This study contributes to the discourse on sustainability integration within mathematics education by offering a comparative perspective across two educational systems. It highlights the potential of localized, nature-based practices in Indonesia and contrasts them with the systematized national model employed in Singapore (Paryono, 2017). The documentation of practices at Bandung Nature School and Al-Falah Integrated Islamic Elementary School Jepara illustrates the creative possibilities of environmental integration under diverse conditions, while Singapore's example affirms the scalability of such integration through structured support.

The findings align with constructivist learning theory, demonstrating that mathematics instruction is most meaningful when grounded in students' real-world experiences. They also affirm the relevance of culturally responsive curriculum development, particularly through Indonesia's Merdeka Curriculum and the P5 thematic framework.

#### **Limitations**

This study is limited by its methodological scope. The data were drawn exclusively from document analysis, without direct classroom observation, which may limit the depth of insight into teaching practices and student engagement. Furthermore, the study focuses on selected case examples from Central Java and Singapore, which may not fully represent the diversity of practices within each national system. Future research should employ mixed-method and longitudinal designs to examine the evolving impacts of environment-based mathematics learning across broader contexts.

#### **Suggestions**

To strengthen the integration of environmental themes into mathematics education, several strategic directions are proposed. First, curriculum reform must be coupled with teacher empowerment. Education authorities are encouraged to design interdisciplinary curriculum modules that align sustainability topics with essential mathematical competencies. These modules should be supported by consistent, context-sensitive professional development programs that enable teachers to translate abstract environmental concepts into concrete mathematical instruction. Second, resource mobilization is vital. Schools need to be equipped with appropriate infrastructure and locally relevant materials to facilitate environment-based instruction. Initiatives such as student-maintained garden plots, school-level waste management audits, and environmental monitoring projects can serve as practical learning platforms that contextualize mathematical learning. Third, institutional support systems must be reinforced. Governments should introduce structured incentives, such as green school certifications, sustainability awards, or performance-based funding, to promote innovation in sustainability-integrated pedagogy. These systems not only provide recognition but also stimulate broader adoption of environmentally conscious teaching practices. Lastly, fostering cross-sector collaboration with local communities, higher education institutions, and non-governmental organizations can enrich instructional practices. Such partnerships offer access to real-world data, opportunities for co-teaching and field-based learning, and exposure to sustainability issues that are directly relevant to students' everyday experiences.

#### **Conclusion**

This study concludes that environment-based mathematics learning in Indonesia is effectively implemented in nature-based schools, where the environment serves as a core learning context. In contrast, conventional schools show sporadic integration, driven mainly by individual teacher initiatives. The study offers a comparative framework that highlights the structural and pedagogical conditions needed for systemic integration, contributing to the theoretical discourse on contextual and sustainable mathematics education. The absence of structured policy directives, limited access to integrative pedagogical training, and insufficient curricular embedding of

environmental themes hinder the scalability of such practices. In contrast, Singapore represents a model of comprehensive integration, where environmental literacy is embedded at multiple levels policy formulation, curriculum design, instructional methodology, and teacher professional development thereby ensuring institutional consistency and sustainability in pedagogical innovation.

To move towards sustainable and equitable implementation, the Indonesian education system must address critical structural barriers. These include enhancing institutional alignment between curricular goals and environmental priorities, expanding teacher access to interdisciplinary training opportunities, and embedding environmental themes explicitly within national mathematics curriculum standards. Policy measures must be accompanied by targeted investments in capacity building, infrastructure, and instructional materials that support contextual, project-based learning.

Furthermore, future research is essential to advance this field by validating implementation strategies through field-based studies and longitudinal evaluations. The development of model schools that exemplify best practices in integrating environmental education into mathematics instruction would provide a scalable framework for other institutions. These models can serve not only as centers of innovation but also as training hubs for teachers and policymakers aiming to harmonize mathematical literacy with ecological consciousness in line with the goals of Education for Sustainable Development (ESD) and the Merdeka Curriculum.

### **Acknowledgment**

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### **Author contribution statement**

NS was solely responsible for the conception and design of the research, the systematic collection and analysis of data, the interpretation of findings, and the drafting of the full manuscript. All stages of the research process were conducted independently and rigorously to uphold scholarly integrity, methodological coherence, and ethical research standards.

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