Addressing Sustainability in Initial Mathematics Teacher Education

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This article presents a scoping review of international peer-reviewed literature (2015–2025) examining how sustainability is addressed in initial mathematics teacher education (IMTE). Guided by five research questions, the review synthesised 24 empirical studies to explore how sustainability is conceptualised, integrated, and challenged in IMTE contexts. Two dominant conceptualisations emerged: "mathematics for sustainable development," which positions mathematics as a tool for engaging with socio-environmental issues; and "sustainability of mathematics-related knowledge," which emphasises the lasting impact of IMTE on prospective teachers' knowledge, skills, and dispositions. Each conceptualisation gives rise to distinct, yet sometimes overlapping, pedagogical approaches. The former is associated with socio-critical mathematical modelling, interdisciplinary project-based learning, and reflective pedagogy, while the latter foregrounds technology-enhanced instruction, culturally responsive teaching, and development of transferable competencies. Persistent barriers, however, include rigid curricula, limited faculty expertise, conceptual uncertainty, and misaligned policy frameworks. Addressing these challenges requires systemic action through curriculum reform, interdisciplinary professional development, and integration of sustainability competencies into accreditation standards. The review showed how conceptual framings of sustainability inform pedagogical practice, reveal structural obstacles, and guide strategic responses, offering a foundation for reimagining IMTE as a transformative space for preparing mathematics teachers to contribute meaningfully to sustainable futures.

Keywords · mathematics teacher education research · sustainability · mathematics · initial teacher education · literature review

Introduction

The concepts of sustainability and sustainable development have increasingly become part of everyday discourse[1]. Despite its relatively recent acclaim in several fields, sustainability has been a central concept in forestry for more than two centuries (Wiersum, 1995), originally meaning "never harvesting more than what the forest yields in new growth" (Kuhlman & Farrington, 2010, p. 3437). Nowadays, sustainability is understood as a multidimensional concept, primarily involving meeting the needs of the present without compromising the ability of future generations to meet their own needs. As such,

[1] In this review, *sustainability* denotes a multidimensional, long-term condition or orientation concerned with ecological integrity, social well-being, economic viability, and democratic participation across generations. *Sustainable development* refers more specifically to the processes, policies, and collective actions directed toward achieving such conditions. *Education for sustainable development* (ESD), in turn, refers to educational efforts intended to develop the knowledge, competencies, values, dispositions, and agency required to participate in these processes. We acknowledge that the literature reviewed does not always distinguish these terms consistently.

it is often conceptualised through three interconnected pillars: the environmental, the economic, and the social (Clune & Zehnder, 2020; Giovannoni & Fabietti, 2013). Briefly, environmental sustainability focuses on the conservation of natural resources, the protection of ecosystems, and the reduction of pollution and waste (Vezzoli, 2018). Economic sustainability involves supporting long-term economic growth while ensuring that it does not negatively impact the social, environmental, and cultural aspects of the community (Anand & Sen, 2000). Social sustainability emphasises maintaining and improving social well-being, ensuring equitable access to resources, and fostering communities that are inclusive, resilient, and fair (Davidson, 2010). Recently, a fourth pillar has garnered distinct attention: democratic sustainability (see for instance, Goetz et al., 2020). Emerging from the concept of social sustainability, it now stands on its own, referring to the democratic processes and principles that guide sustainability transformations, with an emphasis on inclusive participation, contestation, and reflexive governance across socio-ecological, economic, and political domains (Goetz et al., 2020).

The urgency of integrating teaching and learning about sustainability into education and school curricula became prominent in the late 1980s and early 1990s, influenced by key global reports and initiatives that stressed the importance of this integration (e.g., the United Nations-commissioned Brundtland Report; see Brundtland, 1987). The focus shifted in response to urgent environmental, economic, and social challenges (Gough & Scott, 2003). Consequently, the critical role of integrating sustainability into initial teacher education (ITE) in general is increasingly acknowledged as essential for fostering a sustainable future. Teachers play a crucial role in shaping the values and behaviours of future citizens (UNESCO, 2024), making it vital to prepare prospective teachers with the knowledge, skills, and attitudes needed to advance sustainable development (Nguyen et al., 2023; Rieckmann & Barth, 2022). There has been, however, little focus on integration of suitability in initial mathematics teacher education.

Recent work by Makramalla et al. (2025) provided a comprehensive, strengths-based survey of how mathematics education can respond to sustainability challenges. Their article outlined key conceptual and practical "invitations" to researchers, particularly emphasising the need for deep reflexivity and localised, political framings of sustainability. This review responds to that call by examining how sustainability is conceptualised and operationalised in initial mathematics teacher education (IMTE), through a scoping review of peer reviewed empirical studies from the past decade. This review begins by exploring the general mathematics education literature and how sustainability can be addressed in the mathematics classroom. We then review how general research in ITE has responded to sustainability concerns. Subsequently, included are the research questions to be addressed, methodology, and main findings. Finally, the article concludes with a discussion of the findings and recommendations for future directions in the field.

Sustainability in the Mathematics Classroom

The integration of sustainability into mathematics education has gained traction especially through the lens of critical mathematics education, which encourages learners and teachers to interrogate real-world issues using mathematical tools. This approach foregrounds the ethical responsibility of teachers to embed socio-environmental issues in their pedagogy (Barwell, 2018; Barwell et al., 2022). Scholars such as D'Ambrosio (2015), Li (2023), and Skovsmose (2023) advocated for a paradigm shift that integrates ethics, creativity, and systems thinking into mathematics education. In practice, this shift includes using real-world contexts to explore sustainability through socio-critical mathematical modelling and ethnomathematics (Coles et al., 2024; Renert, 2011; Solares-Rojas et al., 2022). These approaches encourage learners to investigate social inequalities, environmental issues, and economic imbalances through mathematics. Statistical literacy, for example, is central to understanding sustainability-related data, such as carbon emissions, access to clean water, or income disparity (Hamilton & Pfaff, 2014; Vásquez et al., 2023). Real-world tasks, like analysing pollution levels or modelling climate change scenarios, anchor abstract mathematical concepts in tangible social contexts (Steffensen & Kacerja, 2021). Further, STEM integration, particularly through project-based learning, strengthens sustainability education by engaging students in interdisciplinary problem-solving (Bonora et al., 2019; Lavicza et al., 2020; Li & Tsai, 2022). For instance, students might design sustainable cities, evaluate renewable energy systems using mathematical reasoning, or explore environmental data through digital tools and platforms (Laudares et al., 2024).

Overall, sustainability in the mathematics classroom is no longer viewed as a peripheral issue of mathematics teaching and learning. Instead, it is increasingly seen as a central component of ethical, relevant, and future-oriented mathematics education. This framing positions mathematics as a tool for cultivating ecological consciousness, socio-political awareness, and critical agency in learners (Coles et al., 2024; D'Ambrosio, 2015). As Makramalla et al. (2025) argued, integrating sustainability into established topics like modelling or statistics invites reflexive scrutiny, not only of what type of mathematics is taught, but also how it might reinforce or challenge socio-ecological inequities. This reflexive approach adds depth to efforts that embed sustainability through mathematical content and pedagogical practices.

Sustainability in Initial Teacher Education

Parallel to the evolution of mathematics education, sustainability in ITE has emerged as a crucial focus area. Our review of the relevant literature reveals four recurring themes: conceptualisations of sustainability, integrative practices, barriers to implementation, and the need for systemic change.

In terms of conceptualisation, sustainability is often understood through the tripartite lens of environmental, economic, and social pillars, reflecting global frameworks like the Sustainable Development Goals—SDGs (Aikens et al., 2016; Clune & Zehnder, 2020; Giovannoni & Fabietti, 2013). This evolution from early environmental education toward a broader framework of education for sustainable development (ESD) is well-documented (Blom & Karrow, 2024; Brandt et al., 2019). Teacher education scholars argue that sustainability must be contextualised within specific disciplinary practices to gain relevance for future teachers (Goller & Rieckmann, 2022).

Practically, effective integration in ITE involves interdisciplinary and experiential learning approaches that cut across subject boundaries. Pedagogical strategies include problem-based learning, self-directed inquiry, and action-oriented teaching methods (Corres et al., 2020; Ferreira et al., 2019; Fischer et al., 2022). Experiential activities, such as field-based investigations or community partnerships, are especially effective in deepening preservice teachers' understanding of sustainability issues (Bürgener & Barth, 2018; Evans et al., 2021). Embedding sustainability throughout ITE curriculum rather than confining it to elective modules has been recommended to ensure continuity and depth (Brandt et al., 2019).

Despite promising practices, substantial challenges persist. A recurring concern is the absence of explicit policy guidance on sustainability in teacher education, which leads to inconsistent integration across programmes (Aikens et al., 2016; Higgins & Kirk, 2006; Mavrokefalidou & Siatras, 2026). Curriculum overload and rigid structures often prevent meaningful inclusion of new topics such as sustainability (Buchanan, 2012; Evans et al., 2017). Moreover, many teacher educators lack specialised knowledge or confidence in teaching sustainability content, creating further implementation gaps (Gavinolla et al., 2022; Goller & Rieckmann, 2022). Structural and institutional factors compound these challenges. Workload pressures, limited time for collaboration, and disciplinary silos restrict the adoption of interdisciplinary approaches (Clarke & McPhie, 2016; Falkenberg & Babiuk, 2014). In some cases, policymakers and institutions have been reluctant to prioritise sustainability education, favouring more traditional issues like literacy and numeracy (Fischer et al., 2022).

To address these issues, systemic change is needed at multiple levels. From this perspective, Renert (2011) highlighted how sustainability can be addressed in (mathematics) education in different ways, ranging from moderate (i.e., education about sustainability) to more explicit (i.e., education for sustainability) to more radical forms (i.e., education as sustainability). The latter forms require "a transformation of existing systems and allowing learners to make connections across the material, the emotional, the environmental, the spiritual, and more" (Makramalla et al., 2025, p. 12). In regard to ITE, studies emphasise the alignment of ITE curricula with sustainability competencies, professional development frameworks, and accreditation policies (Evans & Ferreira, 2020; Wolff et al., 2022). Embedding ESD in curricula, national standards and assessment frameworks is seen as essential to legitimising its role in ITE. Furthermore, communities of practice, bringing together researchers, teachers, teacher educators, and policymakers, can foster innovation and continuity in sustainability teaching (Bürgener & Barth, 2018; del Carmen Pegalajar-Palomino et al., 2021).

In sum, the literature on sustainability in ITE emphasises the complexity and necessity of preparing future teachers to engage critically and constructively with sustainability challenges. Effective integration requires not only curricular and pedagogical change but also institutional transformation, policy alignment, and long-term vision. This aligns with critiques by Makramalla et al. (2025), who noted that mathematics education often functions as a "certification institution" rather than a transformative force, limiting its ability to respond meaningfully to sustainability imperatives. In other words, (mathematics) education is oriented mainly towards the acquisition of credentials and success within established curricular and assessment structures, rather than towards critical engagement with complex social and ecological problems. Sustainability may consequently remain a peripheral addition to the curriculum instead of becoming a principle through which the aims, content, pedagogy, and assessment of mathematics education are reconsidered. This critique further demonstrates why curricular reform must be accompanied by broader institutional and policy-level change.

Recognising the significance of the themes identified in general teacher education literature, this article examines how research in initial mathematics teacher education (IMTE) has addressed these themes thus far. Specifically, our work aims to answer the following research questions:

1. *How is sustainability conceptualised in studies concerning IMTE?*
2. *What practices are recommended for integrating sustainability into IMTE?*
3. *What are the potential barriers and challenges in incorporating sustainability into IMTE?*
4. *To what extent, and in what ways, does IMTE research address the role of systemic change related to sustainability?*

Nevertheless, we acknowledge that IMTE-related research may have diverged from general ITE research on sustainability. To remain open to any unique directions specific to IMTE, we included a fifth research question:

5. *In what ways does IMTE research on sustainability diverge from prevailing patterns in general ITE research?*

This question was particularly important because our initial, pre-systematic search suggested that some IMTE studies may conceptualise sustainability in ways that extend beyond, or differ from, the dominant ESD-oriented framing in general teacher education research. This preliminary impression motivated us to include the question.

Methodology

To address the five exploratory research questions, we conducted a scoping review of international peer-reviewed research. A scoping review was selected because the purpose of the study was to map the breadth, conceptual range, methodological diversity, and research gaps within an emerging and heterogeneous body of literature, rather than to evaluate the effectiveness of a narrowly specified intervention or to produce an aggregated estimate of effect. The review was informed by the methodological framework proposed by Arksey and O'Malley (2005) and its subsequent refinement by Levac et al. (2010), and it was reported with reference to the PRISMA extension for scoping reviews, PRISMA-ScR (Tricco et al., 2018). Although systematic and scoping reviews employ both transparent and reproducible procedures for searching, selecting, and synthesising literature (Munn et al., 2018), the scoping approach was better aligned with our aim of examining how sustainability is conceptualised, integrated, challenged, and connected to systemic change across diverse IMTE contexts (Horsley, 2019).

Inclusion/exclusion Criteria

Before searching for articles, all authors agreed upon the following inclusion/exclusion criteria:

Criterion 1: Subject area

The papers had to be concerned with issues of initial mathematics teacher education and sustainability. For this reason, the terms "math*" and "sustainab*" had to be included in the title, abstract, and/or keywords. It was decided that articles on STEM teacher education should be excluded, as the role of mathematics (M) in STEM education is not always well-defined (see Nicol et al., 2020; Raymond, 2018). Because this was a scoping review, we intentionally did not restrict inclusion to studies that defined sustainability exclusively in terms of education *for* sustainable development. Instead, we included studies that explicitly connected sustainability with IMTE and allowed the different meanings of sustainability to emerge through the analysis. This broader criterion enabled us to identify conceptual variation within the field, including studies concerned with the durability of mathematics-related knowledge, skills, dispositions, or pedagogical practices. We therefore treat these studies not as equivalent to IMTE in the service of ESD, but as evidence of how the term sustainability is used divergently in the literature.

Criterion 2: Source

We focused on studies published in peer-reviewed journals. We excluded book chapters and conference proceedings, which do not always undergo a peer-review process. Including only peer-reviewed journal articles served as an indirect measure of the "quality" of the work selected (Kilfoil, 2014). Even though issues of quality and its measurement are quite controversial in academia, the process of peer reviewing acts as a mechanism for assessing and preserving the trustworthiness of reporting scientific findings.

Criterion 3: Time range

The studies were published between January 2015 and January 2025 (the latter being the last month in which the search for papers took place). We chose 2015 as the starting point for this review because it marks the adoption of the *United Nations Sustainable Development Goals* (see https://sdgs.un.org/goals), including Goal 4: Quality Education, which has significantly influenced global education policies and research priorities (Smith & Heyward, 2024).

Criterion 4. Research methods

We focused on articles reporting empirical findings based on quantitative, qualitative, or mixed methods. At the same time, theoretical and review articles were excluded.

Criterion 5: Language

For pragmatic reasons, articles had to be published in English.

Identification of Studies

The identification of studies took place in three sequentially structured phases. This process is illustrated in Figure 1, in which we present the exact numbers of studies at different stages, in an adapted version of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009). In Phase 1, a search was conducted in three databases (ERIC, Education Source, and Web of Science), using the following keywords:

1. sustainab*;
2. math*;
3. "initial teacher" OR "pre-service teacher" OR "preservice teacher" OR "prospective teachers" OR "teacher education" OR "teacher preparation" OR "teacher training" OR "teacher students" OR "student teachers" OR "student-teachers".

Upon initial identification, the three co-authors met and discussed the articles in detail, applying the inclusion/exclusion criteria. This process led to the identification of 21 relevant articles.

In Phase 2, we conducted referential backtracking on the 21 articles identified in Phase 1. Referential backtracking is a methodological approach used to enhance the comprehensiveness of a literature review by examining the references cited in selected articles (backward tracking) and identifying subsequent works that have cited these studies (forward tracking). This process helps uncover relevant literature that may not have been retrieved through initial database searches, ensuring a more thorough and systematic approach (Alexander, 2020). This process led to the identification of three additional articles for inclusion in the review. Phase 3 involved searching the content of targeted journals, a method known as handsearching (Pallath & Zhang, 2022). This method requires manual browsing through a curated list of field-specific journals to find articles relevant to the review topic. We included targeted journals in three areas, as shown in Table 1. This phase did not lead to the identification of additional articles.

Table 1
Handsearching in Targeted Journals

Research field	Journals	Justification
Mathematics education	*Educational Studies in Mathematics* *Journal for Research in Mathematics Education* *Journal of Mathematical Behavior* *For the Learning of Mathematics* *Mathematical Thinking and Learning* *Journal of Mathematics Teacher Education* *ZDM–Mathematics Education* *Mathematics Education Research Journal* *International Journal of Mathematical Education in Science and Technology* *School Science and Mathematics*	We focused on the 10 top journals of the field, based on the citation rankings provided by Williams and Leatham (2017).
Teacher education	*Teaching and Teacher Education* *Journal of Teacher Education* *European Journal of Teacher Education* *Teachers and Teaching: theory and practice* *Journal of Mathematics Teacher Education (overlap with mathematics education)*	We focused on all journals within this field marked as Level 2 (top journals), as indicated in the Norwegian Register for Scientific Journals, Series and Publishers (see https://kanalregister.hkdir.no/en).
Sustainability research	*Environmental Education Research* *Journal of Cleaner Production* *Journal of Educational Change*	First, we focused on journals reported in the bibliometric analysis of Gavinolla et al. (2022), about the state of the research on teacher education and sustainability. Second, we included only those journals marked as Level 2 (top journals) in the Norwegian Register for Scientific Journals, Series and Publishers (see https://kanalregister.hkdir.no/en).

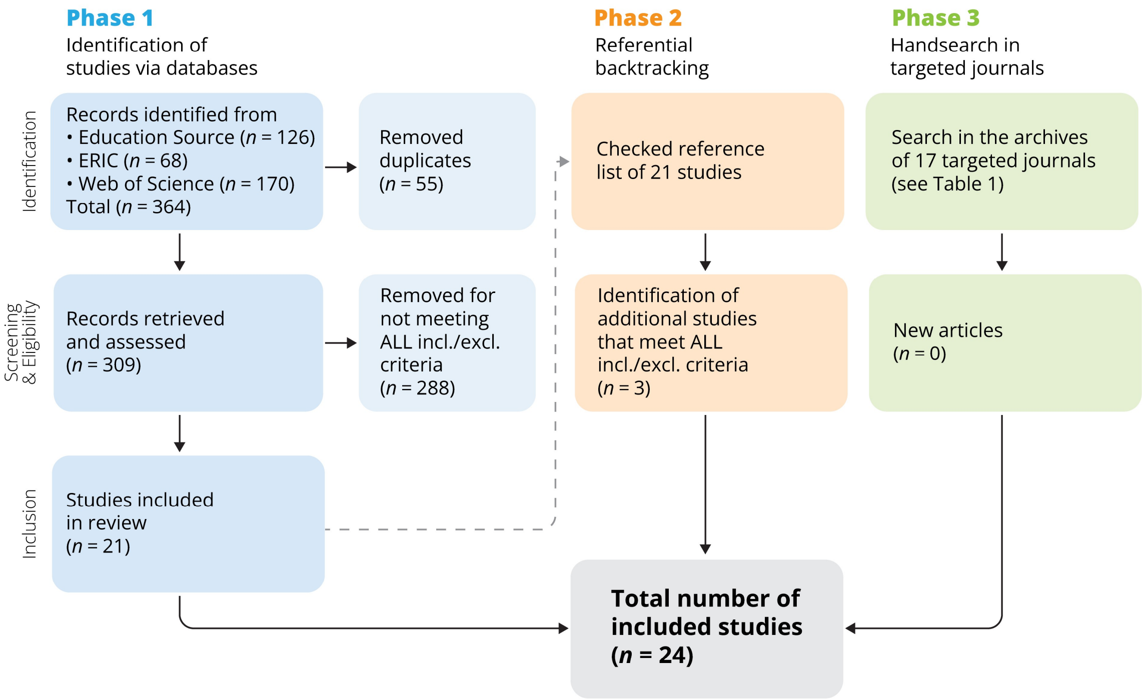

Figure 1. An adapted version of PRISMA diagram—Identification of articles

We used the PRISMA-ScR checklist to guide transparent reporting of the review, while the study-selection process is presented in Figure 1 through an adapted PRISMA flow diagram. Still, there are several limitations to this approach. One key limitation is that the review depended on the search terms we chose. These terms may not have captured all relevant studies, especially if researchers used different terms to describe similar concepts. Additionally, the databases we used may not have included every significant publication on the topic. Another limitation is that we did not specifically focus on research related to mathematical topics such as statistics, mathematical literacy, STEM education, or modelling. These topics can be closely connected to sustainability in mathematics teacher education, even if the studies did not use the word "sustainability." Including these kinds of studies in future reviews—by using broader or more varied search terms—could lead to more complete and insightful results. Also, we only included studies written in English. This means our findings might have been different if we had considered studies in other languages.

Critical Appraisal of Studies: Data Charting and Narrative Synthesis

Following study selection, we developed a data-charting matrix capturing each study's bibliographic information, geographical context, participants, research methods, conceptualisation of sustainability, recommended pedagogical practices, reported barriers, and implications for systemic change. A simplified version informed the design of Table 2 (see the Appendix), which summarises the 24 studies included. The five research questions provided the initial deductive framework, while more specific themes and subthemes were generated inductively through iterative comparison across the dataset. The studies were distributed among the three authors for preliminary charting and coding using the shared matrix and agreed category definitions. Each author's work was then reviewed by at least one colleague. The team subsequently compared interpretations, refined the thematic structure, and resolved discrepancies through consensus. Before preparing the narrative synthesis, all authors collectively checked the final framework against the full set of studies.

Our work was guided by an exploratory and mapping approach (Christou et al., 2025; Kain et al., 2024), rather than an effort to impose a singular framework on sustainability in IMTE. The articles reviewed reflect a diverse and evolving landscape of studies, highlighting the various ways that sustainability has been conceptualised and integrated. Our analysis followed a narrative synthesis approach, guided by our five research questions, along the lines of other recent reviews in educational research (see, for example, Green et al., 2024; Jameson et al., 2023; Lee et al., 2025). This method allowed us to systematically organise and interpret findings across the included articles, identifying key themes, patterns, and relationships. The synthesis was conducted iteratively, grouping results thematically in alignment with our research questions and exploring similarities and differences in study outcomes. Given the heterogeneity of study designs and findings, we argue that this approach provided a structured yet flexible framework for deriving meaningful insights from the literature.

As a descriptive characteristic of the evidence base, Table 2 (Appendix) indicates a geographically uneven distribution of the studies included. Europe is represented in 15 studies, Asia in five, Africa in two, South America in two, and North America in two. These regional categories are not mutually exclusive because two studies involve countries from more than one region. Of the 24 studies, 22 focused on a single country, while two involved two countries: Sweden and the United States, and the United Kingdom and Hong Kong. Spain is the most frequently represented country, appearing in eight articles, whereas Chile and South Korea each appear in two. The United States and Hong Kong also appear in two studies each when the multi-country studies are included, while ten additional countries are represented in one study each.

Findings

Our findings section is organised to respond to the five research questions outlined earlier. Each of the first four subsections corresponds directly to one of the first four research questions. The fifth research question, concerning emerging directions in IMTE research, is addressed within the first subsection, as we observe novelty in how sustainability is being conceptualised in the field.

Conceptualisations of Sustainability

Across the studies identified, sustainability is conceptualised in two main ways, representing opposite ends of a continuum. This finding resonates with Makramalla et al. (2025), who call for a critical interrogation of sustainability itself, asking “sustainability for whom, and where?” and caution against uncritically adopting global framings like the SDGs without attending to local socio-political complexities.

At one end of a continuum, we found studies exploring various sustainability issues as contexts in which mathematics serve to develop prospective teachers’ critical consciousness, in the same spirit critical mathematics education aims to do. We refer to this perspective as **mathematics *for* sustainable development**. In several cases, this is framed by the SDGs. Eleven studies explicitly follow this perspective. One example is the work of Anderson and Register (2023), who reported on a statistics course exploring topics of social sustainability and critical mathematics education, using big data to foster ethical reasoning and critical consciousness among prospective mathematics teachers. As well, Rico et al. (2021) reported on a course designed to bring together mathematics and science for prospective teachers by exploring topics like air pollution and climate change. Another example is the work of Su et al. (2024), who focused on the UN’s SDG of gender equality and developed a statistics course addressing issues of gender inequality.

At the other end of the continuum are studies that conceptualise sustainability quite differently. Specifically, the focus is on how sustainable the impact of IMTE courses is for prospective teachers, and how this impact can be enhanced. This perspective is concerned with the long-term retention and application of mathematics-related knowledge, skills, and dispositions. Five of the identified studies aligned explicitly with what we call **sustainability *of* mathematics-related knowledge, skills, and**

dispositions. From this standpoint, Summer (2019) discussed a mathematics and entrepreneurship course, describing entrepreneurship as a learning process that equips students to develop and apply their ideas. Similarly, Williams (2016) examined how prospective mathematics teachers' beliefs and knowledge about culturally responsive pedagogy can be sustained over time. In turn, both Alex et al. (2023) and Jeong and González-Gómez (2020) investigated how mathematical knowledge can be maintained using technology-enhanced pedagogical approaches. Overall, this conceptualisation of sustainability is quite unique to IMTE, and, to the best of our knowledge, does not appear in the general ITE sustainability literature.

Interestingly, eight of the studies selected could be positioned between the two poles of the continuum, as they shared characteristics of both. This indicates that, to varying degrees, they address both mathematics for sustainable development and the sustainability *of* mathematical knowledge, skills, and dispositions among prospective teachers. One such example is the work of Vásquez et al. (2020), who framed their study with the SDGs to explore the sustainability of prospective mathematics teachers' knowledge and beliefs when confronted with situations where prior knowledge is insufficient. Another related example that blends these two conceptualisations can be found in Pasichnyk et al. (2020), who explored the sustainability of prospective mathematics teachers' beliefs and knowledge, while also emphasising the importance of fostering awareness of human interconnectedness with nature and promoting a peaceful, inclusive society grounded in equality and opportunity for all.

Recommended Practices for Initial Mathematics Teacher Education

To address the question of which practices are recommended for the integration of sustainability in IMTE, we distinguish among the two broad conceptualisations of sustainability, as discussed in the section above.

In regard to the first conceptualisation (mathematics *for* sustainable development), we observe an array of recommendations, summarised below.

Embedding mathematical modelling with real-world contexts

Several studies emphasised mathematical modelling as a key practice for integrating sustainability, particularly through socio-critical and authentic problem-solving activities. For instance, Steffensen (2023) and Wiegand and Borromeo Ferri (2023) demonstrated how modelling can empower prospective teachers to critically engage with environmental issues, such as littering or industrial pollution. These studies highlighted the importance of addressing the assumptions embedded in models and connecting abstract mathematics to tangible ecological and social concerns.

Promoting statistical literacy for social justice

Statistics education emerged as a fertile ground for embedding sustainability discussions, particularly when paired with themes of equity and decision-making. From this perspective, Suh et al. (2020) and Su et al. (2024) argued that engaging prospective teachers in data-driven projects enhances their understanding of sustainability while developing key competencies such as critical thinking and collaboration.

Designing interdisciplinary, problem-based learning tasks

Integrating sustainability into IMTE often requires a shift toward interdisciplinary and inquiry-based approaches. Rico et al. (2021), for instance, discussed the value of a teaching-learning sequence that integrates mathematics and science in a project on air quality. Their approach leverages place-based education and organic learning gardens to ground abstract content in environmental realities. This aligned with findings from Suh and Han (2019), who emphasised the power of project-based learning in enabling students to connect classroom knowledge with complex global challenges.

Supporting curriculum innovation and reflective practice

Curriculum redesign and reflective pedagogical inquiry are central to several studies focused on transformative teacher education. Helliwell and Ng (2022), through an action research study, explored speculative fiction as a method for helping prospective teachers imagine and articulate future-oriented teaching practices. Their work suggested that curriculum innovation must go beyond technical modifications and engage prospective teachers in envisioning mathematics teaching as a tool for sustainable futures. Ghazali et al. (2024) echoed this by recommending concept mapping and curriculum mapping aligned with SDGs as part of module redesign efforts.

Cultivating key competencies for sustainability

Across studies, there is consensus on the value of fostering UNESCO's key competencies for sustainability within IMTE, including systems thinking, anticipatory skills, and normative thinking. As seen in Kanandjebo (2024), there is a need to build prospective teachers' pedagogical knowledge of education for sustainability, enabling them to design lessons that link mathematical content with sustainability themes. Suh et al. (2020) further emphasised that statistical investigations can help prospective teachers cultivate action-oriented decision-making skills, while Su et al. (2024) stressed the importance of embedding gender equity (SDG5) within mathematics instruction.

Utilising assessment tools for sustainability integration

Assessment tools such as sustainability-aligned rubrics and reflective writing are recommended for supporting and evaluating the integration of education for sustainable development in mathematics education. García-Alonso et al. (2023) presented a rubric based on UNESCO's eight key sustainability competencies, which prospective teachers used to design and evaluate their lesson proposals. Similarly, Wiegand and Borromeo Ferri (2023) used qualitative analysis of prospective teachers' written reflections to assess their conceptual understanding of sustainability within modelling tasks.

Regarding the second conceptualisation (sustainability *of* mathematics-related knowledge, skills, and dispositions), we observed a variety of recommended approaches, as summarised below.

Technology-enhanced and digitally sustainable pedagogy

These approaches highlight the role of digital innovation in promoting sustainability. The studies by Alex et al. (2023), Jeong and González-Gómez (2020), and Lo et al. (2024) illustrated how tools such as blended learning models, flipped classrooms, and open educational resources (OER) can enhance teaching effectiveness, access, and adaptability.

Human-centered and socially responsive mathematics education

This perspective focuses on preparing teachers to connect mathematics with students' lived experiences, cultural identities, and societal challenges. The articles by Summer (2019) and Williams (2016) emphasised the importance of embedding financial literacy, entrepreneurship, and culturally responsive dispositions into teacher education.

All the above recommendations can also be observed across the eight studies that blend the two conceptualisations of sustainability. Nevertheless, these eight studies point to additional considerations, which we summarise below.

Developing ethically aware and reflective teacher identities

A number of studies highlighted the importance of supporting prospective teachers in developing ethically grounded professional identities. This involves creating opportunities for them to critically reflect on their beliefs, values, and responsibilities as educators within the context of sustainability. Alsina and Mulà (2019), for example, emphasised reflective learning as central to transforming belief systems into professional competencies. Similarly, Moreno-Pino et al. (2022) and Moreno-Pino et al. (2023) argued for a critical mathematics education that positions teachers as agents of ethical and social change.

Embedding sustainability through integrated STEM and experiential learning

Some studies feature interdisciplinary, hands-on approaches that connect mathematics with broader sustainability goals through STEM frameworks and real-world exploration. Martín-Cudero et al. (2024) implemented mathematics trails, combining STEM and sustainability. Pasichnyk et al. (2020) advocated for systemically integrating sustainability into teacher education curricula via interdisciplinary content.

Çibik & Boz-Yaman (2024) also used cross-curricular modelling courses to link mathematics and sustainable development goals.

Aligning teacher beliefs and values with sustainability principles

The integration of sustainability into IMTE is influenced by the values and beliefs held by prospective teachers. Several studies note that without alignment between teacher values and sustainability goals, implementation remains superficial. For example, Vásquez et al. (2020) argued that while prospective teachers value sustainability, they lack clarity on how to integrate it into practice. In turn, Moreno-Pino et al. (2021) also noted the limited depth of sustainability competencies when belief systems are not explicitly addressed.

Barriers and Challenges to Sustainability Integration in Initial Mathematics Teacher Education

Analysing the eleven studies that follow the first conceptualisation—mathematics *for* sustainable development—revealed five recurring barriers.

Insufficient teacher preparation and pedagogical tools

The most frequently cited barrier was the lack of adequate preparation and pedagogical preparation among prospective teachers. Eight studies (e.g., Ghazali et al., 2024; García-Alonso et al., 2023; Wiegand & Borromeo Ferri, 2023) indicated that future mathematics educators are not being equipped with the practical skills, didactic strategies, or conceptual frameworks needed to integrate sustainability themes into mathematics education.

Lack of curriculum integration

Five studies (e.g., Kanandjebo, 2024; Helliwell & Ng, 2022) reported that sustainability concepts are often underrepresented or absent in mathematics curricula and national assessment frameworks. In many contexts, education for sustainable development exists only as a cross-curricular aim rather than as a specific learning outcome, leaving mathematics teachers without clear guidance or structural support for integration.

Conceptual confusion about how mathematics connects to sustainability

Six studies (e.g., Suh et al., 2020; Su et al., 2024) highlighted that both prospective teachers and their instructors frequently struggle to understand how mathematics relates to sustainability. Some teachers perceive mathematics as too abstract or procedural to meaningfully engage with real-world environmental or social issues. Others expressed uncertainty about how to frame mathematical content, such as statistics or modelling, in ways that authentically support sustainability education.

Institutional and policy-level inertia

Institutional resistance and vague policy directives were cited as barriers in two studies (Wiegand & Borromeo Ferri, 2023; Helliwell & Ng, 2022). While some educational policies made reference to the UN's SDGs, implementation is often left to individual institutions or instructors, leading to inconsistency and a lack of systemic support.

Scarcity of proven models and resources

Finally, two studies (García-Alonso et al., 2023; Wiegand & Borromeo Ferri, 2023) emphasised the absence of established, empirically validated models for integrating sustainability into IMTE. The lack of accessible teaching materials, lesson plans, and case studies created uncertainty among teacher educators and hindered the development of sustainable teaching practices.

Concerning the second conceptualisation of sustainability (sustainability *of* mathematics-related knowledge, skills, and dispositions), the five studies identified underline some complementary barriers to those listed above.

Structural and systemic inequities

A recurring challenge across the reviewed literature is the presence of deeply rooted structural inequalities that limit opportunities for prospective mathematics teachers. Alex et al. (2023) highlighted the persistent disparities in rural South-African contexts, where inadequate infrastructure, historical educational inequalities, and lack of support systems severely hampered the preparation of student teachers. These systemic deficits extended to the broader curriculum as well. Summer (2019) noted the limited inclusion of entrepreneurship and financial education in Austrian primary mathematics curricula, which restricted the development of broader economic competencies essential for sustainability.

Gaps in knowledge and pedagogical preparedness

Another prominent theme is the lack of subject-specific and pedagogical content knowledge among prospective teachers. Jeong and González-Gómez (2020) found that approximately 80% of their student cohort in Spain had a weak background in mathematics, which posed a substantial challenge when adapting to flipped classroom models and sustainability-focused pedagogy. This knowledge gap was compounded by limited prior exposure to the principles of sustainable mathematics education. Lo et al. (2024) echo this concern, reporting that prospective teachers often lack the skills necessary to produce high-quality, pedagogically sound OER. The underdevelopment of such competencies limits their ability to contribute to sustainable teaching practices.

Technological and infrastructure limitations

The integration of digital technologies in mathematics education is widely recognised as essential for sustainability in an increasingly digital world. However, several studies identified significant technological and infrastructural barriers. Alex et al. (2023) documented the scarcity of technological resources in South-African rural schools, where student teachers struggle to implement technology-enhanced learning due to lack of internet access, hardware, and digital literacy. In a different context, Jeong and González-Gómez (2020) revealed that although flipped e-learning models show promise, many prospective teachers lack the digital fluency required to engage effectively with these tools.

Dispositions, beliefs, and cultural responsiveness: The role of teacher dispositions and cultural competence in sustaining effective teaching practices is well documented in the literature. Williams (2016) focused on the cultural dispositions of prospective mathematics teachers in the United States, noting a significant gap between theoretical understanding and practical application of culturally responsive teaching. Many participants expressed discomfort when working with culturally and linguistically diverse students, underscoring the need for deliberate and structured training in inclusive pedagogies. Summer (2019) also highlighted the importance of reflective practice, particularly in the domain of financial education.

Resistance to innovation and change

Finally, the literature reveals substantial resistance to pedagogical innovation, both at individual and institutional levels. Alex et al. (2023) reported that despite the introduction of blended learning tools like *GammaTutor*, many teachers remain reliant on traditional "chalk-and-talk" methods. This reluctance is often due to a lack of training, confidence, or motivation to adopt new methodologies. Jeong and González-Gómez (2020) further identified scepticism towards flipped learning among prospective teachers, which they attribute to limited exposure and the perceived complexity of implementing such models.

A review of the eight studies situated between the two main conceptualisations of sustainability in IMTE revealed no additional barriers beyond those already mentioned above. While some studies offered further nuance, such as the disconnect between institutional expectations and actual classroom implementation (Alsina & Mulà, 2019; Moreno-Pino et al., 2021), or the tendency to prioritise technical competencies over critical and ethical reflection (Vásquez et al., 2020; Moreno-Pino et al., 2023), these insights align closely with the existing themes. Consequently, the barriers previously identified remain comprehensive and sufficiently encompass the challenges reported across the full set of studies.

Systemic Change and Policy Recommendations

The issue of systemic change is addressed by several identified studies. We first begin by reviewing how this is addressed in the eleven studies that conceptualise sustainability from the first perspective.

Curriculum-level transformation

Several studies adopted a structural approach by embedding sustainability within the formal curricula of mathematics teacher education. García-Alonso et al. (2023) and Ghazali et al. (2024) presented frameworks for aligning IMTE curricula with sustainability principles, using tools such as rubric-based assessment and curriculum mapping. These efforts reflect a recognition that sustainability cannot remain peripheral in teacher education but must instead shape learning outcomes, course content, and pedagogical objectives. Similarly, Wiegand and Borromeo Ferri (2023) advocated for a theoretically grounded integration of mathematical modelling for sustainable development through a model that supports institutional anchoring, moving from project-based implementations to sustainable curricular structures. Kanandjebo (2024), focusing on the Namibian context, emphasised the need for IMTE curricula to prepare prospective teachers not only with knowledge, but with pedagogical strategies to integrate sustainability themes meaningfully in mathematics classrooms.

Shifting mathematics teacher educator practices and pedagogical paradigms

Systemic change also requires rethinking the roles and practices of mathematics teacher educators themselves. Helliwell and Ng (2022) provided an action research study where speculative fiction and pedagogical imagination are employed to reorient mathematics teacher education toward sustainable futures. Here, systemic change is enacted through reflection, innovation, and intentional curriculum design that disrupts conventional approaches. Suh and Han (2019) similarly promoted the use of STEM-based mathematical modelling projects as a vehicle to foster interdisciplinary thinking and future-oriented problem solving, requiring educators to adopt new roles as facilitators of complex, real-world inquiry.

Competency-based approaches to systemic change

A third route to systemic change lies in the development of key competencies among future teachers. Su et al. (2024) and Suh et al. (2020) demonstrated how the integration of statistical literacy, sustainability, and gender equity can be operationalised through targeted training cycles. These studies emphasise that IMTE must cultivate competencies aligned with UNESCO's ESD framework—such as systems thinking, anticipatory skills, critical reflection, and collaborative problem solving—so that prospective teachers can both navigate and lead sustainability-related educational reforms. Rico et al. (2021) further argued that transformative learning experiences in sustainability-linked STEM contexts can empower future teachers as agents of systemic educational change.

Ground-level innovation with systemic potential

Steffensen (2023) illustrated how practice-based change, even at the classroom level, can carry systemic potential. The study engaged prospective teachers in socio-critical modelling tasks focused on environmental issues, demonstrating a meaningful integration of sustainability into everyday teaching practice. Although localised, this approach offers a scalable model that could inform broader systemic transformation in IMTE.

The five studies conceptualising sustainability from the second perspective introduce three additional themes about the role of systemic change.

Technological integration as a lever for systemic change

Two studies identify technology as a structural driver of change in IMTE. Alex et al. (2023) introduced *GammaTutor*, a portable, offline device designed for rural South-African schools, supporting a techno-blended model aimed at equitable and sustainable mathematics instruction. Jeong and González-Gómez (2020) employed a decision-analysis framework to assess how flipped e-learning environments support prospective teachers in adapting to pedagogical shifts aligned with sustainable development.

Both studies highlight how context-sensitive technological integration can mitigate systemic barriers related to access, quality, and future-readiness.

Co-construction and professional collaboration as pathways to change

Lo et al. (2024) and Jeong and González-Gómez (2020) emphasised collaborative models as foundations for sustainable systemic transformation. Lo et al. describe a dual-cycle action research project in which pre- and in-service teachers co-develop and iteratively refine open educational resources for secondary mathematics. This approach frames sustainability as both content and process, leveraging professional communities to create adaptable, enduring tools. Jeong and González-Gómez (2020) similarly underscored the role of shared input in shaping pedagogical criteria for sustainability.

Competency frameworks aligned with sustainability

Three studies address systemic change through the cultivation of sustainability-related competencies. For instance, Jeong and González-Gómez (2020) prioritised digital fluency, systems thinking, and adaptability within flipped learning contexts. While primarily focused on technological delivery, Alex et al. (2023) also highlighted the importance of 21st-century skills as foundational for sustainability in an increasingly digital world.

Analyses of the eight studies blending the two sustainability conceptualisations indicated that the themes identified above sufficiently capture how systemic change related to sustainability is addressed in IMTE. For instance, several studies highlight curriculum transformation through program redesign and policy alignment (Alsina & Mulà, 2019; Moreno-Pino et al., 2021). Others emphasised teacher educator practice change and reflective pedagogy (Moreno-Pino et al., 2022; Vásquez et al., 2020) or apply competency-based approaches aligned with ESD frameworks (Moreno-Pino et al., 2023; Vásquez et al., 2020). Technology integration (Martín-Cudero et al., 2024), collaborative resource design (Martín-Cudero et al., 2024), and mathematical modelling for real-world issues (Çibik & Boz-Yaman, 2024) also aligned clearly with these themes.

Discussion: Rethinking Initial Mathematics Teacher Education for Sustainable Futures

This review reveals a field in transition but lacking cohesion. Despite an increase in scholarship, sustainability in IMTE remains conceptually fragmented and structurally peripheral. The studies reviewed fall along a continuum, from using mathematics as a lens to explore sustainability challenges (e.g., Rico et al., 2021; Su et al., 2024), to focusing on sustaining mathematical knowledge itself (e.g., Alex et al., 2023; Williams, 2016). While both perspectives hold value, their coexistence without explicit awareness signals a deeper theoretical confusion. The absence of a unified conceptual framework of sustainability in IMTE impedes the development of comprehensive pedagogies and weakens the potential of IMTE to act as a coherent driver of sustainability education.

This conceptual ambiguity is compounded by a broader institutional inertia. Many IMTE programs continue to prioritise traditionalist models that emphasise procedural fluency and abstract reasoning, often at the expense of interdisciplinary, context-responsive, or ethically grounded teaching (Ghazali et al., 2024; Goller & Rieckmann, 2022). Faculty uncertainty, rigid curricula, and narrow policy mandates leave little room for transformative approaches. While several studies showcase innovative teaching practices and course designs (e.g., Helliwell & Ng, 2022; Steffensen, 2023), these remain largely isolated. The systemic enablers required to support and scale such innovations—including accreditation standards, professional development, and policy frameworks—are largely absent or misaligned (Evans & Ferreira, 2020; Wolff et al., 2022).

A key finding is the misalignment between the sustainability values held by prospective teachers and the structural realities of their training environments. Many prospective teachers express strong commitments to sustainability (Moreno-Pino et al., 2021; Vásquez et al., 2020), yet struggle to translate these values into practice. This values-to-practice gap reveals a critical shortfall: institutions may signal support for sustainability rhetorically but fail to enact it structurally. Without clear guidance, curricular space, or assessment criteria, sustainability remains an abstract ideal rather than a pedagogical imperative.

The review also uncovers critical absences in the literature. There is minimal engagement with Indigenous, decolonial, or Global South perspectives on sustainability in mathematics education, although a small number of studies are situated in Global South contexts, including South Africa (Alex et al., 2023), Chile (Vásquez et al., 2020), and Namibia (Kanandjebo, 2024). The geographical distribution of the included studies further contextualises these absences. The evidence base is concentrated in a limited number of national settings, with a particularly strong representation of studies conducted in Spain, while many countries and regions are represented by only one study or are absent altogether. This concentration may shape the conceptual frameworks, policy priorities, and institutional conditions reflected in the literature. The patterns identified in this review should therefore be interpreted cautiously and should not be assumed to represent IMTE internationally. Research conducted across a broader range of cultural, political, linguistic, and educational contexts may reveal additional conceptualisations of sustainability, pedagogical practices, and structural challenges. A further limitation is the literature's dominant emphasis on environmental issues, often at the expense of social justice, economic equity, and cultural sustainability. This narrow framing constrains the transformative potential of sustainability education, particularly within mathematics, a discipline that is central to modelling systems, interrogating data, and envisioning alternatives (Barwell et al., 2022; Hamilton & Pfaff, 2014).

Toward a Re-imagined Purpose for Initial Mathematics Teacher Education

To move forward, IMTE must be reimagined not as a site of technical preparation, but as a formative space where future teachers engage critically with the social and ecological crises of their time. Mathematics education should be reframed as a tool for systems thinking, ethical reasoning, and democratic engagement (Coles et al., 2024; Skovsmose, 2023). This means shifting from content delivery toward pedagogies that are socially responsive and epistemologically diverse, incorporating perspectives from critical mathematics, Indigenous knowledge/epistemologies, and local sustainability practices. In this sense, IMTE needs to move from moderate forms (i.e., education *about* sustainability) to more transformative, radical forms, that is, education *as* sustainability (Renert, 2011).

Practically, this demands curriculum transformation (Renert, 2011). Mathematical concepts should be systematically linked to real-world sustainability challenges, such as using statistics to analyse climate data or geometry to model spatial inequities (Rico et al., 2021; Steffensen & Kacerja, 2021), in ways that encourage reflexive scrutiny (Makramalla et al., 2025). Accreditation frameworks for ITME must mandate sustainability competencies, including systems thinking and anticipatory skills, ensuring these are not optional extras but core elements of teacher preparation (Brandt et al., 2019; UNESCO, 2024). Faculty development and cross-disciplinary learning communities must be institutionally supported to shift educator practices (Ferreira et al., 2019). Policy reform is also essential. National teaching standards, program accreditation, and funding priorities should explicitly recognise sustainability as a foundational competency. As the review shows, innovative practices exist, but without alignment across institutional and policy levels, their impact remains limited (Evans & Ferreira, 2020; Wolff et al., 2022).

This review has mapped the emerging landscape of sustainability within initial mathematics teacher education, identifying two dominant conceptualisations and a range of pedagogical innovations and challenges. Yet, in line with the reflexive and ethically grounded vision proposed by Makramalla et al. (2025), it is clear that preparing mathematics teachers for sustainable futures requires more than curriculum adjustments or new instructional models. It demands a deeper reimagining of the aims of mathematics education itself, one that foregrounds relational approaches, challenges reductive or purely technical interpretations of sustainability, and engages critically with questions about who benefits from sustainability efforts and what impacts they have. IMTE should be conceived not merely as a site for transmitting knowledge but as a transformative space where prospective teachers develop the critical, emotional, and ethical capacities needed to navigate complex socio-ecological realities. Approaching sustainability as both content and disposition enables mathematics teacher education to contribute meaningfully to the cultivation of just, inclusive, and ecologically attuned futures.

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Competing interests

The authors declare there are no competing interests.

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Appendix

Table 2: *An Overview of the 24 Studies Included*

	Authors	Title and DOI	Journal	Year	Country of study	Methods
1	Jogymol Alex, Werner Olivier, Folake Modupe Adelabu	GammaTutor: A techno-blended model for sustainable mathematics teaching in the 4IR/Post-COVID-19 era. https://doi.org/10.18848/2327-0144/CGP/v31i01/25-44	*The International Journal of Technologies in Learning*	2023	South Africa	Qualitative reflections from 6 student teachers using a techno-blended teaching model (GammaTutor) in rural schools.
2	Ángel Alsina, Ingrid Mulà	Advancing towards a transformational professional competence model through reflective learning and sustainability: The case of mathematics teacher education. https://doi.org/10.3390/su11154039	*Sustainability*	2019	Spain	Qualitative analysis of 30 class sessions from a university course; identification of key elements in reflective teaching.
3	Christian H. Andersson, Jordan T. Register	An examination of pre-service mathematics teachers' ethical reasoning in big data with considerations of access to data. https://doi.org/10.1016/j.jmathb.2022.101029	*Journal of Mathematical Behavior*	2023	Sweden, USA	Qualitative interview study; part of design-based research exploring ethical reasoning in data science contexts.
4	Israel García-Alonso, Diana Sosa-Martín, Rodrigo Trujillo-González	Assessing sustainability competencies present in class proposals developed by prospective mathematics teachers. https://doi.org/10.35763/aiem23.5419	*AIEM—Avances de Investigación en Educación Matemática*	2023	Spain	Rubric-based analysis of classroom proposals developed during a sustainability-focused training program.
5	Munirah Ghazali, Muzirah Musa, Nooraida Yakob, et al.	Promoting Sustainable Development Goals (SDGs) in an undergraduate preservice teachers' mathematics course using DeCoRe+ methodology and assessing students' SDG understanding through concept mapping. https://doi.org/10.1177/27527263241231997	*Asian Journal for Mathematics Education*	2024	Malaysia	Mixed-methods; syllabus review, development and implementation of modules, and concept map analysis from 39 students.
6	Tracy Helliwell, Oi-Lam Ng	Imagining possibilities: innovating mathematics (teacher) education for sustainable futures. https://doi.org/10.1080/14794802.2022.2079553	*Research in Mathematics Education*	2022	United Kingdom, Hong Kong	Action research with three phases involving speculative fiction tasks and curriculum innovation for sustainability.
7	Jin Su Jeong, David González-Gómez	Adapting to PSTs' pedagogical changes in sustainable mathematics education through flipped e-learning: Ranking its criteria with MCDA/F-DEMATEL. https://doi.org/10.3390/math8050858	*Mathematics*	2020	Spain	Applied MCDA/F-DEMATEL with SAW and professional survey; course involved 230 students across 3 groups.

	Authors	Title and DOI	Journal	Year	Country of study	Methods
8	Leena N. Kanandjebo	Mathematics as a driver for sustainable development: Pre-service teachers' perspectives on awareness, challenges, and implications for teacher training. https://doi.org/10.38140/ijer-2024.vol6.26	*Interdisciplinary Journal of Education Research*	2024	Namibia	Qualitative exploratory case study; open-ended questionnaire with 8 third-year pre-service mathematics teachers.
9	Chung Kwan Lo, Fletcher Ng, Ka Luen Cheung	Sustainable development and formative evaluation of mathematics open educational resources created by pre-service teachers: An action research study. https://doi.org/10.1186/s40561-024-00311-y	*Smart Learning Environments*	2024	Hong Kong	Dual-cycle action research with pre- and in-service teachers; formative evaluation and learning outcomes tested on 35 students.
10	Daniel Martín-Cudero, Rocío Guede-Cid, Piedad Tolmos, Ana Isabel Cid-Cid	Development of a mathematical experience from a STEM and sustainable development approach for primary education pre-service teachers. https://doi.org/10.3390/educsci14050495	*Education Sciences*	2024	Spain	Quantitative and qualitative analysis of STEM-based math trails; Likert-scale questionnaires, open-ended questions, interviews.
11	Francisco M. Moreno-Pino, Rocío Jiménez-Fontana, José María Cardeñoso Domingo, Pilar Azcárate Goded	Study of the presence of sustainability competencies in teacher training in mathematics education. https://doi.org/10.3390/su13105629	*Sustainability*	2021	Spain	Content analysis of course syllabi using the EDINSOST model and Green Curriculum framework.
12	Francisco M. Moreno-Pino, Rocío Jiménez-Fontana, José María Cardeñoso Domingo, Pilar Azcárate Goded	Training in mathematics education from a sustainability perspective: A case study of university teachers' views. https://doi.org/10.3390/educsci12030199	*Education Sciences*	2022	Spain	Case study using exploratory questionnaires, course syllabus review, and semi-structured interviews with university teachers.
13	Francisco M. Moreno-Pino, Rocío Jiménez-Fontana, Daniel Romero-Portillo	Development of sustainability competencies in the area of didactics of mathematics. https://doi.org/10.35763/aiem23.5373	*AIEM - Avances de Investigación en Educación Matemática*	2023	Spain	Quantitative study using EDINSOST questionnaire (Likert scale) on 105 students across three education programs.
14	Natalia Pasichnyk, Renat Rizhniak, Inna Krasnoshchok, Yuliia Botuzova, Kateryna Akbash	Construction of theoretical model for sustainable development in future mathematical teachers of higher education. https://doi.org/10.13189/ujer.2020.080546	*Universal Journal of Educational Research*	2020	Ukraine	Expert survey involving educators and master's students to design a theoretical model of sustainability-focused math teacher education.
15	Arantza Rico, Elena Agirre-Basurko, Aritz Ruiz-González, Igone Palacios-Agundez, Daniel Zuazagoitia	Integrating mathematics and science teaching in the context of education for sustainable development: Design and pilot implementation of a teaching-learning sequence about air quality with pre-service primary teachers. https://doi.org/10.3390/su13084500	*Sustainability*	2021	Spain	Design and pilot study using constructivist strategies; interdisciplinary teaching-learning sequence integrating STEM and ESD.

	Authors	Title and DOI	Journal	Year	Country of study	Methods
16	Lisa Steffensen	Sustainability and mathematical modelling in 5th grade. https://doi.org/10.34024/prometeica.2023.27.15290	*PROMETEICA - Revista de Filosofia y Ciencias*	2023	Norway	Thematic analysis of modelling tasks designed and implemented by pre-service teachers during practicum in primary schools.
17	Chia Shih Su, Danilo Díaz-Levicoy, Chuan Chih Hsu	The impact of a training cycle on statistics and probability for future primary schoolteachers with a gender-focused approach within the framework of education for sustainable development. https://doi.org/10.29333/ejmste/14177	*EURASIA Journal of Mathematics, Science and Technology Education*	2024	Chile	Mixed methods; lesson study and statistical projects with 25 future teachers evaluated via tests and focus groups.
18	Heejoo Suh, Sohyung Kim, Seonyoung Hwang, Sunyoung Han	Enhancing preservice teachers' key competencies for promoting sustainability in a university statistics course. https://doi.org/10.3390/su12219051	*Sustainability*	2020	South Korea	Mixed methods; statistical investigation project with pre/post-tests, surveys, and qualitative data from reflections.
19	Heejoo Suh, Sunyoung Han	Promoting sustainability in university classrooms using a STEM project with mathematical modeling. https://doi.org/10.3390/su11113080	*Sustainability*	2019	South Korea	Mixed methods; STEM project in algebra class using modeling; pre/post surveys and qualitative journals/interviews.
20	Anita Summer	Entrepreneurship education in mathematics education for future primary school teachers. https://doi.org/10.2478/dcse-2019-0020	*Discourse and Communication for Sustainable Education*	2019	Austria	Case study of a university course implemented since 2015; analysis of curriculum and practical integration of entrepreneurship education.
21	Claudia Vásquez, María José Seckel, Ángel Alsina	Belief system of future teachers on education for sustainable development in math classes. http://dx.doi.org/10.15359/ru.34-2.1	*Uniciencia*	2020	Chile	Interpretive study using surveys with 145 pre-service teachers from early childhood and primary education programs.
22	Sabine Wiegand, Rita Borromeo Ferri	Promoting pre-service teachers' professionalism in STEAM education and education for sustainable development through mathematical modelling activities. https://doi.org/10.1007/s11858-023-01500-8	*ZDM–Mathematics Education*	2023	Germany	Qualitative type-forming content analysis of written reflections by 14 pre-service teachers after a university seminar on mathematical modelling and ESD.
23	Desha L. Williams, Belinda Edwards, Karen A. Kuhel, Woong Lim	Culturally responsive dispositions in prospective mathematics teachers. https://doi.org/10.1515/dcse-2016-0013	*Discourse and Communication for Sustainable Education*	2016	United States	Qualitative case study on 5 pre-service teachers; explored impact of culturally responsive preparation programs.
24	Naz Fulya Çibik, Burçak Boz-Yaman	The effect of a cross-curricular course on pre-service teachers' sustainable development attitudes and mathematical modeling self-efficacy beliefs. https://doi.org/10.1007/s10763-024-10497-9	*International Journal of Science and Mathematics Education*	2024	Turkey	Mixed-method with concurrent triangulation design; pre- and post-course surveys and open-ended questions with 44 pre-service teachers.