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A Thematic Literature Review on Integrating Circular Economy in Contextual Mathematics Learning at Green-Based Schools

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Abstract

Background of study: Global environmental challenges such as climate change and waste growth are rising. These require sustainable approaches in education.One such approach is the circular economy, which emphasizes reducing, reusing, and recycling to foster environmentally responsible behavior from an early age.

Aims and scope of paper: This study aims to evaluate the extent to which the circular economy concept has been integrated into contextual mathematics learning in elementary schools implementing green learning programs. It also seeks to identify best practices and challenges encountered in its implementation.

Methods: This study employed a thematic literature review involving 22 sources to explore how circular economy (CE) principles are integrated into contextual mathematics learning at green-based schools. Thematic analysis revealed four key themes: (1) Mathematical Applications in Waste Quantification, (2) Integration Through the P5 Project and Interdisciplinary Contexts, (3) Implementation Gaps and Institutional Disparities, and (4) Best Practices in CE-Math Integration at Model Schools. These findings contribute a conceptual framework for sustainability-oriented mathematics education aligned with the Merdeka Curriculum.

Result: Students improved their data analysis and awareness of sustainability through hands-on recycling math projects. These include measuring waste volume, calculating land area, and analyzing environmental data. Best practices were found in schools such as SDN Larangan and MI Al-Falah Jepara, where reduce, reuse, and recycle principles were applied through contextual, project-based mathematics activities.

Conclusion: Mathematics learning based on circular economy principles can serve as a strategic pedagogical approach to support the Merdeka Curriculum and the development of the Pancasila Student Profile. This integration promotes not only numeracy competencies but also sustainable character formation by involving students in contextual activities that cultivate environmental responsibility and awareness.

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INTRODUCTION

Global environmental problems such as climate change, excessive exploitation of natural resources, and increasing waste volumes demand the adoption of sustainable, system-oriented solutions (Judijanto et al., 2023). One promising approach is the circular economy (CE), which emphasizes the principles of reduce, reuse, and recycle to minimize waste and optimize resource use (Batista et al., 2021; Syarif et al., 2022).

The integration of circular economy (CE) principles into education particularly at the primary level is increasingly recognized as essential for fostering environmental awareness and social responsibility from an early age (Suwignyo et al., 2021). This stage of education is formative for shaping values and habits that persist into adulthood. According to Pribadi et al., (2024) the adoption of circular strategies could reduce global greenhouse gas emissions by as much as 39%, demonstrating the broader systemic impact of early CE education initiatives.

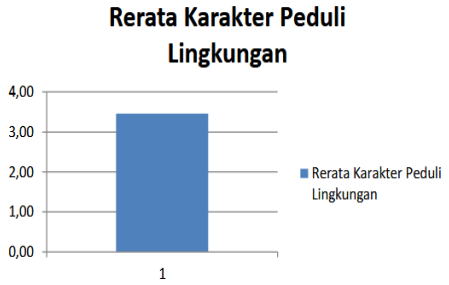

Figure 1. Average Environmental Awareness Character of Students at SD Adiwiyata Banjarmasin (Jamilah et al., 2024)

Empirical studies have affirmed the role of CE-based education in enhancing environmental awareness and fostering sustainable practices (Alissa., 2022; Kencanawaty et al., 2020). Kirchherr et al., (2017) further emphasize that education serves as a key driver in transitioning from a linear to a circular economic model. In the Indonesian context, initiatives such as the Adiwiyata program offer structured integration of sustainability themes within curriculum and school culture. For example, at SD Adiwiyata Banjarmasin, a project involving the repurposing of plastic waste into plant pots led to a student environmental awareness score of 3.448 classified as "very good" (Jamilah et al., 2024). Meanwhile, SDN Larangan has implemented CE-aligned practices such as waste sorting, biopore usage, compost measurement, and school gardening, which also serve as effective contexts for teaching mathematics (Silvia & Tirtoni., 2023). These practices are consistent with findings from Haryadi., (2021) and Apriliani et al., (2024), who note that the Adiwiyata program successfully embeds sustainability principles through the integration of curriculum content, extracurricular initiatives, and eco-friendly infrastructure.

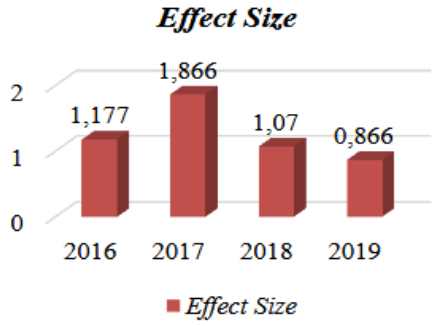

Figure 2. Annual Effect Size Scores of Green Learning-Based Instructional Models (Nugroho et al., 2020)

Several studies have also demonstrated the educational benefits of CE-based mathematics instruction. Nugroho et al., (2020) found that environmentally contextualized mathematics learning improved students' problem-solving skills with an effect size of 1.245 significantly higher than conventional discovery learning (0.762). Mutiara., (2020) and Nizaar., (2022) reported gains in numeracy, data representation, and environmental values through arithmetic and measurement tasks using recycled materials. Similarly, Widiani., (2019) showed that integrating mathematics with sustainable agriculture activities, such as calculating fertilizer needs and planting distances, promoted both numeracy and resource awareness.

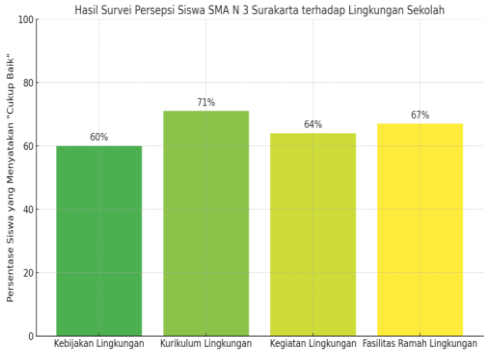

Figure 3. Student Survey Results at SMA N 3 Surakarta (Hidayat et al., 2023)

Despite these promising outcomes, the integration of circular economy principles into contextual mathematics learning remains limited, particularly under the Merdeka Curriculum and Green Learning initiatives (Hariyanto., 2019). Student participation in CE-based mathematics instruction at SMA N 3 Surakarta ranged from 60% to 71%, indicating moderate engagement (Hidayat et al., 2023). Moreover, implementation challenges such as limited resources and the absence of interdisciplinary teaching guidelines continue to hinder broader adoption (Simon Paulus Olak Wuwur., 2023).

This study is grounded in constructivist learning theory, which posits that students construct mathematical understanding through socially mediated, contextually relevant experiences (Vygotsky, 1978). Such an approach aligns closely with the goals of contextual mathematics education. Furthermore, the study is informed by the framework of Education for Sustainable Development (ESD), which advocates for integrative, transformative pedagogy that empowers learners to address global sustainability challenges (UNESCO, 2020). Both frameworks provide a strong theoretical foundation for linking mathematical literacy with environmental responsibility.

The urgency of this study lies in the need for a learning model that not only develops mathematical competence but also fosters environmental care character. The Merdeka Curriculum, through the P5 Project and the Adiwiyata program, provides integrative space between environmental education and numeracy. SDN Larangan serves as a good practice example, with students actively involved in composting, recycling, and measuring waste volume, all linked to contextual mathematics learning (Ilmi et al., 2024; Kamil et al., 2020; Silvia & Tirtoni., 2023).

Therefore, this study aims to examine how circular economy principles have been integrated into contextual mathematics learning within green-based elementary schools. Specifically, it seeks to identify successful models, assess implementation challenges, and propose practical and policy-based recommendations to strengthen sustainability-oriented mathematics education.

METHOD

Research Design

This study adopted a qualitative descriptive approach using a thematic literature review aligned with the Standards for Reporting Qualitative Research (SRQR). The objective was to examine the integration of circular economy (CE) concepts into contextual mathematics instruction in green-based schools. The study relied on a structured analysis of peer-reviewed journal articles, policy documents, and school reports to identify patterns, strategies, and challenges in implementing sustainability-themed mathematics learning.

Participant

As this study did not involve human subjects, there were no individual participants. Instead, the unit of analysis comprised documented practices in selected green-based elementary schools. SDN Larangan and MI Terpadu Al-Falah Jepara were purposively selected as reference cases due to the availability of comprehensive documentation related to CE-oriented mathematics instruction. These schools exemplify models of good practice in integrating environmental education into core numeracy competencies.

Population and the Methods of Sampling Instrumentation

The population consisted of 22 relevant sources published between 20017 and 2024. These included academic journal articles, government education policies, curriculum frameworks, and school practice reports. Sources were selected through purposive sampling based on relevance to three core themes: circular economy, contextual mathematics learning, and education for sustainable development. Selection criteria emphasized methodological transparency, practical relevance, and representativeness of different stakeholder perspectives.

Instrument

The primary instruments employed in this study consisted of a document analysis matrix and a thematic coding framework specifically developed by the researchers. The matrix was designed to identify patterns related to basic numeracy, problem-solving, data representation, and circular economy principles. The thematic coding framework facilitated systematic classification and interpretation of data aligned with the research focus. Utilizing these instruments enabled the researchers to conduct an in-depth analysis of learning materials and curriculum context. This approach ensured the validity and reliability of findings concerning the integration of mathematical concepts and circular economy principles.

Procedures and if Relevant, the Time Frame

Data collection and analysis were conducted from January to April 2024. The researchers applied a structured document review protocol, which involved four main steps: (1) identifying relevant documents, (2) organizing them in a coding matrix, (3) conducting open and axial coding, and (4) synthesizing emergent themes. In parallel, documented learning activities from SDN Larangan and MI Terpadu Al-Falah Jepara were examined to explore practical implementations of CE-themed mathematics instruction. Peer debriefing and member checking were carried out to ensure the trustworthiness of interpretations and thematic classifications.

Analysis Plan

Thematic analysis was conducted inductively to categorize data into four key themes: circular economy, basic numeracy, problem-solving, and data representation. Coding was carried out in two stages: open coding to identify initial data patterns, and axial coding to connect related categories and refine themes. Constant comparison across data sources allowed for iterative refinement of interpretations. To enhance trustworthiness, Lincoln and Guba's (1985) criteria credibility, transferability, dependability, and confirmability were applied throughout the analysis process. Independent coder validation and source triangulation were also conducted.

Scope and/or Limitations of the Methodology Used

This study is limited to secondary data and does not include direct classroom observations or empirical testing. Therefore, the findings are descriptive and exploratory in nature. Nonetheless, the use of validated qualitative techniques, triangulated data sources, and adherence to established standards enhances the rigor of the research and provides a strong foundation for future empirical studies.

RESULTS AND DISCUSSION

Results

Table 1. Analysis of Circular Economy Implementation in Mathematics Learning

No	School	CE Implementation Approach	Mathematics Learning Activities	Student Engagement	Notes
1	SDN Larangan	Integrated into Merdeka Curriculum (P5 framework)	Measuring compost volume, data processing, calculating garden area	Active & direct	Considered a holistic best practice
2	SMA N 3 Surakarta	Reflected in school policy and curriculum	Statistical analysis and mathematical modeling using school waste data	Moderately active (60–71%)	Requires stronger student engagement
3	MI Al-Falah Jepara	Integrated through environmental education	Arithmetic using reused materials, measurement of length and weight	Highly participatory	Creative reuse in project-based learning
4	Compilation of 8 studies (Central Java)	Environmental-based instructional models	Problem-solving based on local ecological issues	Active in discussions	Average effect size: 1.245
5	Madrasah in Islamic Boarding School	Based on Islamic and ecological values	Geometry and logical reasoning contextualized in mosque/co-op settings	Experience-centered	Strong alignment with local cultural values

The findings indicate that the integration of Circular Economy (CE) principles into contextual mathematics instruction has been variably implemented across school types, with several exemplary practices and areas for improvement. A thematic synthesis of the data generated four overarching themes:

Theme 1: Mathematical Applications in Waste Quantification

In several schools, including SDN Larangan and MI Al-Falah Jepara, mathematics instruction was contextualized through environmental activities designed to quantify school-generated waste. Students engaged in tasks such as estimating the volume of compostable and non-compostable waste, calculating weekly waste production, and determining percentage reductions over time. These project-based activities facilitated the development of core mathematical competencies,

particularly in measurement, unit conversion, and basic statistics, while simultaneously fostering environmental awareness.

Figure 4. Sample bar graph comparison of total trash and compostable waste over 14 days in a school waste audit activity.

Figure 4 illustrates student-generated data from a 14-day waste audit, highlighting comparisons between total waste (blue bars) and compostable waste (red bars). The visual representation provides evidence of students' ability to apply mathematical concepts such as proportional reasoning and data analysis within an authentic environmental context. The integration of quantitative tasks with real-world environmental challenges proved pedagogically meaningful and cognitively engaging, reinforcing both numeracy skills and sustainability-oriented thinking.

Theme 2: Integration Through the P5 Project and Interdisciplinary Contexts

The integration of Circular Economy (CE) principles into mathematics learning is most effective when supported by structured, interdisciplinary frameworks. The *Pancasila Student Profile* (P5) Project exemplifies such a framework, providing a systematic platform for linking environmental practices with core mathematical competencies across different subjects in line with the *Merdeka Curriculum*.

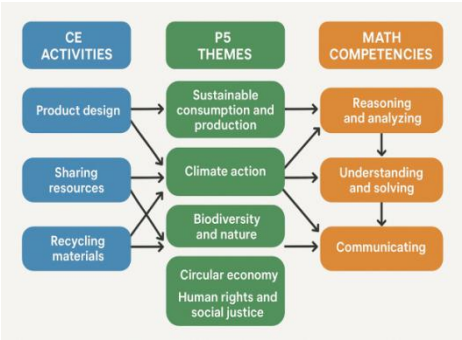

Figure 5. Thematic flowchart connecting CE activities, P5 themes, and math competencies

Figure 5 presents a thematic flowchart that visualizes the structured pathway connecting CE activities with the P5 thematic framework and key mathematical competencies. This integrative model demonstrates how sustainability-oriented, contextual instruction can enrich mathematics learning by embedding real-world practices into the educational process.

Empirical findings from this study indicate that CE practices such as eco-friendly product design, resource sharing, composting, and recycling function not merely as environmental actions but also as pedagogical tools. These practices are embedded in broader P5 themes, including sustainable consumption, climate action, biodiversity, and social justice. In practice, schools like SDN Larangan and MI Al-Falah Jepara implement these activities through student engagement in

composting, school gardening, and waste audits, which generate real-life data that serve as inputs for mathematical problem-solving.

Mathematics instruction is then reinforced through tasks involving estimation, measurement of volume and area, and data visualization using bar and pie charts. These activities are aligned with key numeracy competencies such as reasoning, problem-solving, and the effective communication of mathematical ideas. Thus, the flowchart represents an interdisciplinary instructional model where environmental education, civic values, and mathematical understanding converge meaningfully.

The thematic analysis confirms that the P5 Project particularly under the theme of "Sustainable Lifestyle" acts as an effective vehicle for designing project-based, interdisciplinary learning activities. These learning experiences foster not only cognitive development in mathematics but also emotional and social engagement by confronting real-world sustainability challenges. As a result, the integration of CE principles into mathematics instruction becomes a transformative pedagogical strategy that advances both the *Merdeka Curriculum*'s educational vision and the broader objectives of Education for Sustainable Development (ESD).

Theme 3: Implementation Gaps and Institutional Disparities

While some schools demonstrated strong integration of circular economy (CE) concepts, others encountered challenges due to limited teacher capacity, inadequate facilities, and rigid curriculum structures. For example, although SMA N 3 Surakarta had policies encouraging green learning, implementation within mathematics lessons remained limited. Student participation in environmentally related math activities was categorized as moderate (60–71%). Furthermore, environmental program data collected at the school level were often underutilized in classroom instruction.

This disparity highlights that beyond curricular directives, successful integration of CE into mathematics learning requires adequate infrastructure, teacher professional development, and cohesive school-wide support systems.

Table 2. Comparative matrix of CE integration, math linkage, and institutional support across 3 schools

School	Circular Economy Integration	Linkage to Mathematics	Institutional Support
SDN Larangan	Very good (composting, gardens, graphical data)	Very strong, explicitly embedded in curriculum	Strong, with teacher training and available facilities
SMPN 12 Bandar Lampung	Fair (waste bank and hydroponics)	Moderate, only integrated through the P5 theme	Moderate
SMA N 3 Surakarta	Low, not yet integrated	Weak, still separated from classroom instruction	Fair, but weak implementation

This study found that CE integration into contextual mathematics learning at green-based schools is commonly implemented through project-based approaches. These approaches link environmental activities with numerical concepts, especially in elementary settings. Students participated in measuring organic and inorganic waste, composting, and classifying recycling data activities connected to mathematical topics such as measurement, volume, and basic statistics.

These activities were frequently conducted within the framework of the Pancasila Student Profile (P5) Project, particularly under the theme "Sustainable Lifestyle." Such projects allowed students to estimate quantities, calculate ratios, and visualize data using bar and pie charts.

However, variations in implementation were evident across the schools. Institutions with strong leadership, adequate environmental facilities (such as organic gardens and waste stations), and innovative teachers who designed thematic lessons exhibited higher levels of CE integration. In contrast, schools lacking alignment among facilities, policies, and teacher readiness often struggled to embed CE principles into mathematics learning. These disparities underscore that the effectiveness of integration is largely influenced by the preparedness of each school's learning ecosystem.

Theme 4: Best Practices in CE-Math Integration at Model Schools

Model schools that have effectively integrated circular economy (CE) principles into contextual mathematics learning demonstrate a synergistic alignment between environmental engagement, cognitive development, and character formation. Rather than approaching sustainability and numeracy as separate educational targets, these institutions fuse them into a holistic learning framework. Project-based learning strategies are employed to transform environmental data into meaningful mathematical content, promoting both conceptual understanding and real-world problem-solving.

Figure 6 shows a Venn diagram illustrating the intersection of CE practices, mathematical competencies, and student learning outcomes. This convergence represents an optimal integration zone that promotes transformative learning, higher-order thinking, and sustainability mindset.

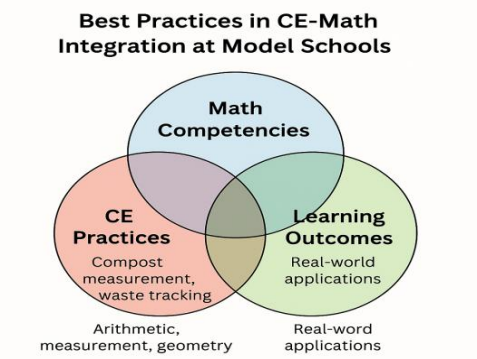

Figure 6. illustrates the intersection of circular economy practices, mathematical competencies, and student learning outcomes.

At SDN Larangan, students measured compost volume, monitored school garden productivity, and analyzed cafeteria waste data activities that were directly linked to units on measurement, volume, and statistics. Meanwhile, at MI Al-Falah Jepara, discarded food packaging was used in mathematics lessons to teach concepts such as area, perimeter, and data visualization. These practices support the development of key competencies including estimation, unit conversion, and the creation of tables, bar graphs, and pie charts.

Notably, this pedagogical approach yields both academic and behavioral outcomes. Students demonstrated improved contextual understanding of mathematics and exhibited pro-environmental behaviors such as consistent waste segregation and active participation in sustainability initiatives under the P5 "Sustainable Lifestyle" theme. These outcomes suggest a reinforcing loop between cognitive skills and character-based values.

This study provides both a conceptual and applied framework for integrating CE into mathematics instruction, aligned with the Merdeka Curriculum and the Pancasila Student Profile

(P5) Project. By leveraging authentic environmental practices, the model promotes curriculum innovation across thematic, interdisciplinary, and contextual dimensions.

The integration of CE in mathematics not only aligns with the theoretical principles of constructivism and Education for Sustainable Development (ESD) but also offers a scalable policy framework. It has implications for curriculum planning, teacher professional development, and whole-school approaches aimed at developing numeracy alongside ecological citizenship.

Discussion:

The findings reveal that integrating circular economy (CE) concepts into contextual mathematics learning in green-oriented schools is most effectively realized through project-based activities that embed environmental issues within mathematical content. This aligns with the principles of Contextual Teaching and Learning (CTL), which advocate real-life problem solving to strengthen conceptual understanding (Johnson., 2002; Darling-Hammond et al., 2020). Moreover, the application of social constructivist theory (Vygotsky, 1978) is evident, as students construct mathematical knowledge through interaction with authentic environmental contexts.

Context

Successful integration of CE principles is closely linked to a school's sustainability vision, leadership, and institutional commitment. Schools engaged in programs like *Adiwiyata*, supported by internal waste management policies and strong principal leadership, demonstrated deeper CE–math integration. Sterling (2010) and Barth et al. (2007) highlight that transformative learning environments depend heavily on leadership engagement and a whole-school approach to sustainability.

Input

Availability of environmental infrastructure such as organic gardens, waste banks, and measuring tools facilitates the contextualization of mathematical concepts. However, disparities in resource availability between schools remain a barrier. According to Tilbury (2011), institutional readiness and access to localized resources are key enablers of Education for Sustainable Development (ESD). Likewise, Mochizuki & Fadeeva (2010) emphasize the critical role of teacher professional development and contextually relevant curriculum materials.

Process

Teachers who design localized project-based lessons particularly under the P5 "Sustainable Lifestyle" theme were better able to integrate CE activities with mathematical skills, such as waste quantification, material estimation, and data visualization using bar and pie charts. Evidence supports Boaler's (2016) claim that context-driven, collaborative mathematics learning fosters engagement and conceptual depth. Bell (2010) also underscores the role of project-based approaches in enhancing STEM problem-solving competencies.

Product

Outcomes indicate gains in both numeracy and sustainability awareness. Students developed contextual mathematics skills while demonstrating environmentally responsible behaviors. As Wiek et al. (2011) and UNESCO (2017) argue, sustainability competencies are best cultivated through interdisciplinary, community-engaged projects that integrate cognitive, affective, and social learning outcomes.

Research Contribution

This study advances the discourse on sustainability-based mathematics pedagogy by offering grounded examples from both public and faith-based schools. The documented cases SDN Larangan and MI Al-Falah Jepara demonstrate the feasibility of CE integration in diverse settings and affirm constructivist and ESD principles. The study also supports culturally responsive

curriculum development aligned with the Merdeka Curriculum and the Pancasila Student Profile (P5) framework (Silvia & Tirtoni., 2023).

From a policy perspective, the findings call for curriculum reform that embeds sustainability themes within numeracy standards, promotes interdisciplinary teaching modules, and strengthens institutional support through infrastructure, monitoring tools, and teacher training.

Limitations

This study is limited in scope to three schools in Central Java and relies on document analysis rather than classroom observations, which may affect generalizability. Moreover, implementation disparities, such as those observed in SMA N 3 Surakarta, underscore systemic gaps in infrastructure, teacher capacity, and interdisciplinary integration. Future studies should adopt mixed-method and longitudinal approaches to evaluate long-term impacts of CE integration on learning outcomes.

Suggestions

To advance the integration of circular economy principles into mathematics education, schools must adopt a more comprehensive approach that moves beyond formal policy documents. Flexible and adaptive learning modules, supported by hands-on teacher training and community engagement, are critical to achieving transformative outcomes. Educational stakeholders should foster collaborative curriculum design that links mathematics instruction with real-life sustainability challenges faced by students. Policymakers should pair infrastructure support with capacity-building initiatives that empower teachers as agents of pedagogical innovation. Future research should explore scalable models of circular economy-based mathematics instruction, drawing on exemplars such as SDN Larangan and MI Al-Falah Jepara to develop technical guidance, monitoring tools, and community-aligned instructional strategies that align with the vision of the Merdeka Curriculum.

Thus, the integration of circular economy into mathematics learning is not only feasible but also effective in developing students' numerical understanding and ecological awareness. However, to ensure equitable implementation, support is needed in the form of curriculum policy, teacher training based on best practices, and the development of thematic teaching materials that are responsive to sustainability issues.

CONCLUSION

This study evaluated the integration of circular economy (CE) principles into contextual mathematics instruction in green-based schools. The findings indicate that CE-related practices such as reduce, reuse, and recycle have been embedded within project-based learning through the Pancasila Student Profile (P5) framework, particularly in cases such as SDN Larangan. These practices contributed to the development of students' numeracy competencies and nurtured pro-environmental attitudes through authentic, real-world applications.

This study contributes theoretically to the development of sustainability-oriented mathematics pedagogy by linking constructivist and Education for Sustainable Development (ESD) frameworks with practical instructional models. It highlights how contextual environmental activities can serve as effective vehicles for strengthening numeracy and character education in primary education.

Despite these promising outcomes, widespread implementation remains limited due to systemic challenges, including limited pedagogical resources, insufficient teacher training, and the absence of structured opportunities for student engagement in sustainability projects.

Future research should adopt longitudinal and mixed-method approaches to explore the long-term impacts of CE integration on students' mathematical performance, sustainability literacy,

and behavioral transformation. Expanding the research scope beyond Central Java to include diverse socio-educational contexts will improve the generalizability and relevance of findings.

To address these gaps, the development of practitioner-oriented implementation frameworks is essential. These frameworks should be supported by exemplars drawn from high-performing schools and include practical guidance on integrating CE into mathematics instruction through interdisciplinary and project-based approaches. Capacity building through sustained professional development is also necessary to enhance teachers' competencies in designing and facilitating contextualized environmental learning.

Furthermore, collaboration among schools, local education authorities, and environmental organizations is critical to support innovation and knowledge exchange. National initiatives such as the Adiwiyata Program and the Merdeka Curriculum offer strategic platforms to institutionalize CE practices in schools. Integrating waste audits, recycling activities, and school garden projects into mathematics learning modules provides meaningful opportunities to strengthen numeracy through sustainability-oriented content.

Future research should investigate the scalability of this model and its measurable effects on students' mathematical performance, sustainability literacy, and behavioral outcomes. Studies involving diverse school contexts beyond Central Java, as well as longitudinal approaches, are recommended to assess long-term impacts and inform broader educational policy reforms.

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AUTHOR CONTRIBUTION STATEMENT

Jovita Sandi Irawati: Conceptualization, Writing – Original Draft, Supervision
Mujib: Methodology, Formal Analysis, Visualization
Agung Wicaksono: Investigation, Data Curation, Writing – Review & Editing
Pandya Azalia: Resources, Project Administration

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