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Integrating environmental sustainability and values in mathematics education: A comparative bibliometric analysis and framework for sustainable mathematics learning (2005–2026)

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Abstract

Background: Environmental sustainability and values-oriented mathematics education have gained increasing scholarly attention, yet their conceptual and intellectual connections remain insufficiently mapped.
Aims: This study aimed to compare the knowledge structures of these research domains, assess their observable convergence, and formulate an integrative agenda for sustainable mathematics learning.
Method: A comparative bibliometric analysis was conducted using English-language Scopus records published between 2005 and 2026. The analysis included mathematics × environment (n = 209) and mathematics × values/ethnomathematics (n = 362) corpora, with an environment × values corpus (n = 3,853) serving as a contextual benchmark. Publication performance, geographical distribution, journals, co-authorship, keyword co-occurrence, co-citation, and bibliographic coupling were examined.
Results: Limited convergence was identified. Only three records emerged from the direct three-block search, while four overlap candidates were found among 567 deduplicated focal records (0.71%). The environmental corpus centered on sustainability, climate, and modelling, whereas the values corpus emphasized ethnomathematics, culture, local wisdom, and character.
Conclusion: The findings demonstrate distinct yet potentially complementary knowledge structures. The proposed ESME-V framework connects cognitive-ecological literacy, affective-ethical engagement, and spiritual-cultural grounding as a testable framework for advancing sustainable mathematics learning.

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INTRODUCTION

Mathematics education is increasingly expected to equip learners with the capacity to interpret complex socio-ecological systems, evaluate quantitative evidence, and make informed decisions concerning contemporary sustainability challenges. The growing complexity of climate change, biodiversity loss, energy consumption, resource depletion, and other environmental pressures requires educational approaches that connect disciplinary knowledge with meaningful real-world contexts (Bates et al., 2022; Cross & Congreve, 2021; Guerrero & Sjöström, 2025; Morales-Aguilar et al., 2025; Routray & Mohanty, 2024). Education for Sustainable Development positions learning as an important means of developing the knowledge, competencies, agency, and ethical responsibility required to

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contribute to more sustainable futures (UNESCO, 2020). Within this agenda, mathematics provides distinctive analytical resources through measurement, mathematical modelling, proportional reasoning, statistics, optimization, and the critical interpretation of quantitative information. These mathematical competencies allow learners to represent environmental phenomena, recognize relationships among variables, evaluate alternative scenarios, and examine the consequences associated with different courses of action. Mathematics learning can therefore extend beyond procedural mastery by engaging students with environmental problems whose interpretation requires both quantitative reasoning and contextual understanding. Recent sustainability-oriented research has demonstrated that mathematical tasks and modelling activities can provide productive opportunities for investigating authentic environmental and socio-ecological issues (Vásquez et al., 2023; Wiegand & Borromeo Ferri, 2023). Such learning experiences can strengthen the relevance of mathematics by positioning mathematical knowledge as a means of understanding problems that directly affect communities and their environments. At the same time, incorporating sustainability into mathematics education creates opportunities to connect mathematical competence with critical reflection on the implications of evidence-based decisions. Consequently, sustainable mathematics learning represents an increasingly important educational direction for connecting mathematical reasoning with the interpretation of environmental systems and responsible responses to sustainability challenges.

Environmental sustainability in mathematics education, however, cannot be reduced to the quantitative representation of ecological phenomena because sustainability decisions are also shaped by ethical considerations, cultural meanings, community priorities, and differing perceptions of responsibility. Values-oriented mathematics education provides a complementary perspective by recognizing that mathematical knowledge is learned and applied within particular social and cultural contexts (Ariza et al., 2021; Dorji & Gyeltshen, 2026; Fabiala et al., 2026; Saavedra et al., 2026). From this perspective, environmental problems can become contexts in which students not only calculate quantities but also examine how mathematical evidence relates to fairness, responsibility, local knowledge, and the consequences of human action. Ethnomathematical perspectives further demonstrate that mathematical ideas may be embedded within cultural practices, community knowledge, and locally situated ways of interpreting social and environmental realities (Rosa & Orey, 2021). This orientation is particularly relevant to sustainable mathematics learning because communities may understand environmental resources and responsibilities through culturally specific forms of knowledge and practice. Recent reviews of sustainability in mathematics and statistics education have similarly emphasized the importance of connecting mathematical learning with broader sustainability concerns rather than treating sustainability merely as an illustrative classroom context (Vásquez et al., 2023). Integrating environmental and values-oriented perspectives can therefore provide a more comprehensive learning structure in which quantitative competence is accompanied by reflection on the ethical, cultural, and social dimensions of environmental decisions. Such integration also creates opportunities for mathematical modelling to move beyond technically accurate representations toward consideration of who is affected by environmental problems and how alternative solutions may be interpreted within different

communities. In this way, environmental understanding, mathematical reasoning, ethical engagement, and culturally situated knowledge can function as mutually reinforcing dimensions of mathematics learning. A coherent integration of these dimensions may ultimately provide a stronger conceptual foundation for sustainable mathematics learning that is mathematically rigorous while remaining responsive to environmental and societal contexts.

Despite their conceptual complementarity, environmental sustainability and values-oriented mathematics education appear to have developed through partially separate scholarly traditions. Sustainability-oriented mathematics research has commonly emphasized climate-related issues, environmental contexts, mathematical modelling, quantitative reasoning, and Education for Sustainable Development, whereas values-oriented research has more frequently addressed ethnomathematics, culture, local wisdom, identity, and character. Existing reviews have contributed substantially to mapping sustainability in mathematics education, Education for Sustainable Development, and ethnomathematics, thereby demonstrating the increasing scholarly visibility of these research domains (Giraldo et al., 2026; Kabul & Kaleci, 2024; Rawat & Nagaraju, 2026). However, these studies have generally examined their respective fields independently rather than systematically comparing environmental and values-oriented mathematics education as potentially interconnected knowledge structures. Consequently, it remains unclear whether the apparent thematic complementarity between these traditions is accompanied by shared scholarly communities, conceptual vocabularies, intellectual foundations, or contemporary research fronts. The presence of sustainability, culture, values, or environmental terminology within individual publications cannot itself establish structural convergence because similar themes may emerge from substantially different citation networks and research communities. A comparative bibliometric perspective is therefore required to examine convergence through multiple complementary dimensions, including publication patterns, co-authorship structures, keyword co-occurrence, co-citation relationships, bibliographic coupling, and document-level overlap. Such an approach can distinguish superficial thematic proximity from deeper connections in the social, conceptual, and intellectual organization of the literature. More importantly, identifying both convergence and separation can reveal where meaningful opportunities exist for connecting environmental reasoning with ethical, cultural, and values-oriented dimensions of mathematics learning. Comparative mapping can consequently provide an empirical basis for moving beyond parallel research trajectories toward a more coherent and testable agenda for integrating environmental sustainability and values within sustainable mathematics learning.

Recent scholarship has increasingly positioned sustainability as an important direction in mathematics education, with studies addressing Education for Sustainable Development (ESD), curriculum reform, sustainability competencies in teacher education, mathematical modelling, STEAM-based environmental learning, and mathematics learning situated within socio-environmental problems (Ferri & Bulut, 2026; Li, 2025; Li & Tsai, 2022; Lucas & Paulo, 2023; Su et al., 2023; Tesfamicael & Enge, 2024). Alongside this development, emerging research has begun to incorporate values, cultural perspectives, ethnomathematics, Indigenous knowledge, and local wisdom into mathematics and

sustainability-related learning, suggesting a gradual movement toward more culturally and ethically responsive approaches (Djam'an, 2025; López-Serentill et al., 2024; Opesemowo, 2025; Vásquez et al., 2023). Nevertheless, these developments appear to remain distributed across partially distinct scholarly traditions, with sustainability-oriented research primarily emphasizing environmental issues, ESD competencies, mathematical modelling, and socio-ecological applications, while values-oriented mathematics education more frequently foregrounds ethnomathematics, culture, local wisdom, identity, and character. Although previous systematic reviews have synthesized sustainability within mathematics education, they have primarily examined developments within particular domains rather than comparatively determining whether environmental sustainability and values-oriented mathematics education share similar conceptual structures, scholarly communities, intellectual foundations, and research fronts (Ferri & Bulut, 2026; Su et al., 2023; Vásquez et al., 2023). Consequently, limited evidence is available regarding the extent to which these increasingly relevant research traditions have actually converged within the broader knowledge structure of mathematics education. This limitation is particularly important because the presence of sustainability and value-related concepts within individual studies does not necessarily indicate systematic convergence at the levels of collaboration, keywords, cited knowledge bases, or emerging research clusters. Therefore, a comparative bibliometric analysis is needed to examine their relationship through multiple complementary indicators, including publication patterns, co-authorship, keyword co-occurrence, co-citation, bibliographic coupling, and document-level overlap. Such analysis can shift the scholarly discussion from whether sustainability and values *can* be integrated in mathematics education toward determining how extensively this integration is already represented in the international literature, where structural disconnections remain, and how these findings can inform a more coherent framework for sustainable mathematics learning.

Accordingly, this study aims to comparatively examine the knowledge structures of environmental sustainability and values-oriented mathematics education and determine the extent to which these research traditions demonstrate observable convergence. The investigation is organized around three interconnected corpora, consisting of two focal datasets representing mathematics × environment and mathematics × values/ethnomathematics and a broader environment × values corpus used as a contextual benchmark. First, the study examines publication growth, geographical contributions, leading journals, and collaboration patterns to characterize the performance and social structures of the two focal research domains. Second, keyword co-occurrence is analyzed to identify their dominant conceptual themes and determine whether high-frequency terminology provides evidence of thematic convergence. Third, co-citation analysis is employed to compare the intellectual foundations of the two domains, while bibliographic coupling is used to characterize contemporary research fronts and areas of potential proximity. The analysis additionally uses direct combined retrieval and normalized title-level cross-matching to identify documents that may provide explicit or substantive bridges between environmental and values-oriented mathematics education. By combining these indicators, the study seeks to provide a multidimensional assessment of convergence rather than relying solely on similarities in titles, keywords, or individual publications. The

resulting evidence is subsequently used to formulate the Environmental Sustainability in Mathematics Education through Value Integration (ESME-V) framework as an integrative research agenda connecting cognitive-ecological literacy, affective-ethical engagement, and spiritual-cultural grounding. Rather than presenting ESME-V as an established instructional model, the study positions the framework as a testable conceptual foundation that can guide subsequent curriculum development, instructional design, measurement, and classroom-based investigation. Ultimately, this study seeks to clarify the structural relationship between environmental sustainability and values-oriented mathematics education while providing a research-informed direction for advancing more integrated and contextually responsive sustainable mathematics learning.

LITERATURE REVIEW

Mathematics education has increasingly been discussed as an educational domain capable of contributing to sustainability by equipping learners with quantitative tools for understanding complex environmental and social phenomena. Within Education for Sustainable Development, mathematical competence can support the interpretation of data, comparison of alternatives, recognition of patterns, and evaluation of uncertainty associated with sustainability-related decisions (UNESCO, 2020). Sustainability-oriented mathematics learning consequently extends the function of mathematics beyond procedural competence toward the investigation of authentic problems involving interactions among human activities, resources, and environmental systems. A systematic review demonstrated increasing scholarly attention to the integration of sustainability within mathematics and statistics education. Mathematical activities situated within sustainability contexts can involve measurement, statistical interpretation, proportional reasoning, mathematical modelling, and evidence-based evaluation of alternative scenarios (Vásquez et al., 2023). These applications are particularly relevant because environmental issues frequently involve multidimensional data and relationships that cannot be meaningfully interpreted through isolated numerical procedures. Mathematics learning in sustainability contexts can therefore provide opportunities for students to understand how quantitative information contributes to the representation and interpretation of socio-ecological systems. At the same time, the educational value of sustainability-oriented mathematics depends on whether environmental contexts become integral to mathematical reasoning rather than functioning merely as superficial settings for conventional exercises. This distinction suggests that sustainable mathematics learning requires purposeful alignment among mathematical content, environmental knowledge, learning activities, and intended competencies. Accordingly, sustainability can be conceptualized not simply as an additional topic within mathematics education but as a context through which mathematical reasoning acquires broader environmental and societal relevance.

Mathematical modelling represents one of the most prominent conceptual bridges between mathematics education and environmental sustainability because it enables real-world phenomena to be represented, examined, and evaluated through mathematical structures. Sustainability-related modelling tasks may require learners to identify relevant variables, formulate assumptions, construct relationships, analyze data, compare scenarios, and interpret mathematical outcomes within their original contexts (Guerrero-Ortiz et al., 2025; Incikabi, 2026; Lehrmann et al., 2026; Polydoros & Antoniou, 2026; Schlüter et al., 2026). Research on teacher education has shown that mathematical modelling can be connected with Education for Sustainable Development to strengthen prospective teachers' engagement with interdisciplinary and sustainability-oriented

learning (Wiegand & Borromeo Ferri, 2023). This connection is significant because environmental phenomena such as climate change, resource consumption, emissions, land-use transformation, and biodiversity change involve interacting variables and uncertain outcomes. Mathematical representations can make these relationships more accessible for systematic analysis while simultaneously exposing learners to the limitations and assumptions embedded within models. The sustainability value of modelling, however, depends not only on mathematical accuracy but also on how model outputs are interpreted in relation to environmental and societal consequences. For example, different mathematically plausible solutions to resource-allocation or environmental-management problems may produce unequal implications for communities, ecosystems, or future generations. Sustainable mathematical modelling therefore benefits from learning designs that encourage students to examine both the quantitative performance of alternative scenarios and the consequences associated with selecting them. This orientation broadens mathematical modelling from a primarily technical process toward a form of reasoning that can support informed engagement with socio-ecological problems. Environmental sustainability in mathematics education can thus be strengthened when modelling is connected with contextual interpretation, critical evaluation, and consideration of the implications of mathematically informed decisions.

Values-oriented mathematics education adds another important dimension by emphasizing that mathematical knowledge is developed, communicated, and applied within cultural and social contexts. Ethnomathematics has been particularly influential in demonstrating that mathematical ideas are embedded in cultural practices and can be understood through locally situated forms of knowledge, representation, and problem solving. Contemporary ethnomathematical scholarship continues to emphasize relationships among mathematics, cultural practices, identity, and educational experience (Rosa & Orey, 2021). This perspective challenges the assumption that meaningful mathematics learning must be detached from the cultural contexts in which learners interpret quantitative relationships and practices. In educational settings, culturally situated mathematics can connect formal concepts with architecture, measurement practices, patterns, community activities, traditional technologies, and other forms of local knowledge. The values dimension becomes particularly relevant when mathematical activities involve decisions concerning responsibility, fairness, community priorities, and the consequences of human actions. Local wisdom can additionally provide contextual knowledge through which learners examine how communities understand resources, environmental relationships, and collective responsibilities (Hanapi et al., 2025; Nadilla et al., 2026; Sandoval-Rivera, 2020; Wahyuni et al., 2026; Wardhani et al., 2024). Such perspectives may complement sustainability-oriented mathematics because environmental challenges are experienced and interpreted differently across geographical, cultural, and social settings. Nevertheless, the educational use of cultural or value-related contexts requires clear mathematical and conceptual purposes so that local knowledge is not reduced to a decorative example detached from substantive mathematical reasoning. Values-oriented mathematics education therefore provides an important foundation for developing learning experiences in which mathematical competence can interact with cultural meaning, ethical reflection, and context-sensitive interpretation.

The integration of environmental sustainability and values-oriented mathematics education offers a conceptual pathway toward learning that combines quantitative reasoning with ethical, affective, and culturally situated dimensions. Existing sustainability-oriented scholarship demonstrates how mathematics can support the analysis of environmental systems, while ethnomathematical perspectives demonstrate how mathematical activity can be understood in relation to cultural knowledge and community practices (Rosa & Orey, 2021; Vásquez et al., 2023). These traditions are potentially complementary because environmental decisions rarely depend exclusively on numerical optimization or exclusively on cultural considerations. Instead,

sustainability problems commonly require the simultaneous interpretation of empirical evidence, uncertainty, competing priorities, environmental consequences, and context-dependent values. An integrated mathematics task could therefore require learners to model an environmental phenomenon while also evaluating alternative outcomes through explicitly defined social, ethical, or community-based considerations. Within the present manuscript, possible applications include land-use change, biodiversity, emissions, household livelihoods, coastal erosion, peatland fires, water quality, waste, urban heat, and food systems. Such tasks would position mathematics as a means of connecting environmental evidence with reasoned judgement rather than treating sustainability as an external theme added to existing mathematical content. Integration also requires caution because values and cultural knowledge vary across communities and should not be represented as universal or homogeneous constructs. The manuscript accordingly emphasizes that religious, Indigenous, spiritual, or community obligations may shape environmental judgement differently across contexts and that a single values framework should not be assumed to represent all communities. Sustainable mathematics learning can therefore be conceptualized as an interdisciplinary educational orientation in which mathematical reasoning, environmental understanding, and contextually appropriate value reflection are deliberately connected.

Understanding whether such integration already exists as a coherent research field requires examination of the social, conceptual, and intellectual structures underlying the published literature. Bibliometric analysis is particularly useful for this purpose because different indicators provide complementary evidence regarding the organization and development of a research domain. Performance indicators can characterize publication growth, geographical participation, influential publication venues, and citation patterns, whereas co-authorship analysis can reveal the social organization of scholarly collaboration (Ballesteros-Ballesteros & Zárate-Torres, 2025; Hamdan & Alsuqaih, 2024; Isfandyari-Moghaddam et al., 2023; Mitrović et al., 2023; Razzaq et al., 2022). Keyword co-occurrence provides evidence concerning dominant conceptual themes, while co-citation analysis can identify intellectual foundations represented by frequently connected cited works. Bibliographic coupling offers a complementary perspective by grouping contemporary documents according to shared references and can therefore assist in identifying current research fronts. The manuscript combines these indicators because publication counts alone cannot adequately demonstrate how environmental sustainability and values-oriented mathematics education are related conceptually or intellectually. This multidimensional perspective is particularly important because similarity in titles or broad subject terminology does not necessarily imply common collaboration networks, conceptual structures, or intellectual foundations. Based on these theoretical and methodological considerations, the proposed Environmental Sustainability in Mathematics Education through Value Integration (ESME-V) framework organizes potential integration into three interacting dimensions: cognitive-ecological literacy, affective-ethical engagement, and spiritual-cultural grounding. Cognitive-ecological literacy concerns mathematical representation, data reasoning, uncertainty, and systems understanding; affective-ethical engagement addresses care, fairness, responsibility, and willingness to act; and spiritual-cultural grounding encompasses local knowledge, identity, meaning, and community obligations. ESME-V should therefore be understood as a theoretically and bibliometrically informed framework for subsequent empirical investigation rather than as an already validated instructional model, providing a conceptual basis for future research on integrated sustainable mathematics learning.

METHOD

Research Design

This study employed a comparative bibliometric research design to examine the development, knowledge structures, and observable convergence between environmental sustainability and values-oriented mathematics education. Bibliometric performance analysis was integrated with science mapping because publication counts alone are insufficient to explain how research domains are socially, conceptually, and intellectually organized (Donthu et al., 2021). The comparative design enabled two focal research corpora to be examined using equivalent analytical dimensions while preserving their distinctive publication and network characteristics. The first corpus represented research connecting mathematics with environmental sustainability, whereas the second represented mathematics associated with values and ethnomathematics. A broader environment × values corpus was additionally included as a contextual benchmark to examine the visibility of mathematics within the intersection of environmental and value-related scholarship. The bibliometric workflow incorporated performance analysis and science-mapping procedures to examine multiple dimensions of the retrieved literature. Reporting decisions were documented according to broader transparency principles for systematic evidence synthesis (Page et al., 2021). The study examined research structures through performance, social, conceptual, and intellectual dimensions rather than treating publication volume as the sole indicator of disciplinary development. Convergence between the focal corpora was assessed conservatively through direct combined retrieval, normalized title-level matching, shared high-frequency keywords, shared high-frequency co-cited references, and proximity among bibliographic-coupling research fronts. Accordingly, the design was intended to identify observable structural relationships within the retrieved literature rather than to evaluate pedagogical effectiveness or establish causal relationships among environmental sustainability, values integration, and mathematics learning.

Participant

Because this study used bibliometric data rather than human respondents, the units of analysis consisted of bibliographic records retrieved from Scopus according to predefined search and eligibility criteria. The first focal corpus comprised 209 mathematics × environment records published between 2007 and 2026. The second focal corpus contained 362 mathematics × values/ethnomathematics records published between 2005 and 2026. In addition, the broader environment × values search yielded 3,853 records and was used as a contextual benchmark rather than as an equivalent focal corpus. The analysis was restricted to English-language publications available within the Scopus export generated during the data-collection period. Records indexed in 2026 represented a partial publication year and were therefore interpreted cautiously when annual publication trends were compared. Eligibility was operationalized primarily through the database search query rather than through a full-text relevance assessment of every retrieved publication. Consequently, a record could be included when its indexed title, abstract, or keywords contained the predefined search concepts even when its substantive relationship with mathematics education, environmental sustainability, or values was comparatively weak. Such records were treated as potential retrieval noise during interpretation rather than being assumed to have equivalent thematic centrality within each corpus. Thus, the bibliographic records constituted documentary units of analysis whose inclusion reflected the reproducible boundaries established by the search strategy.

Instrument and Data Collection

The primary data-collection instrument was a structured Scopus search protocol constructed from three predefined conceptual blocks aligned with the objectives of the study. Block A represented mathematics-related concepts, including mathematics education, mathematics learning, and mathematical modelling, whereas Block B covered environment-related concepts such as environment, sustainability, climate, ecology, deforestation, and related socio-ecological

terminology. Block C represented values-oriented concepts, including values, ethics, character, culture, spirituality, local wisdom, and ethnomathematics. Terms representing non-ecological meanings, particularly expressions such as *learning environment*, were excluded where necessary to reduce irrelevant retrieval. Searches were conducted in Scopus in August 2026 using the TITLE-ABS-KEY field to identify records in which the predefined concepts appeared in titles, abstracts, or author keywords. Two focal queries combined Block A with Block B and Block A with Block C, while the contextual query combined Block B with Block C and the direct three-block query simultaneously incorporated all three conceptual blocks. The complete executable search strings and the corresponding export timestamp were retained in the project search log to strengthen transparency and reproducibility. Bibliographic records were exported in RIS format for performance indicators, affiliation information, collaboration structures, and keyword analysis, while CSV files containing the References field were generated for co-citation and bibliographic-coupling analyses. Before cross-corpus matching, publication titles were converted to lower case, punctuation was removed, and whitespace was standardized to enable normalized exact-title comparison. This systematic collection strategy produced standardized bibliographic datasets suitable for examining the performance, social, conceptual, and intellectual structures underlying environmental sustainability and values-oriented mathematics education.

Data Analysis

Data analysis combined bibliometric performance indicators with network-based science-mapping techniques to compare the two focal corpora across complementary analytical dimensions. Performance analysis included annual publication output, citation counts, contributing countries, publication venues, and highly cited records. Country contributions were derived from affiliation-country metadata using full counting at the document-country level, whereby each country represented within a publication received one count while repeated affiliations from the same country within that record were counted only once. The social structure of each corpus was investigated through co-authorship networks to identify patterns of scholarly collaboration. Conceptual structure was examined through keyword co-occurrence analysis using a minimum occurrence frequency of six, while cluster centrality and density were used to characterize motor, basic, specialized, and peripheral themes. The peripheral category was interpreted structurally rather than temporally because the study did not conduct a longitudinal thematic-evolution analysis. Intellectual structure was examined using cited-reference co-citation with a minimum frequency of three and document bibliographic coupling with corpus-specific thresholds of three or four shared references to maintain interpretable network structures. Community detection was conducted using NetworkX and the greedy modularity algorithm, with these parameters treated as explicit analytical choices rather than as equivalents of proprietary clustering procedures implemented in other bibliometric software. Cited-reference identities were normalized into first-author-and-year labels; therefore, interpretations acknowledged that different works by the same first author in the same year could be merged and that some references could remain unresolved. Convergence was ultimately evaluated across multiple indicators, including direct three-block retrieval, normalized title overlap, shared high-frequency keywords, shared high-frequency normalized co-cited references, and thematic proximity among bibliographic-coupling fronts, thereby avoiding conclusions based on any single bibliometric indicator.

Research Procedure

The research procedure was conducted through a sequential bibliometric workflow beginning with conceptual delimitation and ending with comparative interpretation and framework formulation. First, the research domains were operationalized into mathematics, environmental sustainability, and values-oriented concept blocks based on the theoretical scope established in the

Introduction and Literature Review. Second, the search combinations were executed in Scopus in August 2026 to retrieve the mathematics × environment, mathematics × values/ethnomathematics, environment × values, and direct three-block datasets. Third, retrieved metadata were exported in RIS and CSV formats according to the requirements of the subsequent performance and network analyses. Fourth, the datasets were prepared by standardizing relevant metadata and normalizing publication titles before exact cross-corpus matching. Fifth, descriptive bibliometric indicators were calculated to characterize temporal publication patterns, geographical contributions, publication venues, citation performance, and collaboration structures. Sixth, science-mapping analyses were performed to examine keyword co-occurrence, co-authorship, cited-reference co-citation, and bibliographic coupling using the predetermined thresholds. Seventh, convergence between the two focal corpora was evaluated through direct retrieval, document-level title matching, shared high-frequency conceptual nodes, shared normalized intellectual references, and proximity between contemporary research fronts. Eighth, potentially overlapping publications were examined interpretively to distinguish substantive environmental–values integration from records whose overlap reflected only indirect or peripheral thematic relationships. Ninth, findings across the performance, social, conceptual, and intellectual analyses were synthesized to identify areas of separation, complementarity, and potential integration between the two research traditions. Finally, this synthesis informed the formulation of the Environmental Sustainability in Mathematics Education through Value Integration (ESME-V) framework as a testable research agenda comprising cognitive-ecological literacy, affective-ethical engagement, and spiritual-cultural grounding, rather than as an empirically validated instructional model.

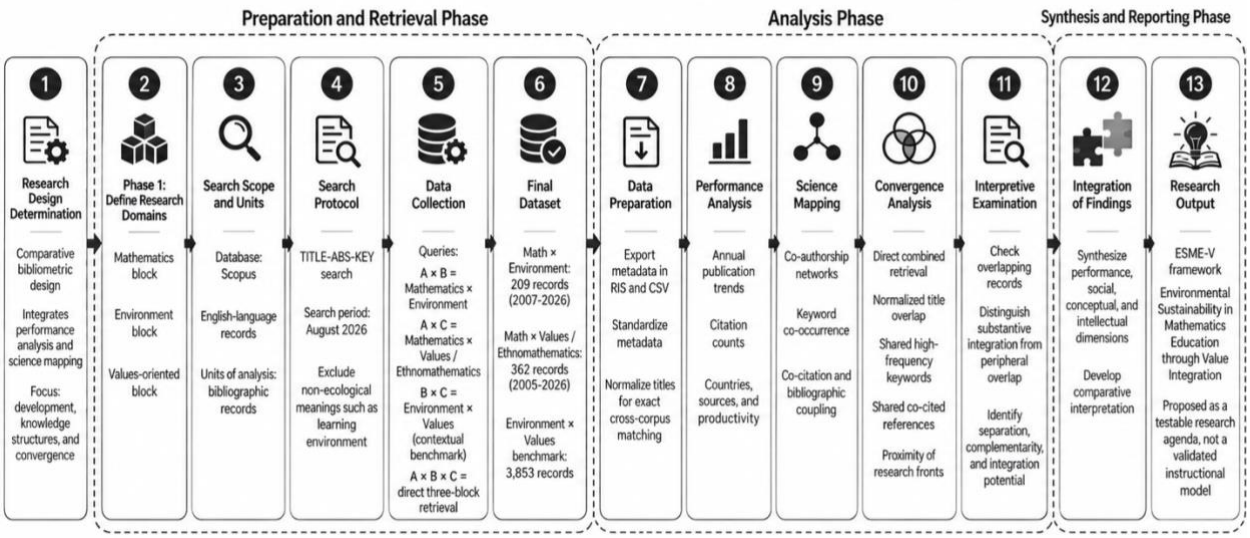

Figure 1. Research Method Flow

RESULTS AND DISCUSSION

Results

Corpus scale and growth. The two focal searches returned 571 records in total before cross-corpus deduplication. Four title-level overlap candidates produced a union of 567 records; therefore, the overlap rate was 4/567, or 0.71%. The direct three-block search returned three records. These are distinct indicators: the direct query measures records satisfying all query blocks, whereas title matching identifies records appearing in both focal exports after normalization.

Table 1. Corpus size, coverage, and principal performance indicators

Search or corpus	Records	Coverage	Principal result
Environment × values benchmark	3,853	2019-2026	737 records in 2025; 2026 is partial
Mathematics × environment	209	2007-2026	4,965 citations; 134 journals; 42 records in 2026 YTD
Mathematics × values/ethnomathematics	362	2005-2026	3,736 citations; 169 journals; 79 records in 2025 and 65 in 2026 YTD
Direct three-block search	3	2022-2026	Records satisfying the combined query
Cross-corpus title overlap	4	All focal years	Four candidates among 567 deduplicated records (0.71%)

The environmental corpus grew from a small baseline after 2007 and reached its highest displayed count in the partial 2026 series. The values corpus expanded earlier and rose sharply after 2019, with a complete-year peak in 2025. The broader environment × values benchmark contained only 26 records with an explicit mathematics term (0.67%), indicating that mathematics was rarely visible in this broad search rather than proving that mathematics was absent from environmental-values scholarship.

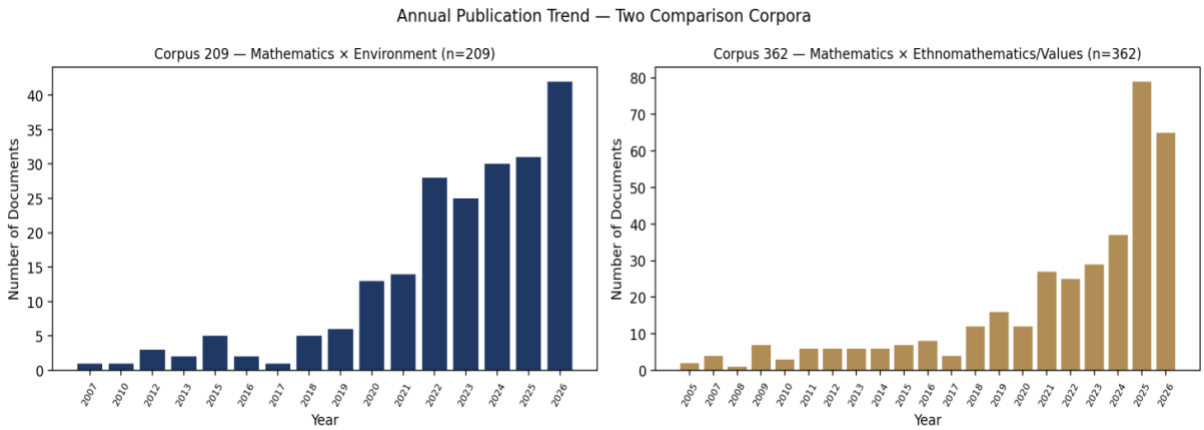

Figure 2. Annual publication output in the two focal corpora. Note. The 2026 values are year-to-date and should not be interpreted as complete annual totals.

Highly cited records revealed both topic relevance and retrieval boundaries. The environmental corpus included work on perceived energy use, climate-risk numeracy, school-based climate literacy, and understanding the climate impact of individual actions (Kumar et al., 2023; Wynes et al., 2020). The values corpus included major mathematics-education studies as well as records whose connection to values or sustainability was indirect, including work on developmental delay, international achievement, STEM learning, creative thinking, and positioning theory (Gil et al., 2020; Suherman & Vidákovich, 2022). These boundary records reinforce the need for screening-based sensitivity analysis.

Geographical and social structure. The United States was the most frequent affiliation country in the mathematics × environment corpus (23 records), followed by Indonesia (20), the United Kingdom (18), and Germany (15). Indonesia dominated the mathematics × values/ethnomathematics corpus with 164 of 362 records (45.3%). The contrast indicates different geographical concentrations across the two datasets.

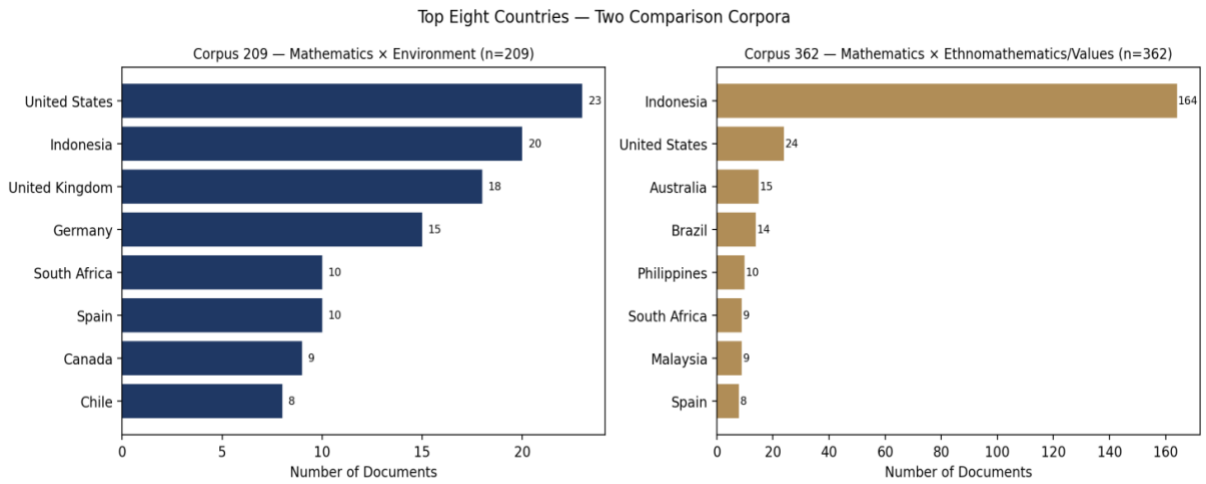

Figure 3. The eight most frequent affiliation countries in each focal corpus. Note. Counts use full counting at the document-country level; a multi-country record contributes once to each represented country.

Co-authorship networks showed dense collaboration within each thematic community and little visible connection between the two focal maps. In the environmental network, links were associated with modelling, sustainability education, and climate-related quantitative reasoning. The values network was larger and strongly shaped by Indonesian ethnomathematics and character-education communities. Because the corpora were mapped separately, visual separation should be interpreted together with direct overlap and shared-node tests rather than treated as independent proof of disconnection.

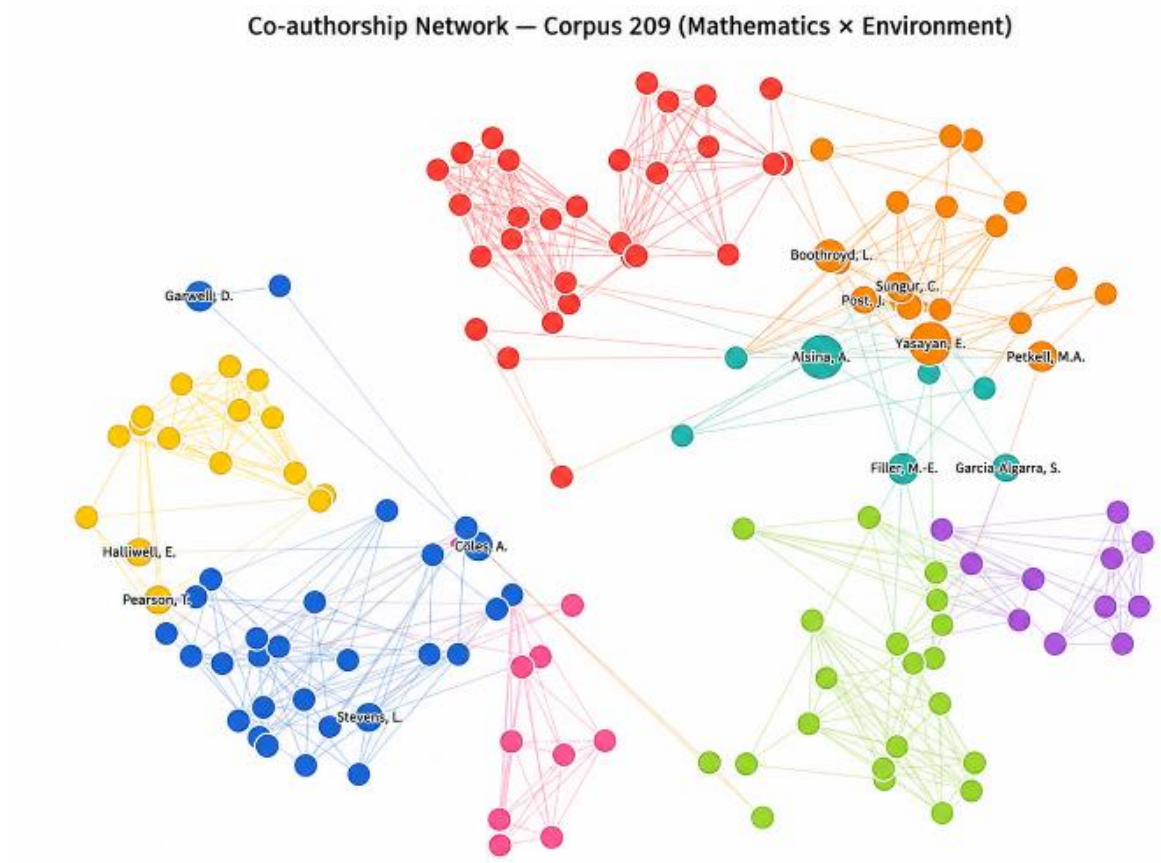

Figure 4. Co-authorship network in the mathematics × environment corpus (n = 209).

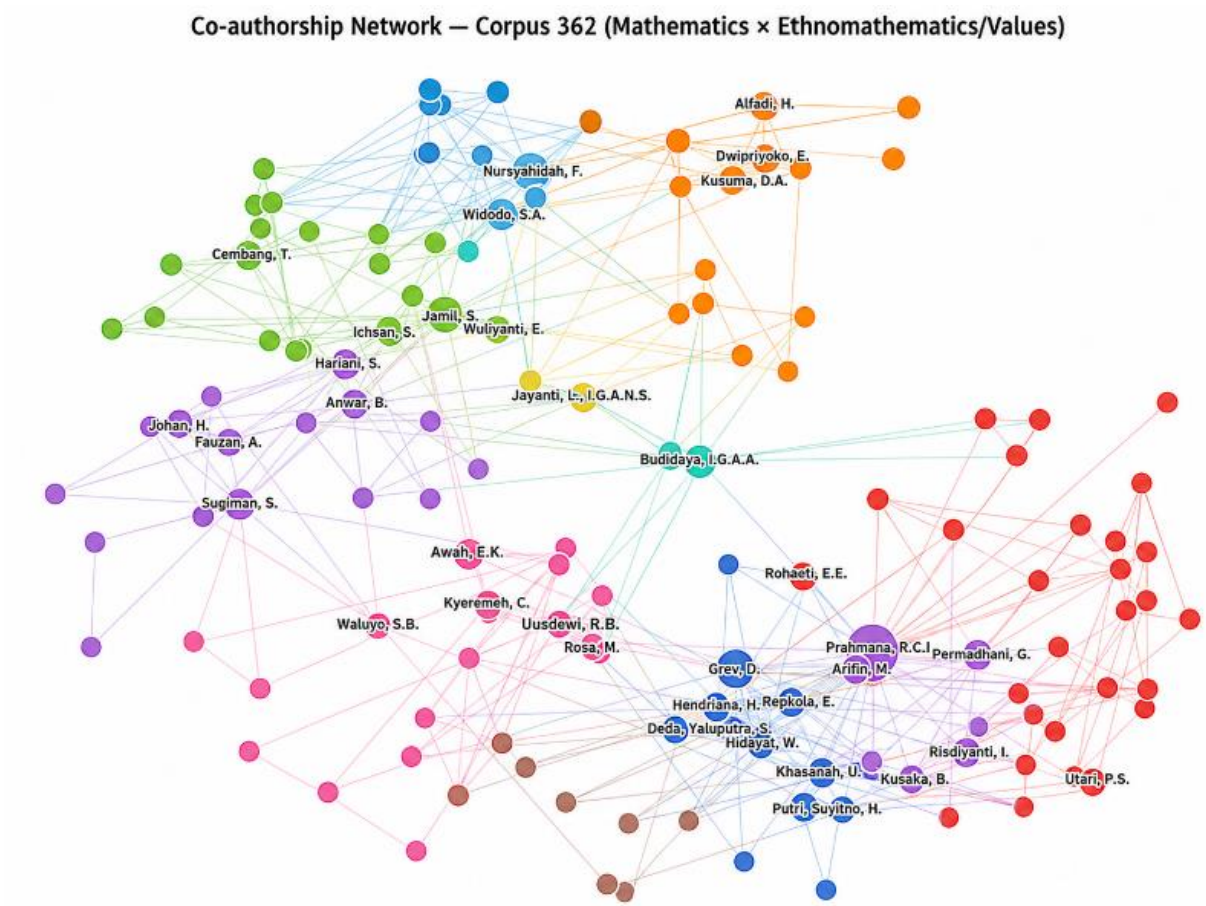

Figure 5. Co-authorship network in the mathematics × values/ethnomathematics corpus (n = 362).

Table 2. Leading publication venues in the focal corpora

Corpus	Journal	Records
Mathematics × environment	Sustainability (Switzerland)	19
Mathematics × environment	Education Sciences	7
Mathematics × environment	Research in Mathematics Education	5
Mathematics × environment	Mathematics Education Journal	5
Mathematics × values/ethnomathematics	Infinity Journal	21
Mathematics × values/ethnomathematics	Journal on Mathematics Education	19
Mathematics × values/ethnomathematics	Mathematics Education Journal	15
Mathematics × values/ethnomathematics	Educational Studies in Mathematics	11

Conceptual structure. At a minimum keyword frequency of six, the environmental corpus centred on sustainability, mathematical modelling, climate change, and education for sustainable development. The values corpus centred on ethnomathematics, culture, character education, local wisdom, and mathematics learning. No identical high-frequency keyword was shared at this threshold. This result refers to thresholded author-keyword nodes; it does not imply that the corpora shared no vocabulary at lower frequencies or in titles and abstracts.

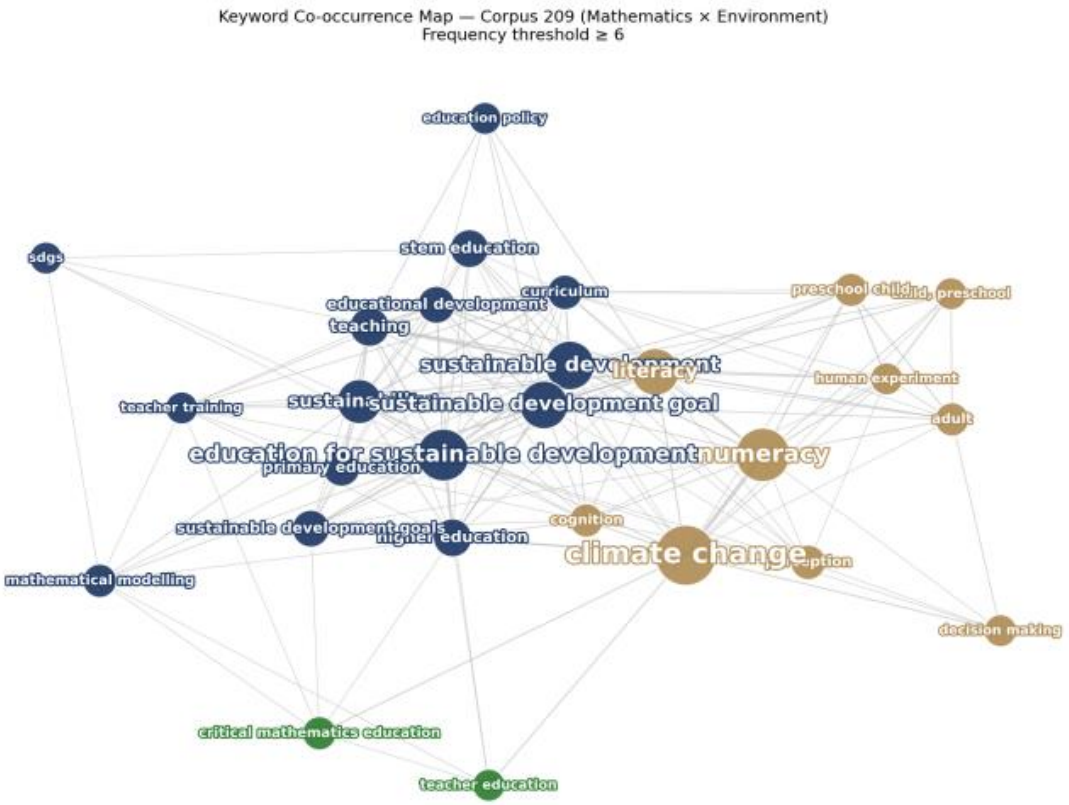

Figure 6. Keyword co-occurrence map for the mathematics × environment corpus (minimum frequency = 6).

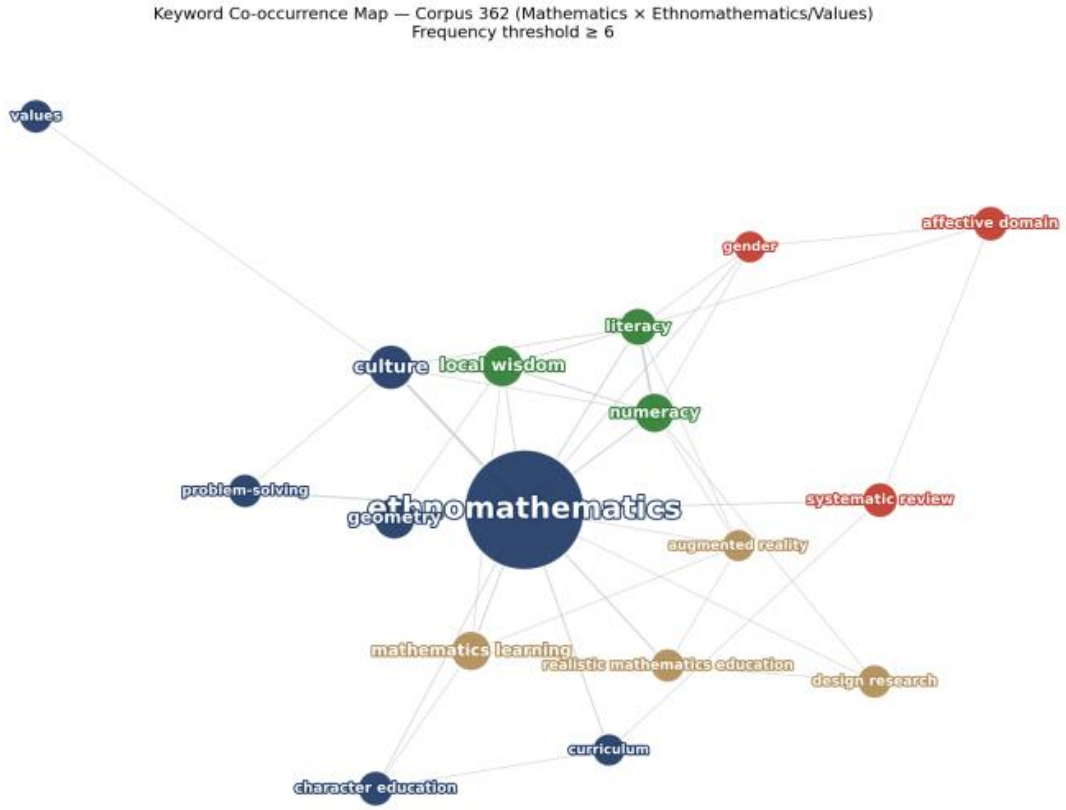

Figure 7. Keyword co-occurrence map for the mathematics × values/ethnomathematics corpus (minimum frequency = 6).

Table 3. Strategic interpretation of keyword clusters

Corpus	Cluster label	Position	Density	Centrality	Nodes
Environment	Education for Sustainable Development	Motor	10.07	88	15
Environment	Climate Change	Motor	9.60	87	10
Environment	Critical Mathematics Education	Peripheral	0.50	13	2
Values	Ethnomathematics	Motor	4.86	28	7
Values	Local Wisdom	Motor	4.33	20	3
Values	Mathematics Learning	Peripheral	1.00	14	4
Values	Systematic Review	Peripheral	0.67	8	3

The low-density, low-centrality positions of Critical Mathematics Education, Mathematics Learning, and Systematic Review identify peripheral themes in the present networks. They do not establish whether those themes are emerging or declining, because that inference requires time-sliced analysis. Their positions instead show that they were weakly connected to the high-frequency conceptual centres under the present data and thresholds.

Intellectual structure. The co-citation maps also differed. Environmental mathematics education drew on critical mathematics education, sustainability task design, and modelling. Values-oriented mathematics education drew heavily on foundational ethnomathematics and culturally situated mathematics education. Table 4 reports the normalized nodes rather than treating every author-year label as a uniquely verified publication.

Table 4. Most frequent normalized cited-reference nodes

Corpus	Count	Parser label	Reference identity or status
Environment	13	Skovsmose (1994)	Skovsmose (1994)
Environment	11	Barwell (2013)	Barwell (2013)
Environment	9	Mula (2019)	Unresolved; probable author-order parsing issue
Environment	9	Alsina (2020)	Unresolved to a unique bibliographic record
Environment	8	Wiegand (2023)	Wiegand and Borromeo Ferri (2023)
Values	63	D'Ambrosio (1985)	D'Ambrosio (1985)
Values	36	D'Ambrosio (2001)	D'Ambrosio (2001)
Values	36	Rosa (2021)	Rosa and Orey (2021)
Values	32	Rosa (2016)	Rosa and Orey (2016)
Values	25	D'Ambrosio (2020)	Unresolved to a unique bibliographic record

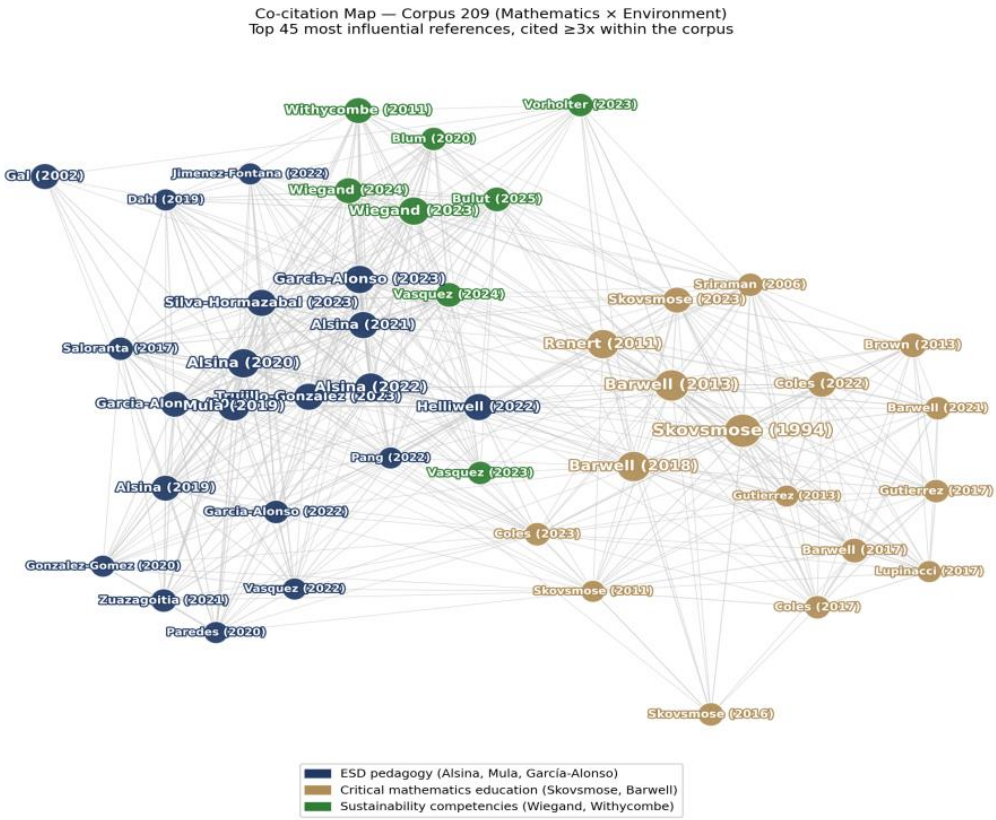

Figure 8. Co-citation map for the mathematics × environment corpus (minimum frequency = 3). Note. Labels are normalized first-author/year nodes and may not uniquely identify a cited work.

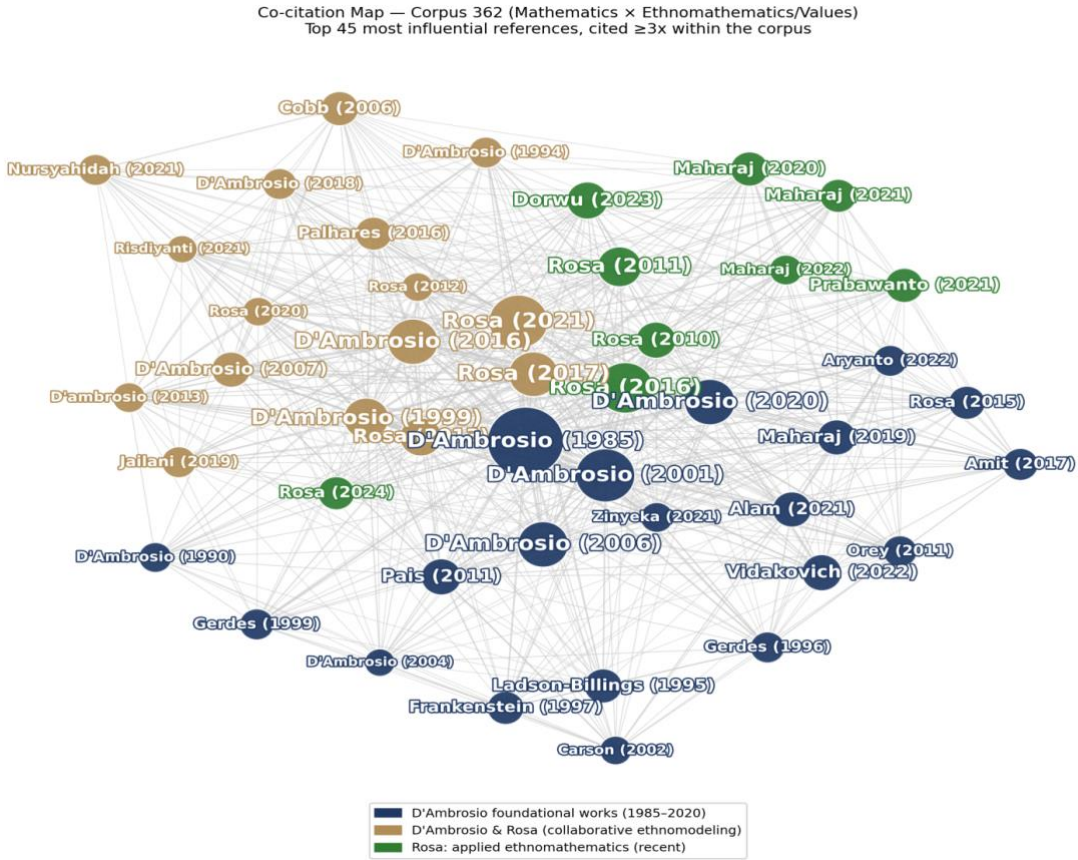

Figure 9. Co-citation map for the mathematics × values/ethnomathematics corpus (minimum frequency = 3). Note. The D'Ambrosio (2020) node could not be resolved to a unique bibliographic record and is therefore not included in the reference list.

No shared high-frequency normalized cited-reference node was detected across the two maps at the minimum frequency of three. The finding is consistent with limited intellectual convergence at the displayed level, but its scope is constrained by the first-author/year parser. A sensitivity analysis based on DOI and complete cited-reference strings is required before making stronger claims about shared foundations.

Table 5. Bibliographic-coupling research fronts

Corpus	Cluster	Documents	Dominant focus
Mathematics × environment	E1	30	Teacher professional development for ESD in mathematics
Mathematics × environment	E2	6	Adult numeracy and climate-learning trajectories
Mathematics × environment	E3	5	Cognitive psychology of climate-risk perception
Mathematics × values	V1	69	Ethnomodelling and ethnomathematics as pedagogy
Mathematics × values	V2	6	Indigenous mathematics education
Mathematics × values	V3	3	Ethnomathematics, social justice, and rural contexts

The coupling fronts reinforce the thematic contrast: environmental work was organized around modelling and socio-ecological data, while values-oriented work was organized around culture, character, and local knowledge. The networks nevertheless suggest possible bridge mechanisms, particularly culturally situated modelling tasks in which learners quantify a local environmental problem and justify action through community values.

Cross-corpus overlap candidates. The four title-level matches are best described as overlap candidates rather than verified three-way bridge studies. Only the Manggarai traditional-house study contained a substantial environmental dimension in addition to cultural mathematics. The other three mainly addressed ethnomathematics, character, or learning outcomes and provide only indirect bridge potential.

Table 6. Title-level cross-corpus overlap candidates

Year	Document	Assessment of bridge relevance
2022	Orang Asli Malaysia systematic review	Indirect: the review references quality-education and inequality SDGs, not the physical environment (Abdullah, 2022)
2026	Manggarai traditional house through ethnomathematics and ethnoscience	Substantive: includes conservation and food-preservation practices (Choirunnisa et al., 2026)
2026	Kapal Pinisi application	Indirect: local wisdom and basic literacy are central; SDGs appear only as a keyword (Gunawan & Laila, 2026)
2026	Baduy Leuit indigenous architecture	Modest: includes SDGs 2, 4, and 11 and some ecological-stewardship content (Kadarisma et al., 2026)

Discussion

The comparative bibliometric findings reveal a marked expansion of scholarship at the intersection of mathematics education, environmental sustainability, and values, but this growth has not yet produced strong structural convergence between the two focal research traditions. The mathematics × environment corpus developed from a relatively small publication base after 2007,

whereas the mathematics × values/ethnomathematics corpus expanded earlier and accelerated substantially after 2019, reaching 79 publications in the complete 2025 publication year. This growth is consistent with the increasing scholarly attention to sustainability in mathematics education identified by (Kabul & Kaleci, 2024), who mapped the development of sustainability-related mathematics education research through bibliometric analysis. It also corresponds with the systematic review of (Vásquez et al., 2023), which demonstrated growing efforts to integrate sustainability into mathematics and statistics education. However, the present analysis extends these earlier studies by demonstrating that expansion within sustainability-oriented and values-oriented scholarship does not necessarily translate into convergence between their respective knowledge structures. Only four title-level overlap candidates were identified among 567 deduplicated focal records, representing an overlap rate of 0.71%, while the direct three-block search retrieved only three records. Moreover, only 26 of the 3,853 records in the broader environment × values benchmark contained an explicit mathematics term, corresponding to 0.67% of that corpus. These results indicate that the increasing visibility of sustainability, values, and mathematics as individual scholarly concerns has not yet resulted in a substantial body of research explicitly connecting all three dimensions. Rather than suggesting complete disciplinary isolation, the small intersection indicates that opportunities remain for studies capable of linking quantitative environmental reasoning with ethical, cultural, and values-oriented perspectives. The present findings therefore refine previous evidence of research growth by showing that expansion within adjacent fields should be distinguished from the emergence of a genuinely integrated sustainable mathematics education research domain.

The geographical and social structures provide additional evidence that the two research traditions have developed through different scholarly communities. In the mathematics × environment corpus, the United States contributed 23 records, followed by Indonesia with 20, the United Kingdom with 18, and Germany with 15, whereas Indonesia alone accounted for 164 of the 362 records in the mathematics × values/ethnomathematics corpus, or 45.3%. The strong Indonesian representation in the values corpus is consistent with the prominence of ethnomathematics and culturally situated mathematics education identified in recent bibliometric research (Rawat & Nagaraju, 2026). The co-authorship networks reinforce this geographical contrast because environmental research was associated predominantly with communities working on modelling, sustainability education, and climate-related quantitative reasoning, whereas the values network was strongly shaped by Indonesian ethnomathematics and character-education communities. This pattern suggests that the separation observed between the two corpora is not exclusively conceptual but is also reflected in the social organization of knowledge production. At the same time, Indonesia's substantial contribution to values-oriented mathematics research creates a potentially important foundation for developing sustainability mathematics grounded in local wisdom and culturally meaningful environmental practices. This opportunity is compatible with the contemporary ethnomathematical perspective of (Rosa & Orey, 2021), which connects mathematical activity with cultural practices within a glocalized educational context. However, the geographical distribution should be interpreted cautiously because the analysis is restricted to English-language Scopus-indexed records and may consequently underrepresent scholarship published in national languages or journals outside the database. Thus, Indonesia's apparent dominance should be understood as prominence within the sampled bibliographic environment rather than definitive evidence of its relative position across all global ethnomathematics research. Nevertheless, the geographical pattern highlights the potential importance of Global South research communities in connecting mathematical knowledge, cultural practices, and locally experienced sustainability challenges.

The conceptual structure provides particularly strong evidence that environmental sustainability and values-oriented mathematics education currently operate around different thematic centres. At the minimum keyword frequency of six, the environmental corpus was organized around sustainability, mathematical modelling, climate change, and Education for Sustainable Development, whereas the values corpus was dominated by ethnomathematics, culture, character education, local wisdom, and mathematics learning. This distinction corresponds with (Vásquez et al., 2023), who identified sustainability-related mathematics and statistics education as an area increasingly concerned with incorporating sustainability issues into mathematical learning. It also aligns with (Wiegand & Borromeo Ferri, 2023), whose work demonstrates how mathematical modelling can connect teacher education, STEAM, and Education for Sustainable Development. By contrast, the prominence of ethnomathematics in the values corpus is consistent with (Rosa & Orey, 2021), who conceptualize mathematics as culturally situated activity that can connect local and global educational contexts. The strategic maps further show that Education for Sustainable Development and climate change functioned as motor themes in the environmental corpus, while ethnomathematics and local wisdom occupied motor positions within the values corpus. Importantly, no identical high-frequency keyword was shared between the two corpora at the specified threshold, indicating that their most visible conceptual vocabularies remain structurally differentiated. This result should not be interpreted as evidence that the corpora share no terminology, because lower-frequency keywords and concepts occurring within titles and abstracts were not captured by this particular thresholded comparison. Instead, the finding suggests that concepts capable of bridging environmental sustainability and values have not yet become sufficiently central to organize both research domains simultaneously. The conceptual contrast therefore identifies an important research opportunity for sustainability-oriented mathematical tasks that combine environmental modelling and data reasoning with explicit consideration of local knowledge, responsibility, fairness, and culturally situated decision-making.

Differences in intellectual structure and contemporary research fronts further reinforce the interpretation of limited convergence. The co-citation analysis indicates that environmental mathematics education draws on intellectual traditions related to critical mathematics education, sustainability-oriented task design, and mathematical modelling, whereas the values-oriented corpus is more strongly anchored in foundational ethnomathematics and culturally situated mathematics education. At the minimum frequency of three, no shared high-frequency normalized cited-reference node was identified across the two co-citation maps. This finding complements the keyword analysis by showing that conceptual differentiation is accompanied by differences in the frequently cited knowledge bases supporting each research tradition. Bibliographic coupling similarly identified environmental research fronts concerned with teacher professional development for ESD, adult numeracy and climate learning, and cognitive dimensions of climate-risk perception, whereas values-oriented fronts focused on ethnomodelling and ethnomathematics pedagogy, Indigenous mathematics education, and connections among ethnomathematics, social justice, and rural contexts. These patterns are consistent with (Wiegand & Borromeo Ferri, 2023), who demonstrate the relevance of mathematical modelling for sustainability-oriented teacher professionalism, and with (Rosa & Orey, 2021), who emphasize culturally grounded perspectives in ethnomathematical learning. At the same time, the contrasting research fronts reveal potentially complementary functions rather than inherently incompatible scholarly agendas. Environmental mathematics contributes approaches for representing systems, evaluating quantitative evidence, and reasoning about sustainability scenarios, whereas ethnomathematics and values-oriented scholarship can foreground cultural knowledge, identity, community perspectives, and the meanings attached to mathematical practices. The absence of shared high-frequency references must nevertheless be interpreted cautiously because cited references were normalized using first-

author/year labels, which may merge distinct publications or fail to resolve particular works. Therefore, the intellectual separation documented here is most appropriately understood as limited convergence under the specific parser, frequency threshold, database, and language conditions employed rather than evidence that the two fields possess entirely independent theoretical foundations.

The document-level analysis provides the clearest illustration of both the present scarcity of integration and its future pedagogical potential. Among the four title-level overlap candidates, only the 2026 study of the Manggarai traditional house demonstrated a substantive environmental dimension alongside cultural mathematics through its attention to conservation and food-preservation practices (Choirunnisa et al., 2026). The Orang Asli review represented only an indirect connection through sustainability-related educational goals (Abdullah, 2022), while the Kapal Pinisi study primarily emphasized local wisdom and basic literacy despite including the SDGs as a keyword (Gunawan & Laila, 2026). The Baduy Leuit study provided a somewhat stronger connection by integrating Indigenous architecture with mathematics and addressing selected SDGs and ecological-stewardship content (Kadarisma et al., 2026). These examples indicate that culturally grounded mathematics can provide an authentic entry point for environmental sustainability, although explicit integration remains uncommon within the retrieved literature. The findings therefore support moving beyond the juxtaposition of cultural examples and environmental topics toward learning designs in which students mathematically investigate environmental systems and evaluate possible actions through explicit ethical and community criteria. Such a direction is represented by the proposed Environmental Sustainability in Mathematics Education through Value Integration (ESME-V) framework, which connects cognitive-ecological literacy, affective-ethical engagement, and spiritual-cultural grounding. The framework responds directly to the complementary strengths revealed by the bibliometric maps: environmental scholarship contributes modelling, data reasoning, uncertainty, and systems thinking, while values-oriented scholarship contributes cultural knowledge, identity, responsibility, and community meaning. An integrated learning design could consequently require students to quantify environmental change, compare alternative scenarios, interpret uncertainty, and justify decisions by considering ecological evidence alongside fairness, cultural knowledge, and community obligations. Nevertheless, ESME-V should remain positioned as a bibliometrically and theoretically informed research framework rather than a validated instructional intervention, and its educational value must subsequently be examined through expert validation, design-based research, measurement studies, and comparative classroom implementation.

Implications

The immediate implication is methodological as well as curricular. Researchers should create transparent cross-domain searches, screen records for substantive relevance, publish code and derived metadata where licensing permits, and test whether results are robust to lower keyword thresholds and DOI-level cited-reference matching. Curriculum researchers should define how mathematics, environmental understanding, and values each contribute to task goals and assessment evidence.

Table 7. Priorities for a value-integrated sustainability mathematics research agenda

Priority	Recommended study	Minimum evidence
Search transparency	Replicate the comparative corpus with complete queries and retrieval dates	Executable queries, screening log, deduplication rules, and sensitivity analyses
Task design	Develop culturally situated environmental modelling units	Task rationale, mathematical demand, environmental system model, and value constructs

Priority	Recommended study	Minimum evidence
Measurement	Validate ESME-V dimensions across contexts	Content validity, factor structure, reliability, and measurement invariance
Classroom efficacy	Compare integrated modules with conventional instruction	Learning, reasoning, ethical judgement, and action-related outcomes
Equity and transfer	Test designs across regions, languages, and community partnerships	Context documentation, subgroup analysis, and evidence of transfer

Limitations and Suggestions for Future Research

This study has several limitations that should be considered when interpreting its findings. First, the analysis was limited to Scopus and English-language records, which may exclude relevant studies indexed elsewhere or published in other languages. Future research should therefore incorporate additional databases and multilingual literature to improve coverage. Second, the 2026 dataset represents a partial year, while query-based retrieval may have included records with only indirect thematic relevance. Future studies should apply systematic title-and-abstract screening and sensitivity analysis to improve retrieval precision. Third, keyword, co-citation, and bibliographic-coupling networks were influenced by selected thresholds, while first-author/year normalization may have merged or failed to resolve some references. DOI-based reference identification and alternative network thresholds should therefore be examined in subsequent bibliometric studies. Fourth, the cross-sectional analysis cannot determine whether peripheral themes are emerging or declining over time. Longitudinal and time-sliced analyses are recommended to clarify the evolution of connections between sustainability and values-oriented mathematics education. Finally, ESME-V remains a conceptual framework rather than a validated instructional model. Future studies should therefore evaluate the framework through expert validation, psychometric analysis, design-based research, and classroom trials across diverse educational and cultural contexts.

CONCLUSION

This comparative bibliometric analysis found limited observable convergence between environmental sustainability mathematics education and values-oriented mathematics education in the sampled Scopus records. The direct combined search returned three records, while title matching identified four overlap candidates among 567 deduplicated focal records (0.71%). At the reported thresholds, the corpora shared no high-frequency keyword and no high-frequency normalized cited-reference node. These findings indicate structural separation under the present database, language, parser, and threshold conditions; they do not establish complete intellectual isolation. The environmental corpus was oriented towards sustainability, modelling, climate, and quantitative reasoning. The values corpus was oriented towards ethnomathematics, culture, character, and local wisdom. Their complementary strengths motivate the proposed ESME-V framework, which connects cognitive-ecological literacy, affective-ethical engagement, and spiritual-cultural grounding. The framework and illustrative task agenda should now be evaluated through transparent, context-sensitive empirical research.

AUTHOR CONTRIBUTIONS STATEMENT

Aisyah Purnama Dewi contributed to the conceptualization, research design, bibliometric data collection, data analysis, interpretation of the findings, framework development, and preparation of the original manuscript. Agung Hartoyo contributed to the methodological development, supervision, interpretation of the bibliometric findings, and critical revision of the manuscript. Nurfadilah Siregar contributed to data validation, bibliometric analysis, visualization, interpretation of the results, and manuscript review and editing. All authors contributed to the development and refinement of the ESME-V framework and read and approved the final version of the manuscript.

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