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Developing Environmental Numeracy Materials through Problem-Based Learning and Contextual Mathematics for Young Learners

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Abstract. This study develops and examines an educational material that integrates mathematics learning with environmental awareness, titled *Mathematics in Action: Counting Waste, Saving the Earth*. Designed for learners aged 8 to 12, the material connects core arithmetic concepts such as addition, multiplication, and estimation with real-world environmental issues, particularly waste management. Using authentic local data from the Citarum River in West Java as a contextual anchor, students engage in mathematical activities that encourage reflection on personal consumption habits and the long-term ecological impact of daily behavior. Employing a descriptive qualitative design that combines a systematic literature review and semi-structured interviews with mathematics teachers, the study synthesizes key perspectives from Environmental Education, Contextual Mathematics, and Problem-Based Learning. The findings indicate that embedding mathematics within environmental contexts enhances student engagement, critical thinking, and emotional connection to sustainability issues. Furthermore, the material aligns with Sustainable Development Goal 12 (Responsible Consumption and Production), offering a practical and values-driven model for integrating ecological literacy into elementary mathematics curricula. This research contributes to the broader discourse on interdisciplinary education and demonstrates how foundational math skills can foster environmental responsibility from an early age.

Keywords: Elementary School; Environmental Numeracy; Mathematics Education; Problem-Based Learning; SDG 12.

1. Introduction

Mathematics as a basic science discipline in education has an important role not only in developing analytical and problem-solving skills (Al-Mutawah et al., 2022), but also in answering real challenges in daily life (Salinas-Hernández et al., 2024), including environmental sustainability issues (Keum & Baek, 2025). In recent years, there has been a strong push to integrate mathematics education with global issues to foster critical thinking, social responsibility and environmental literacy among students (Oikonomou, 2025). Mathematics can serve as an approach to equip the community with ability to understand and take an active role in responding to environmental challenges in a reflective and sustainable manner (Lucas & Paulo, 2023). Environmental problems, especially in terms of waste management, require a quantitative approach to monitor, predict, and make decision (Debrah et al., 2021). Integrating mathematics instruction with real-world contexts such as calculating waste accumulation or analyzing consumption patterns, enhances the meaningfulness and relevance of learning for students (Agamuthu & Babel, 2023).

One of the environmental issues that shows the urgency of the role of mathematics in supporting sustainability is the critical condition of the Citarum River in West Java Province, Indonesia. The Citarum River, stretching approximately 270 kilometers, is a vital water resource that supports the livelihoods of millions of people, irrigates over 320,000 hectares of rice fields, and supplies water to three major hydroelectric power plants in the region (Satgas Citarum Harum, 2018). However, the Citarum River is severely polluted with garbage piles that reach around 15,000 tons per day (Widodo et al., 2023). The majority of this waste comes from

household and industrial waste, consisting of a mixture of organic and plastic waste (Hadfield et al., 2024). This huge volume of waste threatens the sustainability of river ecosystems, water quality, public health, and the local economy that depends on these natural resources.

Despite various government and community-based initiatives aimed at environmental restoration in the Citarum River, public awareness of the cumulative impact of daily waste generation remains limited. Studies have shown that the river continues to suffer from illegal dumping of plastic waste (Sakti et al., 2023), heavy metal pollution (Marselina & Wijaya, 2024), and land degradation (Sule et al., 2025), all of which contribute to the deterioration of both aquatic and agricultural ecosystems. Furthermore, satellite and geospatial analyses confirm the persistent accumulation of unmanaged waste along riverbanks, highlighting the urgency of grassroots behavioral change (Sakti et al., 2023). Given these challenges, it is essential to integrate environmental issues into the education system from an early stage. Embedding such issues into mathematics education provides an opportunity for students to model real data, quantify impacts, and evaluate solutions through arithmetic operations. The contextualization of mathematical learning using real-life environmental cases such as pollution data from the Cikijing River (a tributary of the Citarum), can foster critical thinking and a sense of environmental stewardship in young learners. This approach aligns with findings that support education for sustainable development (ESD) through interdisciplinary and learner-centered pedagogies (Vásquez et al., 2023). Moreover, using authentic environmental data to teach core mathematical concepts not only enhances numeracy but also promotes ecological consciousness in alignment with the Sustainable Development Goals (SDG 12) (Vásquez et al., 2023). As prior research also shows, integrating real-world contexts into mathematical problem-solving significantly improves student engagement and application skills (Baidoo & Ali, 2023).

1.1. Problem Statement

The environmental crisis in Indonesia, especially concerning waste management, continues to escalate despite numerous governmental and community-based interventions. Studies have shown that the river's condition is deteriorating due to illegal plastic dumping (Osra et al., 2021; Sakti et al., 2023), heavy metal contamination (Marselina & Wijaya, 2024), and critical land degradation in surrounding watersheds (Sule et al., 2025). These complex environmental challenges highlight a deeper issue: insufficient public awareness about the cumulative ecological impact of daily behaviors, particularly among the younger generation.

One of the root causes of this awareness gap lies in the disconnect between formal education and environmental realities (Portus et al., 2024). Although mathematics has the potential to help students interpret environmental data and evaluate consumption patterns quantitatively, conventional curricula often lack contextual relevance (Niles, 2025). Young learners aged 8 to 12 are rarely engaged in activities that connect arithmetic to real-world ecological concerns, limiting their ability to develop environmental numeracy (van de Wetering et al., 2022). This study responds to that gap by developing learning materials that combine mathematics with local environmental data using the Citarum River as a learning context to empower students with the skills and mindset necessary to understand and reduce their ecological footprint. This approach not only fosters critical thinking and personal responsibility but also directly supports the achievement of Sustainable Development Goal 12 on responsible consumption and production (Debrah et al., 2021; Vásquez et al., 2023).

1.2. Related Research

Previous research in Environmental Education and Education for Sustainable Development (ESD) has focused largely on promoting environmental awareness and sustainable values, often through science or social studies curricula (Vásquez et al., 2023). While mathematics has been recognized as a tool for solving real-world problems, its application in environmental contexts remains limited especially in primary education. Contextual Mathematics has been explored in various studies, but typically within cultural, economic, or generic real-life settings (Baidoo & Ali, 2023), not specifically targeting environmental crises like river pollution or waste management. Similarly, Problem-Based Learning (PBL) has been employed to enhance engagement and critical thinking, but rarely in combination with quantitative environmental literacy, particularly among younger learners.

This study addresses those gaps by offering a novel integration of PBL, contextual mathematics, and environmental numeracy for students aged 8 to 12. Unlike previous work, it uses real environmental data to develop arithmetic-focused learning activities that link daily consumption behavior to long-term ecological impacts specifically from the polluted Citarum River. The material, Mathematics in Action: Counting Waste, Saving the Earth, transforms abstract math operations into tools for sustainability reflection. This represents a unique pedagogical contribution: it bridges environmental awareness and core mathematics education while aligning directly with SDG 12 (Responsible Consumption and Production), filling a critical void in both curriculum design and early environmental literacy efforts.

1.3. Research Objectives

The growing complexity of waste management challenges necessitates a more contextualized and practical educational approach. One of the strategic opportunities in the context of education is to integrate mathematical concepts with environmental issues, especially waste management. However, this integration has not been systematically implemented in learning media in schools. In addition, it is also important to ensure that this learning approach is in line with the global agenda such as the Sustainable Development Goals, especially SDG 12 which emphasizes the importance of responsible consumption and production. Based on this background, this study formulates three main questions:

1. How can mathematics education be effectively integrated with environmental awareness, particularly in the context of waste management, for young students aged 8 to 12 years?
2. What forms of learning media are most effective in linking mathematical concepts with waste management issues?
3. How can mathematics learning ground in environmental issues contribute to the achievement of SDG 12 (Responsible Consumption and Production)?

These three research questions serve as the foundation for exploring and developing mathematics learning media that address not only cognitive skills but also the values of sustainability and environmental awareness.

This study aims to respond to the growing need for a more contextualized and relevant mathematics learning model that addresses environmental sustainability issues among students aged 8 to 12 years. Aligning with the focus on integrating scientific knowledge and environmental concern, this research specifically seeks to develop interactive learning media that combine mathematical concepts with environmental themes, particularly in the context of waste management, to enhance young students' environmental awareness (Lestari et al., 2024). Furthermore, this study aims to develop mathematics learning materials aligned with the SDG 12 (Responsible Consumption and Production), so that young students not only grasp the theoretical aspects of mathematics but are also empowered to apply them in real-life contexts that are socially and ecologically meaningful.

2. Theoretical Framework

Describe concepts that represent the framework of the research topic. It is derived from the variables or focus of the problem raised in the research. Use well-established reference sources to build a theoretical framework.

2.1. Problem-Based Learning

Problem-Based Learning (PBL) is a pedagogical approach that employs real-world problems as a medium to develop students' critical thinking, problem-solving abilities, and subject-matter comprehension (Anggraeni et al., 2023). Applicable across various educational levels, PBL encourages active student engagement, collaboration, and self-directed learning through problem analysis and group discussions (Shimizu et al., 2019). In this study, PBL serves as the foundational instructional model, chosen for its alignment with active, student-centered learning and its effectiveness in addressing authentic environmental issues. This approach positions students to confront ill-structured problems, in this case, waste management,

promoting deeper cognitive engagement and reflective learning (Stöckert & Bogner, 2020; Villas, 2024). Within the framework of environmental education, PBL enables learners not only to acquire theoretical knowledge but also to construct practical solutions, thereby fostering environmental literacy and empowering young students to act as informed, responsible agents of change.

2.2. Contextual Mathematics

The theoretical underpinning of Contextual Mathematics is pivotal to this study, advocating for the integration of mathematical concepts with tangible, real-world scenarios. Contextualizing mathematics by illustrating its practical utility in daily life enhances learning relevance; accordingly, this study immerses learners in the local context of the Citarum River and uses authentic waste generation data to transform abstract arithmetic operations into meaningful tools for understanding real-world environmental dynamics (Rubel & Mccloskey, 2021).This contextualization not only enhances students' comprehension and retention of mathematical principles but also empowers them to apply these skills to analyze and address pressing environmental issues within their own communities. Contextual learning immerses students in real, collaborative, and physically engaging environments where they take active responsibility for their learning, promoting both deep intellectual growth and the development of social and experiential skills through meaningful, embodied experiences (Morris, 2020). Teachers and curriculum developers can use contextual learning by selecting culturally relevant projects that align with learning objectives and time constraints, integrating it to connect mathematical concepts with students' real-life and cultural experiences, and developing curriculum materials that reflect local contexts to enhance meaningful and reflective learning (Ngala & Marsigit, 2024).

2.3. Environmental Numeracy

Environmental Numeracy forms a crucial theoretical pillar, defining the capacity to comprehend, interpret, and effectively utilize quantitative information pertaining to environmental concerns (Grieger & Leontyev, 2020). Beyond mere mathematical proficiency, this framework emphasizes the critical analysis of environmental data and the ability to make informed decisions for environmental stewardship. The "Mathematics in Action: Counting Waste, Saving the Earth" material is meticulously designed to cultivate this competency, guiding students to engage directly with waste data, perform relevant calculations, and critically interpret the environmental implications of these quantitative insights. This study emphasizes that fostering environmental numeracy in children is more effectively achieved through meaningful, context-based activities such as those in the home or natural environment (Bernabini et al., 2020). By strengthening environmental numeracy, this research aims to equip young learners with the essential skills to become environmentally literate citizens capable of understanding the magnitude of environmental problems and contributing meaningfully to sustainable solutions.

2.4. Education for Sustainable Development (ESD) and SDG 12

This theoretical framework is fundamentally guided by the principles of Education for Sustainable Development (ESD), with a specific focus on achieving the objectives of Sustainable Development Goal 12 (Responsible Consumption and Production). As articulated by UNESCO (2025), ESD seeks to empower learners with the requisite knowledge, skills, values, and attitudes to navigate the intricate challenges of sustainable development. By engaging students in a detailed exploration of waste generation and its multifaceted impacts, this study directly promotes behaviors aligned with responsible consumption and production. The reflective components integrated into the learning process further encourage students to critically examine their own consumption patterns and consider their long-term environmental footprint, thereby nurturing a generation committed to fostering a more sustainable future. Education plays a pivotal role in advancing sustainable development by shaping future leaders, embedding sustainability principles into curricula, and fostering a transformative culture, making it a foundational force for achieving the SDGs and driving long-term social change through inclusive, ethical, and globally minded education (Žalėnienė & Pereira, 2021).

3. Method

3.1. Research Design

This study employs a qualitative multi-method design combining a Systematic Literature Review (SLR) and semi-structured interviews with mathematics teachers. The aim is to build a strong theoretical foundation and ensure practical relevance in developing environmental numeracy learning materials for students aged 8 to 12. The SLR provides insight into global trends, theories, and pedagogical models, while the interviews ground the research in classroom realities, revealing curriculum alignment opportunities and pedagogical needs. The literature review was conducted using the Springer Nature database on January 2025, focusing on publications between 2020 and 2025. Data were coded and analyzed thematically using Miles and Huberman's interactive model (Miles et al., 2014), identifying key themes such as contextual mathematics, environmental literacy, and education for sustainable development.

Complementing the literature review, semi-structured interviews were conducted to understand how mathematics is currently taught, what environmental contexts are familiar to students, and which parts of the curriculum could be meaningfully linked to waste management topics.

To strengthen validity, the study applied peer debriefing with two education researchers to cross-check the analysis process and thematic interpretations. Triangulation across data sources (academic literature and teacher insights) helped reduce researcher bias and ensured contextual relevance. Limitations include the narrow scope of teacher interviews and the potential exclusion of relevant non-indexed literature. However, the integration of theoretical and practical insights enhances the reliability and applicability of the developed learning materials for use in real educational settings.

3.2. Characteristic of Learners

This study does not involve human participants in the traditional sense, as it is based on a literature review. However, the target audience for the developed learning material, *Mathematics in Action: Counting Waste, Saving the Earth*, is clearly defined. The characteristics of the intended learners are as follows (Table 1).

Table 1. Characteristic of Learners

Characteristics	Description
Age range	8 to 12 years old
Gender	Male and Female
Educational level	Elementary school students (Grades 3–6)
Relevance	Early environmental education and mathematics learning

Although these individuals are not directly studied, their characteristics are central to the design of the learning material and the selection of literature sources that inform the educational strategies.

3.3. Data Collection

Data collection in this study was conducted through a two-pronged approach: a systematic literature review and semi-structured teacher interviews. The search used the keywords "mathematics" and "waste management". Search filters were applied to limit results to English-language, open access, and document types including articles, research articles, review articles, conference papers, and books. From an initial pool of 871 documents, a total of 103 open access publications were identified, of which 12 education-focused articles were selected for in-depth analysis based on relevance to the research topic.

To complement the literature data, semi-structured interviews were conducted with three mathematics teachers in West Java to gather practical insights into curriculum structure,

student readiness, and opportunities to integrate waste management topics into classroom mathematics. These interviews were used to contextualize and validate the relevance of the literature findings within the Indonesian elementary education setting.

This multi-source data collection approach ensured both a solid theoretical foundation and practical alignment with current classroom realities in the design of the learning material. The following types of data were collected to support the development of the "Mathematics in Action: Counting Waste, Saving the Earth" learning material and to ensure their alignment with broader sustainable development goals.

- Scientific journal articles: Providing insights into theoretical frameworks, pedagogical approaches (e.g., Problem-Based Learning, Contextual Mathematics), environmental education, and environmental numeracy.
- Academic books: Offering foundational knowledge and in-depth discussions on relevant subjects.
- News publications from local media that show about waste management real conditions.

3.4. Data Analysis

The analysis in this study followed Miles and Huberman's interactive model (2014), which includes three stages: data condensation, data display, and conclusion drawing/verification. This model was selected for its systematic yet flexible structure, particularly well-suited for synthesizing data from literature and interviews.

For the systematic literature review, 12 selected education-focused articles were analyzed using manual thematic coding in Microsoft Excel. Each article was read in full, and relevant excerpts were extracted and categorized based on initial themes derived from the research objectives—such as contextual mathematics, environmental education, SDG 12 integration, and problem-based learning. A coding sheet was developed with columns for article source, excerpt, code, emerging theme, and researcher notes. Themes were then clustered using Miro to visualize conceptual links between environmental numeracy, sustainability goals, and mathematics instruction.

For the semi-structured interview data, transcripts from three mathematics teachers were similarly coded in Excel. Open coding was used to identify emerging patterns related to curriculum relevance, instructional challenges, and the feasibility of integrating environmental topics into mathematics learning. Codes from the interviews were then compared and merged with themes from the literature, allowing for cross-source triangulation and contextual validation. This combination of manual coding and visual mapping facilitated an iterative, transparent, and traceable analysis process, suitable for small-scale qualitative research. It ensured that both theoretical and practical insights were systematically integrated into the development of the learning material.

3.5. Validity and Reliability

To ensure the validity of this qualitative study, multiple strategies were applied. First, peer debriefing was conducted with two independent education researchers familiar with environmental education and mathematics curriculum design. They reviewed the coding structure, category definitions, and emerging interpretations. Their feedback was used to refine coding consistency and to avoid overgeneralization in the thematic synthesis.

Triangulation was applied by integrating data from multiple sources—scientific literature, teacher interviews, and local media reports on waste management. This strategy increased the robustness of the analysis by allowing findings to be confirmed across different types of evidence. Additionally, the use of both theory-driven and data-driven coding helped ensure that findings were grounded in both established frameworks and practical realities.

To address the limitation of researcher bias, the researcher maintained a reflexive journal during the data analysis process, noting assumptions, analytic decisions, and potential subjective interpretations. Transparency in methodological decisions, including article selection criteria and coding process, was maintained throughout the study. Nonetheless, limitations remain in

terms of the small sample of interviewed teachers (n = 3) and potential exclusion of relevant but non-indexed local publications, which may limit generalizability. Despite this, the integration of systematic literature evidence with contextual classroom insights enhances the trustworthiness, transferability, and practical relevance of the study's outcomes.

4. Findings

Contextual mathematics education plays a crucial role in enhancing students' understanding of the practical applications of mathematics in everyday life, including environmental issues. By connecting mathematical content to real-world contexts, contextual learning enables students to relate abstract concepts to their immediate surroundings, thereby strengthening their comprehension through relevant and meaningful problems. Moreover, mathematical literacy is a vital skill for competitiveness in the modern world, fostering students' ability to approach societal challenges with practical and analytical thinking (Oikonomou, 2025).

Education that integrates mathematics with sustainability can enhance students' understanding of their role in environmental preservation and better prepare them to address global challenges such as climate change and the management of limited natural resources. Developing an environmental education model from an early age, which is integrated across various school subjects, is essential to deepen students' awareness and comprehension of environmental issues (De Meyer et al., 2021).

4.1. Waste Management in Educational Contexts

The integration of waste management topics into mathematics learning is increasingly viewed as a strategic entry point for fostering environmental awareness among primary school students. Based on the review of 12 relevant studies, it is evident that addressing local environmental issues such as household and school waste and it can make abstract mathematical concepts more tangible and meaningful for young learners (Coles et al., 2024; Morrish & Neesam, 2021; Pinheiro et al., 2024). Activities involving the estimation of daily waste generation, for example, allow students to engage in authentic arithmetic tasks while also reflecting on the long-term environmental consequences of daily behavior.

This strategy is especially relevant in the context of the Citarum River, one of Indonesia's most polluted water bodies, which serves as a real-world anchor for environmental numeracy development. By engaging with contextual data such as the average waste produced per person (0.7 kg/day), students are not only learning to calculate, estimate, and model data but are also encouraged to critically assess their own consumption habits. Research supports the notion that ecological values are more effectively internalized when environmental problems are visualized and quantified, rather than discussed in abstract terms. In this way, mathematics education becomes a powerful medium for cultivating both numeracy skills and environmental responsibility from an early age.

4.2. Sustainable Development Goals (SDGs) and Education

Contextual and participatory learning approaches have emerged as effective strategies for improving the quality and relevance of mathematics education at the elementary level. Findings from the reviewed literature indicate that when mathematics is taught through real-world environmental issues, such as waste management, students demonstrate higher levels of engagement, critical thinking, and conceptual understanding. Learning becomes more meaningful when mathematical problems are situated within the students' immediate environment, allowing them to connect numbers with everyday life situations. In contextual learning approaches, the use of imagery with strong affective value is essential in building a personal connection between students and the subject matter (Lee et al., 2023).

Several studies highlight the benefits of Problem-Based Learning (PBL) as a participatory model that encourages students to explore, question, and collaborate in solving authentic problems. When students are presented with scenarios such as calculating their school's monthly waste output or projecting waste accumulation over time, they are actively involved in mathematical reasoning while simultaneously developing environmental awareness (Iyamuremye et al.,

2025). This participatory process fosters not only cognitive skills but also emotional engagement, as students begin to perceive environmental problems as personally relevant and solvable. Therefore, integrating contextual and participatory methods into mathematics instruction supports the dual goal of enhancing numeracy and nurturing responsible, sustainability-oriented behavior in young learners (Makramalla et al., 2025). In this case, the Citarum River (Figure 1) is no longer perceived merely as a geographical object or a statistical abstraction, but as an integral part of an ecosystem directly connected to their lives.

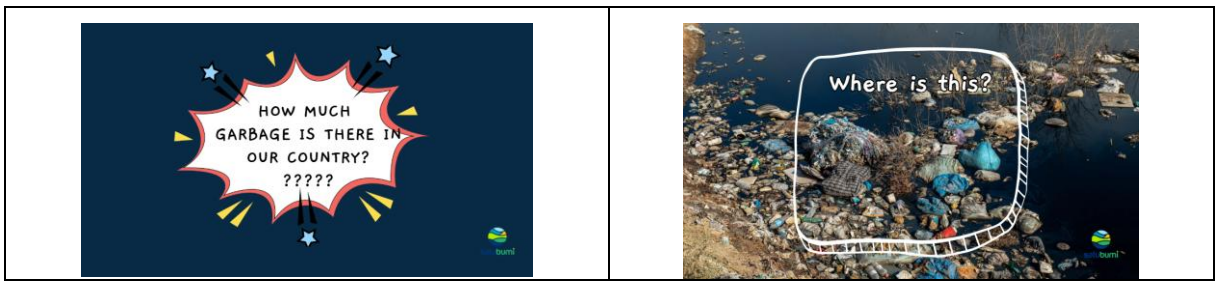

Figure 1. Illustration of the Citarum River Condition and reflective questions as a stimulus of students' environmental awareness.

4.3. Sustainable Development Goals (SDG 12) and Education

SDGs 12 highlights the importance of responsible consumption and production in maintaining ecological balance and preventing environmental degradation caused by the overexploitation of natural resources (Žalėnienė & Pereira, 2021). The integration of mathematics education with the principles of Sustainable Development Goal 12 (Responsible Consumption and Production) represents a progressive shift in the way numeracy is taught to young learners. SDG 12 underscores the importance of transforming human consumption and production patterns to reduce environmental impact, ensure the sustainable use of resources, and prevent social inequalities and threats to global well-being (Capah et al., 2023). Several reviewed studies emphasize that mathematical learning can be a powerful tool for promoting sustainability literacy, especially when focused on real-world issues such as resource consumption, waste generation, and ecological footprints. By involving students in long-term projection tasks, data interpretation, and scenario modeling, mathematics becomes more than a cognitive subject and it becomes a means of understanding and solving environmental problems (Makramalla et al., 2025).

One effective way to support the achievement of SDG 12 is to promote education that emphasizes responsible waste management. Education can empower individuals to understand the importance of reducing, reusing, and recycling waste, as well as minimizing the environmental impact of unsustainable consumption habits. Approaches such as problem-based active learning, cross-disciplinary collaboration, and the role of teachers as facilitators, combined with the integration of sustainability principles into curricula and institutional governance, enable education to play a vital role in building community capacity and competence to advance sustainable development (Kioupi & Voulvoulis, 2019). Education on responsible waste management not only contributes to pollution reduction but also fosters awareness of the critical role individuals play in maintaining environmental sustainability. As Nelson Mandela famously stated, "Education is the most powerful weapon which you can use to change the world," highlighting the transformative potential of education. In this context, the Mindset Network serves as a vital tool within this world-changing arsenal, providing valuable resources to support environmental education and awareness (Mandela, 2003).

The development of the Mathematics in Action: Counting Waste, Saving the Earth learning material reflects this alignment by incorporating environmental data that prompts students to calculate the consequences of daily waste production over time. Tasks such as estimating yearly waste or comparing personal consumption patterns enable students to connect numerical reasoning with ethical decision-making (Elbahan et al., 2022). Furthermore, cross-disciplinary integration where mathematical content intersects with environmental values has been shown to strengthen civic responsibility and student agency when embedded in student-

centered inquiry (Manishimwe et al., 2024; Wang et al., 2025). This positions mathematics not only as a technical skill set, but also as a formative space for cultivating responsible (Bettencourt et al., 2023) and sustainability-minded individuals from an early age.

4.4. Integration of Mathematics and Environmental Issues in Learning Media

The literature reviewed indicates a persistent gap in mathematics curricula, where opportunities to connect arithmetic learning with pressing environmental issues remain largely untapped. Several studies highlight that mathematics lessons often remain abstract, lacking contextual relevance to students lived experiences (Makrooni et al., 2025; Morrish & Neesam, 2021; Pinheiro et al., 2024). This study responds to that gap by designing a learning module that strategically integrates mathematical operations with real environmental data, thereby fostering both numeracy and ecological awareness among primary school students.

The development of the Mathematics in Action: Counting Waste, Saving the Earth module offers a practical example of how environmental issues such as waste accumulation in the Citarum River and it can serve as authentic learning contexts (Figure 2). Supported by findings from Articles 6 and 7, this approach demonstrates that students show higher retention and engagement when mathematical tasks are directly related to their communities. By involving students in exercises like calculating the annual waste generated by their class (e.g., 0.7 kg × 365 days × number of students), the material cultivates computational fluency while simultaneously promoting long-term thinking about environmental impact. This fusion of content and context is a key characteristic of environmental numeracy and aligns with current efforts to embed sustainability into foundational education.

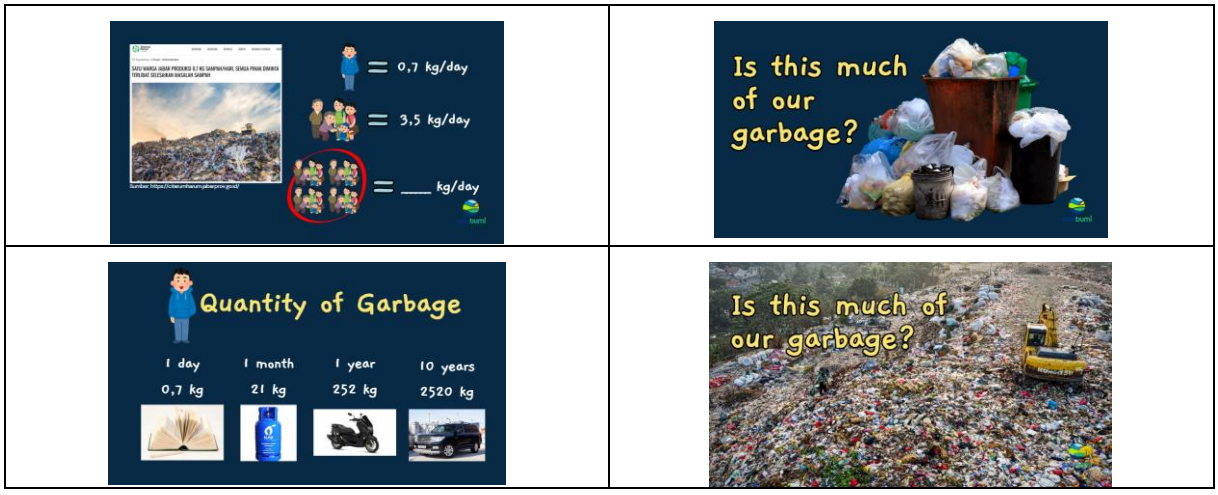

Figure 2. Visual of "Mathematics in Action: Counting Waste, Saving the Earth"

Through this activity, students are engaged in performing basic mathematical operations (such as multiplication and addition) while simultaneously developing an understanding of the long-term consequences of daily consumption behaviors. In this way, mathematics is taught not merely as a cognitive skill, but as a critical thinking tool for interpreting real-world problems (Lo, 2020). When students realize that even seemingly small amounts of daily waste can accumulate into significant impacts over time, they begin to develop mathematical literacy that is closely tied to ecological awareness, also known as environmental numeracy. This activity also supports data-driven learning, encouraging students not only to calculate but also to question and critically analyze the outcomes of their calculations.

5. Discussion

The learning media Mathematics in Action: Counting Waste, Saving the Earth holds significant potential for replication across various educational levels and diverse learning contexts. Although initially developed for children aged 8 to 12 years, the contextual approach employed is flexible and can be adapted to suit the cognitive abilities of learners at higher levels. At the elementary school level, the primary focus may be directed toward fundamental

arithmetic operations and the introduction of environmental values. Meanwhile, at the secondary education level, the material can be further elaborated by integrating concepts such as statistics, graph interpretation, or simple mathematical models to analyze waste production trends or predict the impacts of specific environmental policies. This approach not only maintains educational relevance but also strengthens interdisciplinarity among mathematics, science, and social studies.

5.1. Summary and Interpretation of Findings

This study aimed to develop mathematics learning materials that integrate environmental awareness, contextualize arithmetic within real-world problems, and align with Sustainable Development Goal 12 (Responsible Consumption and Production). The findings indicate that waste management can serve as an accessible and meaningful context for students to engage in arithmetic operations while simultaneously reflecting on their ecological footprint. The use of real data from the Citarum River pollution was particularly effective in anchoring abstract concepts to local realities, thereby fostering environmental numeracy at the elementary level.

The incorporation of contextual and participatory approaches—especially through Problem-Based Learning (PBL) enhanced student engagement, critical thinking, and long-term retention, echoing findings from prior studies (e.g., (Baidoo & Ali, 2023; Lee et al., 2023). Moreover, the integration of sustainability concepts into mathematics education supported both cognitive and affective learning goals, confirming the dual role of mathematics as a tool for computation and ethical reflection.

5.2. Comparison with Previous Studies

The findings of this study are supported by a range of existing literature that advocates for the contextualization of mathematics as a strategy for deepening conceptual understanding and increasing student engagement. When mathematical content is linked to real-life scenarios, particularly those relevant to students' communities, learners demonstrate stronger problem-solving skills and greater interest (Baidoo & Ali, 2023). This aligns with the present study's use of waste data from the Citarum River to make arithmetic tasks meaningful and applicable.

Supporting this view by emphasizing that embedding sustainability themes such as consumption patterns and ecological footprints into mathematics instruction fosters both cognitive development and values-based reasoning (Vásquez et al., 2023). Similarly, (Coles et al., 2024) and (Makrooni et al., 2025) highlight that introducing environmental contexts in math learning not only enhances numeracy skills but also cultivates social awareness and responsible behavior, especially among primary school students.

Articles by (Hadfield et al., 2024) and (Marselina & Wijaya, 2024) contribute an important local dimension by illustrating the educational relevance of environmental data in Indonesian settings. Their work on pollution and plastic waste in West Java underlines the value of using localized environmental problems as a pedagogical tool to approach directly adopted in this study through the "Counting Waste" module. Moreover, environmental degradation in Indonesia, including critical waste and land conditions, requires integration into public education, not just as information but as quantifiable challenges (Hadfield et al., 2024). This further validates the strategy of linking basic mathematical operations such as estimation and multiplication to real-world waste management figures (Keum & Baek, 2025).

While many of these studies advocate for contextual and problem-based instruction, some differences arise when comparing with literature from higher-income setting, where advanced technological tools such as simulation platforms and digital games are used to support environmental numeracy (Piscová et al., 2023). These models often rely on infrastructure that may not be available in all educational contexts. In contrast, the present study favors a low-tech, data-grounded, and locally contextualized approach, making it more feasible and scalable for primary schools in resource-constrained environments.

Despite these methodological differences, the common thread across the reviewed studies is the recognition that mathematics can be used to promote critical thinking, social responsibility, and sustainable behavior when connected to authentic, relatable issues (Jong, 2020). This study contributes by demonstrating how such integration can begin with basic arithmetic operations and locally relevant problems, offering a practical model for early environmental numeracy education.

5.3. Implications for Theory and Practice

Theoretically, this study advances the discourse on environmental numeracy by situating it within the domain of basic mathematics particularly addition, multiplication, and estimation at the elementary school level (Jong, 2020; Piscová et al., 2023). Previous models of environmental numeracy have predominantly focused on statistical literacy or data interpretation among older learners (e.g., upper secondary or tertiary level), often overlooking early-grade arithmetic as a potential entry point. This study fills that gap by demonstrating that even foundational mathematical operations can be meaningfully linked to environmental reasoning when framed through authentic and locally relevant contexts.

By embedding real-world issues such as household waste generation or river pollution into simple arithmetic problems, students are not only developing their numerical skills but are also beginning to internalize sustainability concepts, such as cause-effect thinking, cumulative impact, and responsible consumption (Björklund et al., 2021). This positions basic mathematics as more than a technical subject; it becomes a cognitive and ethical platform for nurturing environmentally conscious citizens from a young age.

Practically, the study offers a replicable and adaptable pedagogical framework for integrating contextual mathematics with environmental education. Through the use of Problem-Based Learning (PBL), real-life data, and student-centered tasks, the learning material designed in this study serves as a model that educators can implement across various educational settings (Stanišić et al., 2023). Teachers can contextualize similar activities using local waste data, student experiences, or school-based environmental problems, thus enhancing the relevance and resonance of mathematics in everyday life (Aslan, 2021).

Furthermore, the study provides an accessible alternative for schools that may not have access to advanced technology (Topal & Korkmaz, 2023). By emphasizing low-tech, data-driven, and locally anchored materials, the approach empowers educators in under-resourced areas to teach both numeracy and environmental awareness effectively (Manishimwe et al., 2024; Pinheiro et al., 2024). This dual focus opens new pathways toward achieving core educational goals: strengthening students' mathematical competence while fostering their ecological responsibility in alignment with the principles of Education for Sustainable Development (ESD).

5.4. Limitations

Despite these contributions, the research has several limitations. First, the sample of teacher interviews was small (n = 3) and regionally limited to West Java, which may restrict the generalizability of insights. Second, while the Systematic Literature Review (SLR) was conducted using clear keywords and filters, it only included English-language open-access sources from Springer Nature, potentially excluding valuable local or non-indexed research. Third, the learning material was developed conceptually but has not yet been implemented in a classroom setting, meaning its effectiveness remains to be validated empirically.

5.5. Theoretical Contribution

This study contributes to the growing discourse on interdisciplinary and values-based mathematics education by advancing a framework for environmental numeracy that is suitable for early-grade learners. It demonstrates how real-world environmental issues—typically addressed in science or civics—can be embedded within mathematics curricula using PBL and contextual learning. By aligning arithmetic instruction with SDG 12, the study provides a model for how mathematics can foster both cognitive development and

sustainability-oriented behavior, offering a unique pedagogical approach to achieving ESD goals in primary education.

6. Conclusion

This study was guided by the question of how mathematics education can be effectively integrated with environmental awareness particularly waste management, to support basic arithmetic learning and the achievement of SDG 12 in students aged 8 to 12. The development of Mathematics in Action: Counting Waste, Saving the Earth demonstrates that contextualizing arithmetic through real-world environmental issues enhances not only computational fluency in operations like addition, multiplication, and estimation, but also nurtures students' critical thinking and sense of environmental responsibility. By grounding learning in authentic, locally relevant contexts such as the Citarum River, the material transforms mathematics into a participatory and values-driven subject, strengthening both engagement and sustainability literacy. The implications of this study are significant: it provides a replicable framework for teachers and curriculum developers to integrate environmental numeracy into foundational education, even in low-resource settings. Through its emphasis on contextual mathematics and environmental problem-solving, this research contributes to both educational theory and practice by positioning basic mathematics as a tool for fostering ecological awareness and responsible consumption behavior from an early age.

Limitation

This study's primary limitation lies in its conceptual and design-focused nature, relying on a systematic literature review and a small-scale qualitative input from three mathematics teachers without conducting empirical classroom implementation. As such, the actual effectiveness of *Mathematics in Action: Counting Waste, Saving the Earth* in enhancing students' environmental numeracy remains untested in practice. Furthermore, the literature review was limited to English-language, open-access articles from the Springer Nature database, which may exclude valuable local or non-indexed sources. Broader field validation and diversified data sources are necessary to ensure generalizability and pedagogical robustness.

Recommendation

Mathematics in Action: Counting Waste, Saving the Earth presents a replicable model for integrating basic arithmetic learning with environmental awareness in primary education. Its contextual, low-tech design makes it adaptable not only across formal, non-formal, and informal learning environments, but also within resource-constrained schools. The learning media's emphasis on real-world data, student participation, and problem-based inquiry aligns strongly with interdisciplinary and values-based education goals. Future research is encouraged to empirically test and refine the material in classroom settings, involve a broader range of teachers and students, and explore digital adaptations to expand accessibility and engagement. As environmental challenges grow increasingly urgent, such innovations are essential for equipping learners with both mathematical competence and ecological responsibility.

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Conflict of Interest

There are no elements in the study or publication of articles that indicate a conflict of interest.

Declaration of Generative AI-assisted Technologies

This manuscript was prepared with the assistance of Generative AI Gemini. The AI was used to assist in language refinement. All intellectual contributions, critical analyses, and final revisions were conducted by the authors. The authors take full responsibility for the accuracy, originality, and integrity of the content presented in this work.

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