



## Transforming mathematics teaching and learning for sustainability in africa: A critical qualitative synthesis of eco-mathematics pedagogy

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### Abstract

**Background:** The escalating ecological crisis has emphasized the need for education systems to actively contribute to sustainable development. Despite this, mathematics education has yet to be systematically theorized or integrated into sustainability agendas, particularly within African contexts.

**Aims:** This study critically synthesizes eco-mathematics pedagogy as a transformative approach to teaching mathematics for sustainability, with special attention to its alignment with African Indigenous Knowledge Systems (IKS).

**Methods:** Employing an interpretivist paradigm, this research uses a critical qualitative synthesis design grounded in critical mathematics education, ethnomathematics, and decolonial theory. Data were analyzed through inductive thematic synthesis and critical discourse analysis, drawing exclusively on peer-reviewed empirical studies, curriculum frameworks, and policy documents.

**Results:** Findings reveal a continuum of eco-mathematics practices, from superficial environmental contextualization to radical, community-based pedagogies rooted in IKS. While IKS integration supports enhanced learning, persistent challenges include limited teacher preparation, inflexible curricula, and insufficient culturally relevant resources, which affect student engagement, critical thinking, and ecological awareness.

**Conclusion:** Sustainability-oriented mathematics education that leverages Indigenous epistemologies can reposition mathematics as central to socio-ecological transformation in Africa. This synthesis provides evidence-informed guidance for curriculum revision, teacher training, and policy coherence, contributing to the development of eco-mathematics as a decolonial and socially just pedagogy.

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## INTRODUCTION

The increasing environmental crisis on Earth has highlighted the urgent need for education systems to contribute effectively to sustainable development. Mathematics education, as a critical cognitive and analytical tool, remains underexplored in its potential to foster sustainability literacy among learners (Ferrer-Estévez & Chalmeta, 2021). Traditional mathematics curricula often emphasize abstract problem-solving detached from socio-ecological contexts, which limits students' capacity to address real-world environmental challenges. Emerging literature on sustainability in mathematics education has led to the development of frameworks such as "mathematics education for sustainable futures" that integrate ethical, cultural, and action-oriented dimensions (Makramalla et al., 2025). Eco-mathematics pedagogy responds to this need by promoting reflective and practice-oriented approaches, integrating ethnomathematics, and situating learning within environmental and societal contexts. Critical Mathematics Education frameworks support this approach by enabling students to understand and interpret the ecological state of the world through mathematical reasoning (Coles et al., 2024). By connecting abstract concepts to concrete environmental issues, eco-mathematics fosters critical thinking, problem-solving, and socio-ecological engagement.

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Furthermore, it empowers learners to recognize the ethical implications of mathematical knowledge in real-life scenarios. Despite these developments, the effective implementation of eco-mathematics in African classrooms remains limited. There is a pressing need to examine how these pedagogical strategies align with local Indigenous Knowledge Systems and cultural practices.

African educational systems offer rich repositories of Indigenous Knowledge Systems (IKS), which present unique opportunities for contextualizing mathematics in ways that enhance both ecological and cultural literacy (Chirume, 2017; Gyamerah, 2025). Integrating IKS into mathematics education allows learners to engage meaningfully with local environments while fostering critical and ethical reasoning. However, these approaches are often marginalized by standardized global curricula and lack systematic incorporation into formal classroom practice (Madimabe-Mofokeng et al., 2025). Eco-mathematics pedagogy in African contexts has the potential to bridge global sustainability frameworks with local realities and decolonial educational perspectives (Khupe & Keane, 2017). Current literature emphasizes fragmented or peripheral applications of sustainability and IKS, leaving critical pedagogical and epistemic aspects underexplored. Such gaps hinder the development of mathematics education that is both culturally responsive and sustainability-oriented. Teacher preparation programs frequently overlook decolonial and context-specific pedagogical skills necessary for implementing eco-mathematics. Additionally, curriculum constraints and a lack of culturally relevant instructional resources further limit classroom application. Therefore, systematic research is needed to operationalize eco-mathematics pedagogy within African educational frameworks. Addressing these gaps is essential for transforming mathematics education into a tool for ecological and social empowerment.

Despite its theoretical promise, eco-mathematics pedagogy requires empirical scrutiny to evaluate its practicality and effectiveness across diverse African educational contexts. There is limited research on how students and educators perceive and enact these pedagogical strategies, particularly regarding critical thinking, engagement, and socio-ecological literacy (Edwards Jr et al., 2024). Existing studies often focus on small-scale or theoretical interventions, leaving structural and systemic challenges largely unexamined. Teacher professional development, curriculum redesign, and policy alignment remain areas in need of evidence-based guidance. The contextualization of global sustainability frameworks to local cultural, ecological, and epistemic realities is underexplored. Moreover, the interaction between Indigenous Knowledge, decolonial approaches, and eco-mathematics pedagogy has received insufficient attention. Understanding these intersections is crucial for designing education that is both socially just and environmentally responsible. There is a need to move beyond tokenistic integration of sustainability concepts, toward transformative and culturally grounded educational practices. Empirical evidence is required to inform curriculum, instructional strategies, and policy. Hence, a critical and systematic examination of eco-mathematics pedagogy is essential to realize its potential in African classrooms.

Existing literature demonstrates notable advances in integrating mathematics with sustainability concepts, ecological modeling, STEM/STEAM education, and Indigenous Knowledge Systems (IKS), including ecological mathematics frameworks (Paton et al., 2026; Unnithan Kumar, 2024), mathematical models for ecological dynamics (McClintock et al., 2020), and sustainability-oriented STEM/STEAM education to enhance problem-solving and critical thinking skills (Belbase et al., 2022; Hsiao & Su, 2021; Sholihah & Lastariwati, 2020), while ethnomathematics approaches have contextualized learning within local cultures (Kabuye Batiibwe, 2024; Lidinillah et al., 2022; Sari et al., 2023) and IKS has been highlighted to strengthen culturally relevant pedagogy and ethical engagement (Ajani et al., 2024; Mbah et al., 2021; Muir et al., 2023). Despite these contributions, there remain significant gaps, including the limited systematic synthesis of eco-mathematics pedagogy in African contexts that bridges IKS, decolonial principles, and curriculum design, insufficient empirical evidence on practical strategies for implementing decolonial pedagogy and professional learning in

mathematics classrooms (Foster et al., 2022; Gyamerah, 2025; Nicol et al., 2020), underexplored challenges such as teacher readiness, curriculum rigidity, and lack of scalable instructional resources, and minimal studies linking decolonial curriculum redesign to measurable outcomes such as student engagement, critical thinking, and ecological literacy. Consequently, there is a critical need for systematic syntheses and empirical investigations that integrate eco-mathematics, decolonial theory, professional learning, and Indigenous Knowledge into mathematics education to provide actionable guidance for educators, curriculum developers, and policymakers in transforming African mathematics classrooms beyond symbolic or theoretical interventions.

This study aims to conduct a critical qualitative synthesis of eco-mathematics pedagogy in African classrooms to examine how sustainability-oriented mathematics education can be operationalized effectively. It seeks to explore the integration of Indigenous Knowledge Systems and decolonial pedagogical principles into formal mathematics teaching. The study aims to identify structural, curricular, and instructional challenges that hinder the practical implementation of eco-mathematics. It also intends to assess the potential of eco-mathematics to foster critical thinking, problem-solving, and ecological literacy among learners. Furthermore, the research examines the role of teacher professional development in supporting decolonial and sustainability-oriented practices. The study consolidates evidence from empirical research, curriculum frameworks, and policy documents to provide actionable guidance for educators and policymakers. It seeks to bridge theoretical frameworks with practical classroom strategies that enhance learner engagement and culturally responsive teaching. The research also aims to highlight gaps in current literature that limit the systematic adoption of eco-mathematics in African contexts. Ultimately, this study provides insights into curriculum design, instructional strategies, and policy coherence for sustainability-oriented mathematics education. By achieving these objectives, the study contributes to transforming mathematics education into a tool for ecological, cultural, and social empowerment.

## LITERATURE REVIEW

The ubiquitous environmental crisis and the universal idea of sustainable development have triggered a paradigm shift across all spheres of education, making it an increasingly pivotal pillar of transformational change (Ferrer-Estévez & Chalmeta, 2021). In this context, mathematics education is reconsidered, as it can play a significant role in the sustainability agenda and is no longer seen as an abstract subject. This literature review summarizes the main conceptualizations of mathematics education to ensure its sustainability, describes the theoretical and pedagogical foundations of eco-mathematics, and critically examines its interface with the African educational context, particularly in relation to indigenous knowledge systems and decolonizing processes.

### *The Changing Landscape of Mathematics Education for Sustainability*

The need to make sustainability an asset of education stems from the international community's awareness of the urgent environmental, social, and economic issues (López-Serentill et al., 2024). Education for Sustainable Development initiatives, including those promoted by UNESCO, are based on a comprehensive and transformative education that integrates sustainability concerns into curriculum development, draws on learner-centred and action-oriented pedagogy, and competencies such as critical and systems thinking (López-Serentill et al., 2024). Mathematics has long been considered a foundational subject, but it is increasingly seen as an important tool for a quantitative way of understanding and solving these issues (Li, 2025). Though the term that is used to mean sustainability of mathematics education is mathematics education of sustainable futures, the problem-solving in a technical manner is foreseen in the term of mathematical modeling of sustainability, where the eco-mathematics pedagogy attempts to reconcile the two orientations by

incorporating ethical, cultural, and action dimensions. This is an indication of a socio-ecological twist in mathematics education, in which the discipline reflects on and reconsiders its priorities and practices in light of ecological collapse (Coles, 2022). The curriculum is changing to focus more on learning outcomes that enable students to engage in a globalized context, comprehend alternative opinions, and act responsibly to support overall well-being and sustainability (Taguma et al., 2023).

### ***Eco-Mathematics Pedagogy: Approaches and Theoretical Bases***

Eco-mathematics pedagogy is one of the important responses to the demand to introduce sustainability into mathematics education. It promotes reflective and action-oriented mathematics instruction, inclusive of ethnomathematics and sustainability challenges, approached with an ethical and pragmatic perspective. Based on constructivist learning theory and critical mathematics education, eco-mathematics is a theory that highlights how learners create a sense of place through meaningful, contextualized learning and that mathematics ought to enable people to critically assess and act on problems in society. The views on mathematics have traditionally been shaped by Critical Mathematics Education (CME) as an approach to social justice and peace. More recently, CME scholarship has increasingly focused on the ecological aspect, showing how mathematics education can be used to read and write the ecological state of the modern world, such as climate change (Coles et al., 2024).

Ethnomathematics is an intervention in the critical epistemology of Western mathematics that questions the universalist assertions of that field and redefines local knowledge systems as acceptable foundations for mathematical thought (Rosa & Orey, 2020). This methodology contradicts the belief that mathematics is a culturally neutral concept and presents it as a human activity firmly embedded in various cultural backgrounds (Atta & Bonyah, 2023). With its combination of cultural relatability and personal experience, ethnomathematics aims to help students understand reality, culture, society, and themselves, thereby promoting new ecological solutions and democratic participation (Atta & Bonyah, 2023). According to this school of thought, one barrier in mathematics education is that it has often failed to recognize the importance of local mathematical practices in its theoretical foundations. Eco-mathematics facilitates a critical pedagogy by adopting ethnomathematics to engage with mathematics, community, culture, and local pathways, and to teach students to read and write the world with mathematics (Nicol, 2018).

### ***Opportunities and Challenges of Eco-Mathematics in African Classrooms***

The implementation of the eco-mathematics pedagogy in African classrooms is a complex and rich situation full of both opportunities and challenges. African indigenous knowledge systems propose holistic, dynamic, and resilient systems of knowledge which have been developed over time through a process of continuing engagement with nature (Gyamerah, 2025). The systems offer high-quality, localized insights into environmental stewardship and sustainable living that can radically transform eco-mathematics pedagogies (Shabalala, 2025). The inclusion of AIKS in mathematics education aims not only at ecological ethics but also at epistemic justice, which is part of decolonizing mathematics education. This kind of integration can revolutionize and decolonize mathematics education for sustainable development, as demonstrated in Nigeria (Salami & Okeke, 2017). The need to Africanize curricula, especially the mathematics curriculum, is increasing to eliminate the impact of colonial history and improve educational outcomes.

Nevertheless, there are various obstacles to the adoption of eco-mathematics and the integration of AIKS in the African settings. Curriculum inflexibility, lack of teacher readiness, and empty symbolic policy engagements that do not necessarily lead to effective implementation are challenges (Shabalala, 2025). There is also the issue of teachers struggling to incorporate the methodology of ethnomathematics into an area of study such as geometry, even though official curricula can support this approach (Sonzuma & Maharaj, 2019). Moreover, there is a lack of

literature on mathematics pedagogies that address sustainable development at the secondary school level in Africa, which suggests a research gap (Gaanya et al., 2025). In some African nations, mathematics textbooks have been reviewed to determine their sustainability within the education system, suggesting the need to contextualize and revise the material to facilitate successful learning (Sunzuma & Luneta, 2023). These obstacles notwithstanding, new innovations in storytelling, community co-teaching and land-based learning can provide viable options for incorporating indigenous knowledge into environmental education and, through it, eco-mathematics (Shabalala, 2025). This review highlights the need to conduct further research on the pedagogical contextualities, application modalities, and effects of eco-mathematics teaching across different African schools, as a necessary and urgent endeavour. This research is necessary to understand how global systems of sustainable mathematics education can truly align with local conditions, culture, and decolonization processes to build a mathematics education that is not only culturally resonant but also ecologically accountable.

## METHOD

### Research Design

This study employed a critical qualitative synthesis design, grounded in an interpretivist research paradigm. The design focuses on synthesizing conceptual, pedagogical, and empirical literature to produce higher-order meanings of eco-mathematics pedagogy in African settings (Marino & Ssentanda, 2025). Rather than statistically generalizing results, the study identifies structural and epistemological patterns across selected literature. African classrooms were treated as analytically constructed cases based on published studies, curriculum analyses, and policy documents. The approach aligns with critical mathematics education, ethnomathematics, and decolonial theory. It also emphasizes interpretation, critique, and theoretical advancement over measurement. The review captures variations in the conceptualization, operationalization, and limitations of eco-mathematics pedagogy. It aims to reveal systemic challenges and opportunities for sustainability-oriented mathematics education. The design facilitates cross-contextual comparisons across multiple African educational settings. Overall, this approach supports the production of evidence-informed insights for curriculum, policy, and teacher professional development.

### Participant

As a literature-based study, the “participants” consisted of published studies, curriculum frameworks, policy documents, textbooks, and institutional reports focusing on mathematics education, eco-mathematics, sustainability education, ethnomathematics, and Indigenous Knowledge Systems in African contexts. An initial pool of 46 studies was identified through systematic database searches, and 30 studies met the inclusion criteria after duplicate removal and title/abstract screening. Included studies represent a range of educational levels, geographic locations, and methodological approaches, encompassing empirical research, conceptual analyses, policy reviews, and curriculum evaluations. This corpus includes studies from early grades to senior secondary and higher education. Both theoretical and applied research were included to ensure comprehensive representation of eco-mathematics pedagogical practices. The studies collectively provide insights into curriculum design, teacher professional development, student engagement, and Indigenous epistemologies. Geographically, studies cover multiple African nations including Ghana, South Africa, Nigeria, Zimbabwe, and Uganda. The participant set also encompasses international comparative studies that relate to African educational contexts. This broad selection ensures analytical rigor and cross-contextual relevance.

## Instrument

Data were collected from peer-reviewed journal articles, curriculum documents, policy papers, textbooks, and institutional reports obtained through systematic searches in Scopus, Web of Science, ERIC, and Google Scholar. The temporal scope included publications from 2017 to 2025, capturing the evolution of eco-mathematics pedagogy and sustainability-oriented mathematics education. Search keywords and Boolean combinations included: *eco-mathematics OR ecological mathematics, ethnomathematics AND environment, decolonial mathematics education, mathematics education AND sustainability*, and *Indigenous knowledge systems AND mathematics*. Inclusion criteria required: (a) explicit relevance to African educational contexts, (b) coverage of mathematics education and sustainability/IKS, and (c) publication in peer-reviewed or reputable institutional journals. Duplicates were removed, and titles and abstracts were screened to identify studies aligning with research objectives. The final dataset consisted of 30 studies, detailed in Table 1 below, summarizing author, geographic focus, study type, eco-mathematics conceptualization, sustainability orientation, engagement with IKS, and epistemology position. Table 1 thus functions as both an instrument for synthesis and a structured overview of data sources.

**Table 1.** Structured synthesis of included studies on eco-mathematics and sustainability in mathematics education

Author(s) & year	Geographic/Contextual Focus	Study Type	Conceptualization of Eco-mathematics	Sustainability Orientation	Engagement with IKS	Epistemology Position
(C. A. Ali & Davis, 2018)	Indigenous basketry context (Early grades)	Empirical	Indigenous artefacts as mathematical resources (prenumber/early number)	Implicit socio-cultural sustainability	Strong	Culturally grounded constructivist
(Atta & Bonyah, 2023)	Ghana (Senior High)	Empirical	Mathematics for social justice	Justice-oriented	Indirect	Critical pedagogy
(Chirume, 2017)	Zimbabwe (Shona community)	Case study	Indigenous mathematical knowledge solving community challenges	Community sustainability	Strong	Indigenous epistemology
(Coles, 2022)	International	Conceptual	Socio-ecological turn in mathematics education	Transformative sustainability	Indirect	Socio-ecological
(Coles et al., 2024)	International	Conceptual	Socio-ecological gestures in mathematics	Transformative sustainability	Indirect	Critical socio-ecological
(Edwards Jr et al., 2024)	Global (SDG 4)	Policy analysis	Critical evaluation of SDG 4 paradigms	Structural sustainability critique	Absent	Critical policy analysis
(Ferrer-Estévez & Chalmeta, 2021)	International	Institutional analysis	Integrating SDGs into education systems	Instrumental SDG integration	Absent	Managerial/institutional

(Fúnez-Flores et al., 2024)	International	Theoretical	Sociopolitical & decolonial turn in mathematics education	Justice-oriented	Strong theoretical engagement	Decolonial
Gerdes (1988)	African contexts	Conceptual	Culture and geometrical thinking	Cultural sustainability	Strong	Ethnomathematics
(Gyamerah, 2025)	Ghana	Theoretical	Anti-colonial turn in science & mathematics	Justice-oriented	Strong	Anti-colonial
(Hurtado et al., 2025)	International	Theoretical	Socio-critical mathematical thinking	Emancipatory sustainability	Indirect	Socio-critical
(Ismael, 2024)	International	Scoping review	Mathematics for sustainability development	Instrumental to transformative	Limited	Mixed/descriptive
(Khupe & Keane, 2017)	South Africa	Methodological	African decolonized research methodology	Justice-oriented	Strong	Decolonial methodology
Lara-Belocura et al. (2025)	International	Empirical	Embedding sustainability in mathematics	Instrumental/Applied	Minimal	Applied curriculum integration
(Li, 2025)	International	Conceptual	Mathematics in climate change & STEM	Applied sustainability	Absent	STEM integrationist
(López-Serentill et al., 2024)	Spain	Curriculum analysis	Integrating sustainability in primary mathematics	Instrumental curricular alignment	Absent	Curriculum reformist
(Machaba & Dhlamini, 2021)	Sub-saharan Africa	Conceptual	Ethnomathematics as fundamental pedagogy	Cultural sustainability	Strong	Ethnomathematical
(Madima-be-Mofokeng et al., 2025)	South Africa	Empirical	Teacher navigation of indigenization	Justice-oriented	Strong	Decolonial pedagogy
(Makramalla et al., 2025)	International	Survey of field	Mathematics education for sustainable futures	Transformative sustainability	Limited explicit	Field mapping/critical
(Maoto, 2023)	Africa	Conceptual	Relevance & responsiveness in 4IR era	Contextual sustainability	Indirect	African transformative
(Marino & Ssentanda, 2025)	Uganda	Comparative empirical	Teacher reform attitude	None (education reform focus)	Absent	Comparative education
(Chabala & Naidoo, 2021)	South Africa	Empirical	Integrating Indigenous knowledge in mathematics	Cultural sustainability	Strong	Culturally responsive pedagogy

(Nicol, 2018)	International	Conceptual	Mathematics, community, culture & place	Place-based sustainability	Strong	Relational pedagogy
Nqabeni & Buka (2023)	South Africa	Empirical	Decolonization in mathematics classroom	Justice-oriented	Strong	Decolonial classroom praxis
(Rosa & Orey, 2020)	International	Conceptual	Ethnomathematics & positive deviance	Cultural/community reliance	Strong	Ethnomodeling
(Salami & Okeke, 2017)	Nigeria	Empirical	Decolonization for sustainable development	Justice-oriented	Moderate	Transformative/decolonial
(Shabalala, 2025)	Africa	Conceptual	Decolonizing environmental education via IKS	Transformative sustainability	Strong	Indigenous ecological
(Sunzuma & Luneta, 2023)	Zimbabwe	Textbook evaluation	Sustainability in mathematics in textbooks	Instrumental sustainability	Minimal	Curriculum evaluation
(Sunzuma & Maharaj, 2019)	Zimbabwe	Empirical	Teacher challenges in ethnomathematics	Cultural sustainability	Strong	Ethnomathematical praxis
(Taguma et al., 2023)	OECD countries	Policy analysis	Learning Compass 2030 implications	Global competency	Absent	Global reformist
(Vaugh & Beer, 2020)	South Africa (Rural)	Empirical	Contextualised teacher PD	Community sustainability	Moderate	Context-responsive

### Data Analysis

The data were analyzed using inductive thematic synthesis, which involved reading, coding, and identifying recurring themes across the corpus (Chabalala & Naidoo, 2021). Critical discourse analysis supported the interpretation, enabling the identification of power relations, epistemic authority, and colonial legacies in curriculum and policy texts (C. Ali, 2018). Analytical decisions were guided explicitly by frameworks from critical mathematics education, ethnomathematics, and decolonial theory. This approach ensured consistency between methodological choices and theoretical assertions, particularly in matters of epistemic justice and sustainability-oriented pedagogy. Thematic coding generated higher-order categories capturing conceptual, pedagogical, and structural patterns in eco-mathematics practice. Cross-study comparisons were conducted to identify systemic constraints and enablers across African contexts. Data triangulation was achieved by synthesizing multiple study types, including empirical research, conceptual analyses, and policy reviews. Themes were iteratively refined and validated to ensure coherence and interpretive rigor. The analysis focused on identifying gaps, opportunities, and practical implications for curriculum and teacher development.

### Research Procedure

The review procedure followed a structured multi-step approach. First, databases were systematically searched using the specified keywords. Second, duplicates were removed, and titles and abstracts were screened for relevance. Third, full texts of eligible studies were reviewed to

confirm alignment with inclusion criteria. Fourth, data were extracted and organized into a structured table (Table 1) summarizing study characteristics. Fifth, inductive thematic synthesis was applied to code, categorize, and identify cross-cutting themes. Sixth, critical discourse analysis was conducted to examine epistemic and structural dimensions in the texts. Seventh, findings were iteratively refined and aligned with theoretical frameworks from CME, ethnomathematics, and decolonial theory. Eighth, synthesized results were cross-checked to ensure transparency, rigor, and theoretical coherence. Finally, the analysis informed the presentation of results, discussion, and implications for curriculum, pedagogy, and policy in African mathematics education.

## RESULTS AND DISCUSSION

### Results

This section contains the synthesized results from the qualitative study of secondary sources. The findings are based on regularities, themes, and understandings that recur across empirical studies, curriculum analyses, and policy reports on eco-mathematics pedagogy in African settings.

#### ***Theme 1: Preponderant Conceptualizations of Eco-Mathematics in African Scholarship***

In the synthesized literature, eco-mathematics is represented in a continuum. On the one hand, several studies portray eco-mathematics as the integration of environmental examples into traditional word problems, which is more of an instrumental orientation (Sunzuma & Luneta, 2023). On the other side, eco-mathematics is presented as a revolutionary pedagogy that makes mathematics a means of environmental analysis and action at the community level (Coles et al., 2024). Sustainability competencies in relation to SDG 4 and SDG 13 are often mentioned in policy and curriculum documents, though there is still limited articulation of eco-mathematics. This implies a lack of pedagogical allegiance to the idea of recognition, which supports fears of a tokenistic implementation of sustainability in mathematics curricula (Ferrer-Estévez & Chalmeta, 2021).

#### ***Theme 2: Aboriginal Knowledge as Pedagogical Resources***

The synthesized literature agrees that Indigenous Knowledge Systems have significant unexplored potential for providing eco-mathematics pedagogy. The effective application of indigenous measurement systems, cultural patterns, and environmental practices to teach mathematical ideas such as geometry, ratio, and data management is documented in the empirical literature (Atta & Bonyah, 2023; Machaba & Dhlamini, 2021). However, the analysis of the curriculum shows that policy texts may rhetorically support local knowledge, but they rarely provide direct instructions or assessment strategies for integrating IKS into the curriculum (Madimabe-Mofokeng et al., 2025). This lack of connection continues to marginalize epistemics even when there is solid theoretical evidence that ethnomathematics is indeed a decolonizing practice (Gyamerah, 2025; Rosa & Orey, 2020).

#### ***Theme 3: Structural and Systemic Constraints***

One of the main themes of secondary sources is the existence of structural impediments that restrain the continued adoption of eco-mathematics. They are the inflexible curricular design, the culture of teaching that relies on exams, and teacher preparation that is inadequate in terms of sustainability education and ethnomathematics (Gaanya et al., 2025; Shabalala, 2025). Some synthesized studies emphasize that teacher professional development programs are still disjointed and poorly coordinated with decolonial or sustainability-oriented pedagogies (Vaugh & Beer, 2020). Consequently, eco-mathematics is not consistently applied and remains reliant on individual teachers' agency rather than systemic support.

**Theme 4: Educational Benefits of Eco-Mathematics**

Though there may be issues with its implementation, the literature concurs that eco-mathematics pedagogy reveals patterns of positive educational outcomes. These include higher levels of learner engagement, greater conceptual knowledge, stronger critical thinking, and better environmental awareness (Hurtado et al., 2025). The secondary evidence also indicates that when mathematics is connected to local environmental contexts and cultural practices, learners interpret it as relevant and socially significant, which supports the idea of mathematics as a form of critical praxis rather than neutral knowledge (Atta & Bonyah, 2023; Coles, 2022).

**Theme 5: Eco-Mathematics: Decolonization Project**

Eco-mathematics is increasingly situated within a broader decolonizing project in African education. Researchers believe that incorporating sustainability and Indigenous epistemologies will combat Eurocentric hegemony over mathematical knowledge and promote epistemic justice (Fúnez-Flores et al., 2024; Gyamerah, 2025). Nevertheless, the literature also warns that unless structural reform is implemented, eco-mathematics can be turned into a symbolic alternative to a change agent. Decolonial eco-mathematics means aligning teacher training, assessment, curriculum design and community interactions. The above themes are not the findings of the empirical research conducted based on primary data, but rather patterns synthesized from existing empirical research, curriculum analysis, policy documents, and theoretical input. These themes provide an interpretative basis for integrating higher-order theories, as the study is a critical qualitative synthesis of the results. The ensuing Discussion, hence, does not reiterate findings or test the effectiveness of instruction; rather, it critically opines on these synthesized patterns to further conceptualize clarity, challenge epistemological frictions and position eco-mathematics pedagogy within sustainability and decolonial mathematics education.

**Discussion**

This section goes on to argue for an interpretively grounded, theoretically informed synthesis of the patterns found in the literature reviewed, rather than an examination of the primary empirical findings. As the study presents a qualitative synthesis, the discussion examines how eco-mathematics pedagogy has been conceptualized, problematized, and positioned within the broader African context in relation to sustainability, Indigenous Knowledge Systems, and decolonial mathematics education. There is great conceptual diversity in the synthesized literature about eco-mathematics pedagogy. Though other developments contextualize traditional mathematics material with examples of the environment, others place eco-mathematics as a radical pedagogical movement that redefines the role of mathematics education in socio-ecological scrutiny and social action (Coles, 2022; Sunzuma & Luneta, 2023). Synthetically, this heterogeneity is an expression of unresolved epistemological struggles in mathematics education rather than inconsistent classroom practice. The dominance of instrumental framings implies that the concept of sustainability has become a rhetorical notion, but its implications on mathematical knowledge, pedagogy, and the power of curriculum are not sufficiently theoretical (Ferrer-Estévez & Chalmeta, 2021).

This conceptual ambiguity is further supported by curriculum and policy-oriented sources. Sustainability, as it relates to global development models, is often mentioned; however, there is little clear guidance on the eco-mathematics pedagogy. Such omissions are understood as signs of more profound contradictions between technocratic logics of curriculum and the transformative ideals of education in the future of sustainable development through this synthesis (Makramalla et al., 2025). Consequently, eco-mathematics can easily be labelled an optional add-on rather than a logical pedagogical system. One of the main integrative understandings emerging from this synthesis is the role of Indigenous Knowledge Systems (IKS). In both empirical research and curriculum reviews, as well as in theoretical discussions, IKS is systematically presented as a culturally grounded

epistemological tool that can be used to ground mathematics learning in the understanding of local ecology, moral relationality, and local practices (Atta & Bonyah, 2023; Gyamerah, 2025). Notably, this synthesis shows that IKS integration is not merely a formulaic approach but an epistemological intervention that questions major Eurocentric constructions of mathematical knowledge (Rosa & Orey, 2020). Nonetheless, a lingering gap between theoretical approbation of IKS and its implementation in the curriculum, however, is also found in the literature, and this finding is indicative of the colonial hierarchies in the epistemology of mathematics education that persist in many countries' education systems (Madimabe-Mofokeng et al., 2025).

The scholarship further redefines teacher preparedness as a structurally mediated state rather than an individual deficiency. Instead of attributing low adoption of eco-mathematics to teachers' attitudes or competencies, the literature highlights structural barriers, such as inflexible curricula, examination-based assessment systems, and disjointed professional development programs (Gaanya et al., 2025; Vaugh & Beer, 2020). Synthetically, these limitations highlight the importance of alignment at the institutional and policy levels in the context of eco-mathematics as an institutional-level sustainable pedagogical orientation. Cumulatively, the literature reviewed makes eco-mathematics seem an instance of critical mathematical praxis that questions the assumed neutrality of mathematical education. Eco-mathematics is speculated to foster critical consciousness, ethical reasoning, and socio-ecological responsibility (Coles et al., 2024; Hurtado et al., 2025), rather than measurable instructional effects. In this study, it is optimal to view such outcomes as conceptual affordances of eco-mathematics pedagogy, supporting the need to advance theoretical coherence and consistency across research, curriculum, and policy.

### Implications

The synthesis of eco-mathematics pedagogy in African educational contexts carries significant implications for policy, curriculum design, and teacher development. Embedding Indigenous Knowledge Systems into mathematics education offers a pathway for culturally responsive pedagogy, fostering epistemic justice while challenging traditional knowledge hierarchies. Aligning sustainability-oriented mathematics with decolonial theory encourages curricula to move beyond tokenistic references to sustainable development, promoting transformative and contextually relevant learning. Teacher professional development programs must integrate sustainability, ethnomathematics, and decolonial pedagogies to equip educators with both conceptual understanding and practical instructional strategies. Policy makers are encouraged to coordinate curriculum frameworks, assessment regimes, and institutional support systems to ensure coherent implementation of eco-mathematics across classrooms. Eco-mathematics can enhance student engagement, critical thinking, and environmental literacy when learning is situated in local ecological and cultural contexts. Longitudinal and comparative studies are necessary to evaluate the long-term impact of eco-mathematics pedagogy on learner outcomes and community awareness. Integrating action-oriented learning strategies can empower students to address local environmental challenges while developing mathematical competence. Collaboration between schools, local communities, and environmental agencies can strengthen the contextual relevance and sustainability of instructional interventions. Curriculum developers should design resources and assessment tools that operationalize eco-mathematics pedagogy authentically, rather than relying on superficial inclusion. Systemic alignment of teacher training, curriculum, and policy enhances scalability and sustainability of pedagogical reforms. Overall, eco-mathematics presents an opportunity to reframe mathematics education as a socially just and ecologically responsible practice, advancing both sustainability literacy and culturally grounded mathematical knowledge.

### Limitations and Suggestions for Future Research

This study is limited by its design as a critical qualitative synthesis, relying exclusively on secondary sources rather than primary empirical data, which constrains the ability to observe emergent classroom practices and novel pedagogical innovations directly. The systematic search, although thorough, may have excluded locally published or non-indexed studies, introducing potential publication and language bias. The interpretivist and critical approach, while theoretically robust, depends on the researchers' positionality and interpretive decisions, which may affect the construction and interpretation of themes. The heterogeneity of included studies in terms of context, methodology, and conceptualization of eco-mathematics limits the comparability and generalizability of findings. Furthermore, the temporal scope may not capture all prior foundational work or the most recent developments in eco-mathematics pedagogy. Future research should incorporate primary empirical studies in African classrooms to validate the synthesized patterns and assess practical implementation outcomes. Longitudinal studies are needed to examine the sustained impact of eco-mathematics on learner engagement, critical thinking, and ecological literacy. Comparative studies across multiple African countries could highlight contextual differences and best practices for scaling pedagogy. Research on teacher professional development should explore effective strategies to integrate sustainability, decolonial approaches, and Indigenous Knowledge Systems. There is also a need to develop and evaluate contextually relevant instructional materials, including textbooks and digital resources. Cross-sector collaboration between schools, communities, and environmental organizations should be investigated to support socially and ecologically relevant pedagogy. Overall, future studies must aim to bridge theoretical synthesis with actionable evidence to strengthen the implementation and sustainability of eco-mathematics in diverse African educational contexts.

### CONCLUSION

This synthesis aimed to critically review current scholarship on eco-mathematics pedagogy in African settings, with a view to enhancing conceptual clarity and theoretical coherence in mathematics education towards sustainability. The study presents itself as a critical qualitative synthesis and does not presume empirical generalization. Rather, it provides an integrative explanation of how the concept of eco-mathematics is conceptualized, legitimized, and constrained within scholarly, curricular and policy literature. At the level of synthesis, the synthesis shows that the persistent problems, including future challenges with curriculum inertia, inadequate teacher preparation, and symbolic policy pledges, are derivatives of more fundamental epistemological and structural challenges in mathematics education systems. To resolve these tensions, coherent alignment among the curriculum frameworks, teacher education programmes, assessment regimes, and policy discourse is necessary rather than individual classroom innovations. The main value of the work is that it provides a synthesis-based definition of eco-mathematics as a consistent conceptual framework of mathematics education for sustainability in Africa. The paper has established a solid base of future empirical research, design-based studies, and policy change by defining the conceptual boundaries, foregrounding Indigenous epistemologies, and situating eco-mathematics within decolonial discourse. Finally, it can be said that, with the reconsideration of mathematics education as eco-mathematics, the field could be an important intellectual and ethical resource for socio-ecological change.

## AUTHOR CONTRIBUTIONS STATEMENT

Moshe M Phoshoko conceptualized the study, developed the research framework, research design, conducted data analysis, led the writing of the manuscript, and provided critical revisions. Bolouembele do Fekumo contributed to the data collection process, literature review development, and manuscript editing.

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