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Review Article

Integrating Mathematics Education with Technology and Sustainability: The Novel IMETS Framework

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Abstract

The growing intersection of global sustainability challenges, mathematics education, and technological advancements has created an urgent need for educational frameworks that foster interdisciplinary learning. This paper introduces the Integrating Mathematics Education, Technology, and Sustainability (IMETS) Framework, a novel approach designed to enhance students' mathematical understanding while promoting sustainable practices and leveraging modern technological tools. The IMETS Framework integrates three key components—sustainability, mathematics education, and technology—into a cohesive curriculum that prepares students to address real-world problems such as climate change, resource management, and social equity. The framework emphasizes using technology to create interactive and personalized learning experiences and embeds sustainability directly into the mathematics curriculum. By fostering critical thinking and problem-solving skills, the IMETS Framework equips students with the tools needed to navigate the complexities of the 21st century. This paper outlines the conceptual foundations of the framework, explores its practical applications in various educational contexts, and discusses its potential contributions to global educational goals, particularly the United Nations' Sustainable Development Goals (SDGs).

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Introduction

Background and Rationale

The role of mathematics education has evolved significantly in recent years, particularly in addressing global sustainability challenges. Mathematics is increasingly recognized as a critical tool for understanding and solving complex issues related to sustainability, such as climate change, resource management, and social equity (Melawati et al., 2022). Integrating mathematical concepts into real-world problems enhances students' analytical skills and empowers them to contribute meaningfully to societal challenges (Angraini & Nurmaliza, 2022). Furthermore, the advent of technology in education has transformed traditional pedagogical approaches, making learning more interactive and engaging (Hidayati & Kurniati, 2018). Recent research has further affirmed the role of digital transformation in reshaping mathematics education for sustainability. Meylani (2025a) emphasized that emerging technologies not only enhance conceptual understanding but also promote interdisciplinary thinking. Incorporating digital tools into mathematics education enhance learning outcomes by providing students with innovative ways to visualize and manipulate mathematical concepts (Kurniati et al., 2022).

However, there is a pressing need for a comprehensive framework that effectively combines sustainability, mathematics education, and technology. Current educational frameworks often operate in silos, failing to integrate these critical areas cohesively (Rohaeti & Koswara, 2018). This lack of integration hinder students' ability to apply mathematical reasoning to real-world sustainability issues. Therefore, developing a framework that bridges these domains is essential for preparing students to tackle the multifaceted challenges of the 21st century (Nashrullah et al., 2023).

Problem Statement

Despite the recognized importance of integrating sustainability and technology within mathematics education, existing frameworks often fall short. Many educational systems prioritize traditional teaching methods that do not adequately prepare students for the complexities of modern sustainability challenges (Lestari et al., 2023). This gap highlights the necessity for a new approach that incorporates mathematical concepts and emphasizes their application in real-world contexts (Harjo et al., 2019). The IMETS Framework aims to address this gap by providing a structured approach to integrating mathematics education with sustainability and technology, thereby equipping students with the skills to navigate contemporary challenges (Kannadass et al., 2023).

Purpose of the Study

The primary purpose of this study is to introduce and thoroughly explain the Integrating Mathematics Education Technology and Sustainability (IMETS) Framework. This framework represents a novel approach to mathematics education that seeks to bridge the gap between traditional mathematics teaching methods and the demands of contemporary global challenges, particularly sustainability-related ones. The IMETS Framework aims to:

- *Integrate Sustainability into Mathematics Education:* It focuses on embedding sustainability principles directly into the mathematics curriculum, ensuring that students not only learn mathematical concepts but also understand how they applied to address real-world sustainability issues. This integration is designed to make mathematics more relevant and engaging for students by connecting abstract concepts to tangible global challenges such as climate change, resource management, and social equity.

- *Leverage Technology to Enhance Learning:* The framework also emphasizes using technology to facilitate and enrich learning. The IMETS Framework seeks to create a more interactive, personalized, and effective educational experience by incorporating digital tools and platforms. Technology is seen as an auxiliary tool and an integral component of the teaching and learning process, enabling students to explore complex mathematical ideas through simulations, data analysis, and collaborative online projects.
- *Prepare Students for the Future:* Another critical objective of the IMETS Framework is to prepare students for the future by equipping them with the critical thinking, problem-solving, and technological skills necessary to navigate and address the challenges of the 21st century. By fostering an interdisciplinary approach that combines mathematics, technology, and sustainability, the framework aims to develop well-rounded individuals capable of contributing positively to society and the environment.

This study will outline the key components and principles of the IMETS Framework, discuss its potential applications in various educational contexts, and explore its implications for both students and educators. Ultimately, the study seeks to demonstrate the IMETS Framework's transformative potential in reshaping mathematics education to better meet the needs of the modern world.

Research Questions

To guide the exploration of the IMETS Framework, several key research questions have been formulated:

- What are the key components and principles of the IMETS Framework?
- How does the IMETS Framework integrate sustainability, mathematics education, and technology?
- What are the implications of applying the IMETS Framework in various educational contexts?

Significance of the Study

The significance of this study lies in its potential to contribute to educational theory and practice by introducing a novel framework that integrates sustainability, mathematics education, and technology. The IMETS Framework offers a new paradigm for teaching and learning that aligns with the evolving needs of the 21st century, where global challenges such as climate change, technological advancement, and social inequality require innovative solutions grounded in solid mathematical understanding.

- *Contribution to Educational Theory:* The study contributes to educational theory by proposing a new interdisciplinary framework bridging the gap between traditional mathematics education and the broader sustainability and technological literacy goals. It provides a theoretical foundation for how these domains integrated to enhance the relevance and effectiveness of mathematics education. By doing so, it addresses existing gaps in the literature and offers a comprehensive model that further developed and tested in various educational contexts.
- *Impact on Educational Practice:* The IMETS Framework has significant implications for educational practice. By embedding sustainability and technology into the mathematics curriculum, the framework offers educators a practical tool for making mathematics more relevant and engaging for students. It also provides strategies for leveraging technology to improve learning outcomes, fostering critical thinking, and preparing students to address real-world challenges. The framework's adaptability across different educational levels and settings makes it a versatile tool for educators, potentially transforming how mathematics is taught and learned.
- *Alignment with Global Educational Goals:* The study is particularly relevant to global educational goals such as the United Nations' Sustainable Development Goals (SDGs), which emphasize the importance of quality education, innovation, and sustainability. By aligning mathematics education with these goals, the IMETS Framework enhances student learning and contributes to broader societal efforts to create a more sustainable and equitable world. This alignment underscores the study's importance in shaping future educational policies and practices that prioritize sustainability and technological literacy.
- *Future-Oriented Education:* The IMETS Framework represents a forward-looking approach to education that anticipates the skills and knowledge students need. By

integrating mathematics with sustainability and technology, the framework prepares students to navigate and address the complex challenges of the 21st century. This study highlights the importance of future-oriented education that equips students with academic knowledge, practical skills, and ethical awareness necessary to contribute positively to society and the environment.

Methodology

Research Design

This study employed a conceptual research methodology grounded in design-based research (DBR) to develop the Integrating Mathematics Education, Technology, and Sustainability (IMETS) Framework. The aim was to construct a theoretically robust and pedagogically actionable model for integrating sustainability and digital technologies into mathematics instruction at the K–12 level.

Although the present study employed elements from a conceptual and partly bibliometric research methodology, its connection to design-based research (DBR) warrants elaboration. DBR is not limited to empirical interventions; it also supports the iterative construction of theoretical models that can guide educational practice (Scott et al., 2020). In this study, DBR principles were adopted in three ways: (a) problem identification through an extensive literature review on mathematics education, technology, and sustainability; (b) iterative model development, in which bibliometric findings and thematic synthesis informed the structuring of the IMETS framework; and (c) design validation, where the emerging framework was mapped against existing interdisciplinary models. By applying DBR in a conceptual manner, the study ensures that the IMETS framework is not only theoretically robust but also pedagogically actionable for future empirical testing.

Design-based research was chosen due to its appropriateness for generating practical innovations while maintaining theoretical rigor (Anindita et al., 2021; Kurniati et al., 2022). The research was conducted independently by the Meylani without collaboration, interviews, or field data collection. All findings and conceptualizations were derived solely through the systematic review and synthesis of existing literature.

Literature Review Process

The conceptualization of the IMETS Framework was informed by an extensive and purposive literature review. The review process involved identifying and analyzing peer-reviewed journal articles, theoretical papers, and empirical studies addressing three intersecting domains: (1) mathematics education; (2) sustainability in educational practice; and (3) the use of digital tools in instructional design.

Sources were selected based on the following inclusion criteria:

- Publication in peer-reviewed journals indexed in Scopus, ERIC, DOAJ, or Web of Science.
- Publication dates between 2010 and 2023.
- Explicit relevance to at least one of the following: critical thinking in mathematics (e.g., Firdaus et al., 2015; Harjo et al., 2019), education for sustainable development (e.g., Alsina & Mulà, 2019; Putra et al., 2022), technology integration in teaching (e.g., Hidayati & Kurniati, 2018; Kurniati et al., 2022) along with mathematics education.
- Studies presenting either conceptual models or empirical data applicable to K–12 educational settings.

The literature review process was iterative. Initial keyword searches were conducted using Boolean operators with terms including "mathematics education AND sustainability," "critical thinking AND digital tools AND K–12," and "sustainability AND mathematical modeling." Articles were then coded according to themes that aligned with the foundational elements of the emerging IMETS Framework.

Table 1. Development stages of the IMETS framework

Stage	Focus Area	Key Activities	Supporting Literature
Stage 1. Thematic Synthesis	Identifying core intersections among mathematics, sustainability, and technology	Review of peer-reviewed studies on critical thinking, real-world math, and SDGs	Firdaus et al. (2015); Alsina and Mulà (2019); Rohaeti and Koswara (2018); Putra et al. (2022)
Stage 2. Framework Structuring	Defining conceptual components and principles	Organizing the IMETS Framework into pillars and principles aligned with educational goals	Delima (2017); Gamage et al. (2022); Kurniati et al. (2022)
Stage 3. Design Validation	Ensuring internal coherence and theoretical alignment	Cross-referencing with interdisciplinary and sustainability-focused education models	Anindita et al. (2021); Chimmalee and Anupan (2023); Karaarslan Semiz and Isler Baykal (2020); Sánchez-Caballé and González-Martínez (2021)

Bibliometric Analysis and Its Role in Framework Development

To strengthen the conceptualization of the IMETS framework, a bibliometric analysis was also conducted using Scopus and Web of Science databases covering publications from 2010 to 2023. Keywords including “mathematics education AND sustainability”, “technology integration AND pedagogy”, and “critical thinking AND STEM” were analyzed. The results revealed three highly connected thematic clusters: (1) education for sustainable development (ESD) in mathematics curricula, (2) digital transformation and personalized learning technologies, and (3) critical thinking and real-world problem solving through modeling. Citation network mapping demonstrated that studies on sustainability in mathematics (Alsina & Mulà, 2019; Putra et al., 2022) frequently intersected with those on digital pedagogies (Hidayati & Kurniati, 2018; Kurniati et al., 2022), yet few frameworks integrated both domains coherently. These bibliometric findings directly informed the structural organization of the IMETS framework, ensuring that its three pillars—sustainability, technology, and mathematics education—emerged from observable scholarly trends rather than arbitrary synthesis.

Framework Development Procedure

The construction of the IMETS Framework proceeded in three sequential stages: thematic synthesis, structural modeling, and theoretical validation (Table 1). Each stage is detailed below.

- *Stage 1: Thematic Synthesis:* In this stage, the Meylani conducted an inductive analysis of the reviewed literature to identify foundational themes across the three domains. Central concepts that emerged included sustainability-centered mathematical modeling (Putra et al., 2022), interdisciplinary learning frameworks (Alsina & Mulà, 2019), real-world problem solving in mathematics (Delima, 2017), and critical thinking enhancement through technology (Hidayati & Kurniati, 2018; Kurniati et al., 2022). Recurring constructs were extracted and organized into conceptual clusters representing core components of the framework: mathematics, sustainability, and technology.
- *Stage 2: Structural Modeling:* Following the thematic synthesis, the IMETS Framework was constructed through a formal organization of its three pillars—mathematics education, technology integration, and sustainability literacy. Each pillar was aligned with pedagogical goals and operational principles, including real-world relevance, technology-enhanced instruction, and interdisciplinary integration. For example,

technology was assigned the function of enabling data visualization, simulation-based exploration, and adaptive learning paths (Saputri & Rusnilawati, 2023). Sustainability was defined in terms of student engagement with climate modeling, resource optimization, and equity-oriented mathematical reasoning (Gamage et al., 2022; Putra et al., 2022). Mathematics was presented as the epistemological core, with specific emphasis on problem-solving, modeling, and statistical analysis (Delima, 2017; Harjo et al., 2019).

- *Stage 3: Theoretical Validation:* The final stage involved ensuring the internal coherence and external relevance of the IMETS Framework. This process entailed mapping the framework's structure against existing educational models in sustainability education and STEM pedagogy. Validation was achieved by confirming that the framework addresses core competencies required by global educational objectives, including SDG 4 (quality education), SDG 9 (innovation and infrastructure), and SDG 13 (climate action) (Alsina & Mulà, 2019; Gamage et al., 2022). The framework was further evaluated for scalability and adaptability by analyzing findings from studies involving digital tool implementation in diverse cultural and institutional settings (Karaarslan Semiz & Isler Baykal, 2020; Sánchez-Caballé & González-Martínez, 2021).

Theoretical Contribution

The theoretical contribution of the IMETS framework lies in its reconceptualization of mathematics education as a triadic system where sustainability and technology are not external supports but constitutive elements. By doing so, IMETS advances educational theory in three ways: first, it extends constructivist perspectives by embedding sustainability as a contextual driver of mathematical learning; second, it refines models of technology-enhanced pedagogy by linking digital tools explicitly to sustainability competencies; and third, it contributes to the growing body of interdisciplinary curriculum theory by offering a replicable structure that unites mathematics, sustainability, and technology under a common design logic. This positioning elevates IMETS beyond a practical teaching model and establishes it as a theoretical framework capable of informing future empirical research and policy development.

Ethical Considerations

This study did not involve human subjects, institutional data, or any form of participant observation. Therefore, formal ethical clearance was not applicable. The research adhered to academic standards of transparency, proper attribution, and intellectual integrity. All sources used in the conceptual development of the IMETS Framework were cited using APA 7th edition conventions, as reflected in the reference list.

Literature Review

The Role of Mathematics Education in Addressing Global Challenges

Historically, mathematics education has evolved from focusing on rote memorization and procedural skills to emphasizing understanding and applying mathematical concepts to real-world problems (Nahdiyah et al., 2020). This shift reflects a growing recognition of the importance of mathematics in addressing global challenges, including those related to sustainability (Santoso, 2018). Mathematical reasoning and modeling provide valuable insights into complex systems, enabling students to analyze data, make predictions, and propose solutions to pressing issues (Samura, 2023).

Moreover, the increasing focus on interdisciplinary approaches in education underscores the need for mathematics to be integrated with other fields, such as environmental science and social studies, to foster a comprehensive understanding of sustainability (Kania et al., 2023; Makramalla et al., 2025). This integration enhances students' mathematical skills and cultivates a sense of responsibility and agency in addressing global challenges (Yanuari & Turmudi, 2023).

The Integration of Sustainability into Education

The integration of sustainability into education has gained traction in recent years, with many educational frameworks recognizing the importance of aligning practices with the United Nations' Sustainable Development Goals (SDGs) (Sukriyah & Juniati, 2023). Existing frameworks often emphasize the need for interdisciplinary learning incorporating sustainability principles across various subjects, including mathematics (Firdaus et al., 2015). By embedding sustainability into the mathematics curriculum, educators help students understand the relevance of mathematical concepts in addressing real-world issues such as climate change and resource management (Candraningtyas & Khusna, 2023).

Furthermore, research indicates that students who engage with sustainability-focused curricula are more likely to develop critical thinking skills and a sense of environmental stewardship (Yerizon et al., 2022). This highlights the potential for mathematics education to play a pivotal role in fostering a sustainability mindset among students, ultimately contributing to a more sustainable future (Mujib et al., 2022).

Technology in Education: Enhancing Learning Outcomes

Technology integration into education has transformed traditional pedagogical practices, offering new opportunities for enhancing learning outcomes (Riawan, 2021). Digital tools such as interactive software and online platforms facilitate personalized learning experiences that cater to diverse student needs (Chasanah, 2019). Technology enhance students' engagement and understanding in mathematics education by providing dynamic visualizations and interactive simulations (Sari & Caswita, 2020).

Moreover, technology in mathematics education promote collaborative learning experiences, allowing students to work together on projects that address sustainability challenges (Sachdeva & Eggen, 2021). This collaborative approach fosters critical thinking and problem-solving skills and encourages students to apply mathematical concepts in meaningful ways (Yuliani et al., 2021). Echoing these findings, Meylani et al. (2025) demonstrated that teacher professional development plays a crucial role in maximizing the pedagogical benefits of educational technologies in middle school mathematics settings. As such, the effective integration of technology into mathematics education is essential for preparing students to navigate the complexities of the modern world (Ayu Trisnawati & Mahmudi, 2023).

Existing Interdisciplinary Frameworks

Several attempts have been made to design interdisciplinary models that integrate diverse domains of knowledge, yet many of these frameworks fall short in addressing the deep interconnectedness of mathematics, technology, and sustainability (Ardhini et al., 2022). While some highlight the importance of interdisciplinary learning, they often lack concrete strategies for embedding mathematical concepts within sustainability and technological contexts (Chimmalee & Anupan, 2023). As a result, mathematics frequently remains isolated from broader educational goals, and the transformative potential of interdisciplinary integration remains underutilized (Atoyebi et al., 2023).

A critical limitation of existing frameworks lies in their treatment of sustainability as a peripheral concern, rather than as an epistemological foundation of mathematics education. This superficial integration reduces their long-term impact on students' capacity for critical reasoning and problem-solving in sustainability-related contexts (Brown, 2019). Similarly, while digital tools are sometimes included, their role in enhancing sustainability-oriented mathematical modeling is rarely theorized in depth, leaving the integration of technology conceptually underdeveloped (Chimmalee & Anupan, 2023). Such gaps underscore the necessity of a model that positions both sustainability and technology as integral—rather than supplemental—components of mathematics education.

The IMETS Framework was developed precisely to respond to these deficiencies. By systematically embedding sustainability and technology into the mathematical core, IMETS provides a more robust and theoretically grounded structure for interdisciplinary education. This approach not only addresses the shortcomings of prior models but also enhances the relevance and effectiveness of mathematics education in equipping learners to confront twenty-first century sustainability challenges (Anindita et al., 2021). In doing so, the framework empowers students to move beyond passive learning and become active participants in addressing global issues through mathematical reasoning and technological innovation (Syahputra & Nasution, 2018).

The IMETS Framework: Conceptual Foundations

Critical Components of the IMETS Framework

The IMETS Framework consists of three essential components that facilitate effective learning: sustainability, mathematics education, and technology (Figure 1). Each component plays a vital role in shaping students' understanding and application of interdisciplinary concepts in a cohesive manner.

- *Sustainability:* Sustainability is a central theme within the IMETS Framework. This focus on sustainability underscores the necessity for education to engage with global challenges like climate change and social inequality. Rather than being treated as a distinct subject, sustainability is integrated with mathematics education, allowing students to utilize mathematical concepts to address real-world issues. Research has indicated that combining sustainability with mathematics enhances learners' understanding of mathematical applications in contexts like environmental stewardship and social justice (Gürbüz & Çalık, 2021), with evidence suggesting that this integration significantly engages students and stimulates their awareness and responsibility toward environmental issues (Gürbüz & Çalık, 2021). A strong emphasis on real-world problems cultivate students' problem-solving skills within the realm of sustainability (*Dawn*, 2011).

- *Mathematics Education:* Mathematics Education is at the core of the IMETS Framework, where interdisciplinary integration is fundamental. This approach emphasizes rigorous teaching methodologies that ensure students not only master mathematical principles but also recognize their significance in addressing global issues. Studies indicate that interdisciplinary approaches in mathematics enhance student interest and learning outcomes, affirming the connection between mathematics and fields such as science and technology (Güder & Gürbüz, 2018; Madlung et al., 2011). Additionally, mathematics serves as a bridge connecting various disciplines, enriching the educational experience through this interdisciplinary learning (Drobnič Vidic, 2023; Rogora & Tortoriello, 2021). Such pedagogical shifts are essential in promoting STEM literacy among students and preparing them for the complexities of contemporary social and environmental challenges (Bennett & Ruchti, 2014; Mayes & Rittschof, 2021).
- *Technology:* Technology is the final critical component of the IMETS Framework, acting as a facilitator in mathematics education. The integration of digital tools significantly enhances pedagogical practices, creating a more interactive and engaging learning environment (Ismail, 2014; Serin, 2023). Current research highlights the positive impacts of technology on student achievement in mathematics, demonstrating how digital learning platforms cater to diverse learning styles and paces (Serin, 2023). Moreover, the use of simulations and data analysis tools helps clarify abstract mathematical concepts, making them more tangible and relevant to students' lives (Ismail, 2014). This personalized learning approach, aided by technology, aligns with the IMETS Framework's objectives to foster critical thinking and adaptability in learners (Chiu, 2024).

IMETS Framework effectively integrates sustainability, mathematics education, and technology to create a robust educational environment. Each component interacts symbiotically, empowering students to leverage their mathematical knowledge and skills to tackle the pressing issues of the 21st century.

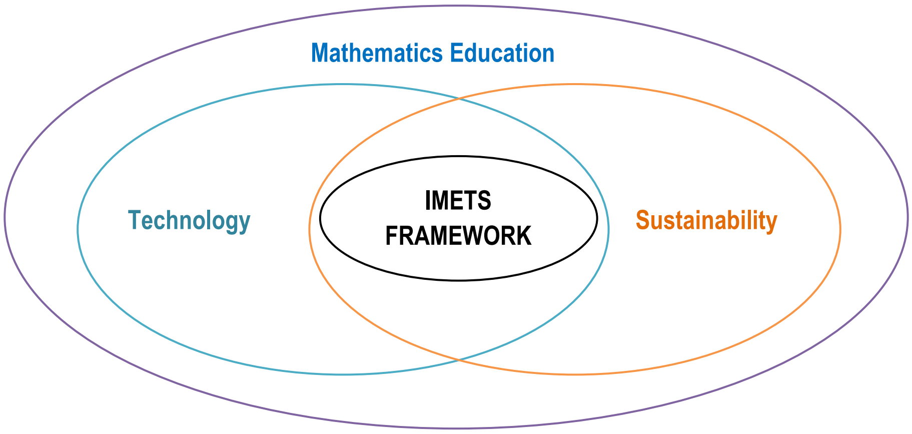

Figure 1. Pictorial representation of the novel IMETS framework

Principles of the IMETS Framework

The IMETS Framework is guided by several fundamental principles that ensure its effectiveness and relevance in a variety of educational contexts:

- *Interdisciplinary Integration:* This principle emphasizes the importance of breaking down traditional educational silos and integrating knowledge from different disciplines. In the IMETS Framework, mathematics education is closely connected with sustainability and technology, creating a holistic learning experience that reflects the interconnected nature of real-world challenges. Research indicates that integrating principles of Education for Sustainable Development (ESD) into mathematics learning enhances the meaningfulness of education, promoting students' mathematical thinking and competencies across various domains (Moreno-Pino et al., 2021; Putra et al., 2022). This interdisciplinary approach enables students to see the relevance of mathematics in different fields and encourages creative and innovative applications of their mathematical knowledge (Karaarslan Semiz & Isler Baykal, 2020).
- *Real-World Relevance:* The IMETS Framework is designed to make mathematics education more relevant to students' lives by connecting abstract concepts to real-world problems. The integration of sustainability into the curriculum ensures students learn to apply mathematical reasoning to pressing issues such as climate change, resource management, and social equity. This connection to real-world contexts is considered essential for effective mathematics education, with studies highlighting the need to articulate how real-world applications enhance learning

outcomes (Brown, 2019; Domínguez-González & Delgado-Martín, 2022; Smith & Morgan, 2016). By relating mathematics to students' daily lives, the framework fosters engagement and prepares them for the challenges of the 21st century (Gottfried, 2016; Kanandjebo, 2024).

- *Technology-Enhanced Learning:* Technology plays a crucial role in the IMETS Framework, providing tools that allow students to explore and apply complex mathematical ideas to real-world scenarios. The framework encourages the use of digital tools and platforms to create interactive and compelling learning experiences. Studies show that technology enhances accessibility and engagement in mathematics education, facilitating a deeper understanding of key concepts and fostering critical thinking and problem-solving skills (Körtesi et al., 2022; Naidoo & Reddy, 2023). Meylani (2024a) explored the integration of Internet of Things (IoT) technologies in smart classrooms and emphasized their potential to personalize learning pathways in mathematics education while supporting sustainability awareness. For example, innovative teaching methodologies that leverage technology significantly enhance learning outcomes, especially in the context of sustainability (Ghazali et al., 2024; Karjanto & Acelajado, 2022).
- *Sustainability-Centered Education:* The IMETS Framework embeds sustainability throughout the mathematics curriculum, ensuring that students grasp both the mathematical concepts and their ethical implications in the context of global sustainability challenges. Literature suggests that this focus helps students develop a sense of responsibility toward the environment and society, equipping them with the skills to apply their mathematical knowledge constructively in promoting sustainable development (Kim & Pang, 2022; Lestari et al., 2024). Integrating sustainability into mathematics education fosters critical and analytical thinking, essential skills in addressing contemporary environmental issues (Szabó et al., 2020).
- *Critical Thinking and Problem-Solving:* The IMETS Framework emphasizes developing critical thinking and problem-solving skills, which are vital for navigating modern societal complexities. Students are encouraged to use mathematical reasoning to analyze and solve real-world problems, supported by technological tools that enhance their exploration of different scenarios (Paredes et al., 2020). This focus on problem-solving aligns with global educational goals that prioritize the cultivation of

competencies required in the workforce and beyond, reinforcing the importance of mathematics as a tool for innovative and impactful decision-making (Alsina & Mulà, 2019; Zehetmeier & Krainer, 2011).

- *Inclusivity and Accessibility:* The IMETS Framework is designed to be inclusive and accessible, ensuring all students, regardless of their background or ability, benefit from its interdisciplinary approach. The framework's adaptability allows educators to customize implementations based on students' diverse needs and available resources, promoting equity in education and reducing disparities in learning opportunities (Krishnan & Raman, 2024; Moreno-Pino et al., 2021). Research highlights the importance of culturally responsive teaching practices that connect content with students' experiences, further enhancing inclusivity (Bazinet & Marshall, 2015; Szabó et al., 2020).
- *Scalability and Flexibility:* Scalability and flexibility are essential principles of the IMETS Framework, which implemented in various educational settings, from primary schools to universities. The framework is designed to be adaptable, allowing educators to tailor its components to fit different cultural, institutional, and curricular contexts (Kanandjebo, 2024; Krishnan & Raman, 2024). This flexibility ensures the framework remains relevant and practical, maintaining its applicability across diverse educational environments (Zehetmeier & Krainer, 2011).
- *Collaboration and Community Engagement:* The IMETS Framework emphasizes collaboration and community engagement as integral to the educational process. By involving a wide range of stakeholders—teachers, students, policymakers, community organizations, and industry partners—the framework connects education to real-world contexts and diverse perspectives (Lafuente-Lechuga et al., 2020; Zehetmeier & Krainer, 2011). Collaborative efforts foster shared responsibility for student learning and establish a supportive environment essential for successfully implementing the IMETS Framework (Karjanto & Acelajado, 2022).

Application of the IMETS Framework

Curriculum Design and Integration

Incorporating sustainability themes into the mathematics curriculum is a critical aspect of the IMETS Framework. Educators develop interdisciplinary units that connect mathematics with other subjects, such as environmental science and social studies, to enhance students' understanding of real-world issues (Gürsan et al., 2022). By designing curricula that emphasize the application of mathematical concepts to sustainability challenges, educators foster critical thinking and problem-solving skills among students (Nurjaman & Sari, 2017).

Professional Development for Educators

Training Programs and Workshops: Successful implementation of the IMETS Framework requires that educators are well-prepared to integrate sustainability, mathematics, and technology into their teaching. Schools and districts should offer professional development programs that focus on the fundamental principles and components of the framework. These programs could include workshops on interdisciplinary curriculum design, training on specific digital tools, and sessions on facilitating student engagement with real-world sustainability challenges. Professional development should also allow educators to collaborate and share best practices. This could involve forming learning communities where teachers collaborate to develop and refine IMETS-based lessons and units (Sutini et al., 2017).

Ongoing Support and Resources: Educators implementing the IMETS Framework need ongoing support to ensure its success. Schools should provide access to lesson plans, digital tools, and instructional guides that align with the framework's principles. Additionally, online platforms created where educators ask questions, share experiences, and receive feedback from peers and experts. Schools and districts might also consider partnering with universities, research institutions, and educational technology companies to provide educators with the latest research and innovations related to sustainability, mathematics, and technology. These partnerships help keep the IMETS Framework current and responsive to new developments in the field (Pentang et al., 2023).

Technology Integration in the Classroom

Utilizing Digital Tools for Interactive Learning: The IMETS Framework emphasizes using technology to enhance mathematics education. Educators should incorporate digital tools that allow students to explore mathematical concepts in depth, engage in interactive simulations, and analyze real-world data. For instance, software that models environmental systems help students understand the mathematical relationships underlying sustainability challenges. At the same time, data visualization tools allow students to interpret and present complex information effectively. Additionally, adaptive learning technologies provide personalized learning experiences, adjusting the level of difficulty based on student performance and offering targeted support where needed. These tools make learning more dynamic and tailored to individual student needs, fostering a deeper understanding of mathematical concepts (Saputri & Rusnilawati, 2023).

Encouraging Collaborative Online Projects: Technology also enables collaborative learning within and beyond the classroom. Educators design online projects where students work together to solve sustainability challenges using mathematical tools. These projects might involve students from different schools or countries, providing a global perspective on the issues they are studying. For example, a project on sustainable energy could involve students from multiple locations using shared online platforms to collect and analyze data on energy consumption, compare different energy sources, and develop models for optimizing energy use. By working collaboratively, students learn mathematics and technology skills and develop important communication and teamwork abilities (Kollosche, 2023).

Assessment and Evaluation

Designing Authentic Assessments: Assessments within the IMETS Framework should measure students' ability to apply mathematical concepts to real-world sustainability problems. This achieved through authentic assessments such as project-based evaluations where students demonstrate their understanding by developing and presenting solutions to sustainability challenges. Examples of authentic assessments might include a project where students use mathematical modeling to predict the impact of deforestation on local ecosystems or a presentation where students analyze and interpret data on water usage to propose conservation strategies. These assessments allow students to demonstrate their mathematical reasoning and problem-solving skills in a context that mirrors real-world applications (Hamidah et al., 2022).

Evaluating the Impact of the IMETS Framework: To ensure the IMETS Framework is achieving its intended outcomes, educators and administrators should regularly evaluate its impact on student learning. This done through qualitative and quantitative measures such as student surveys, interviews, performance data, and standardized test scores. Evaluation should also consider student engagement and attitudes toward mathematics and sustainability. Tools like reflective journals, portfolios, and self-assessments provide insights into how students perceive the relevance of mathematics to their lives and their sense of responsibility toward sustainability. The results of these evaluations then be used to refine and improve the implementation of the IMETS Framework (Hendrajah et al., 2023).

Community and Stakeholder Engagement

Building Partnerships with Local Organizations: The IMETS Framework emphasizes connecting mathematics education with real-world contexts. Schools should build partnerships with local businesses, environmental organizations, and community groups to allow students to apply their learning in practical settings. These partnerships might involve guest speakers, field trips, internships, or collaborative projects that address local sustainability challenges. For example, a partnership with a local environmental organization could involve students working on a project to monitor and improve water quality in nearby rivers or lakes using mathematical models and data analysis to track changes over time. Such partnerships enhance student learning and strengthen the connection between schools and their communities (Nurdin et al., 2023).

Involving Parents and the Wider Community: Engaging parents and the wider community is crucial for successfully implementing the IMETS Framework. Schools organize events such as sustainability fairs, exhibitions, and presentations where students showcase their work on IMETS-related projects. These events allow students to share their learning with their families and the community, raising awareness of the importance of integrating mathematics, technology, and sustainability in education. Schools might also consider creating opportunities for parents and community members to participate in student sustainability initiatives, such as local environmental campaigns or resource conservation efforts. By involving the community, the IMETS Framework fosters a sense of shared responsibility for sustainability and reinforces the real-world relevance of mathematics education (Zhu, 2023).

Case Studies

Integrating mathematics education with technology and sustainability is a burgeoning field that seeks to equip students with the skills necessary to address contemporary global challenges. This synthesis will explore case studies that exemplify how mathematics education effectively integrated with technology and sustainability principles.

- One notable case study, which investigated the integration of Education for Sustainable Development (ESD) principles within mathematics learning, is presented.

Their findings indicate that incorporating sustainability into mathematics education significantly enhances students' problem-solving abilities. This integration fosters a deeper understanding of mathematical concepts and encourages students to apply their knowledge to real-world sustainability issues, thereby promoting critical thinking and awareness of environmental challenges (Putra et al., 2022). Similarly, it emphasizes the importance of reflective learning in mathematics teacher education, advocating for a model incorporating sustainability challenges into teaching practices. They argue that uncovering students' preconceptions about mathematics lead to more effective learning outcomes, mainly when sustainability is a focal point (Alsina & Mulà, 2019).

- In the context of pre-service teacher education, the opinions of middle school pre-service mathematics teachers regarding sustainability in mathematics education were explored. Their study revealed a gap in integrating probability and geometry with sustainability concepts, suggesting that teacher training programs must emphasize these connections more explicitly. This highlights educators' need to be well-versed in mathematics and sustainability to effectively teach future generations (Karaarslan Semiz & Isler Baykal, 2020). Furthermore, it examined the sustainability of transmedia learning approaches in mathematics education, concluding that while these approaches enhance engagement, they often lack a direct focus on sustainability content. This indicates a need for more intentional design in educational resources to ensure that sustainability is a core component of mathematics instruction (Sánchez-Caballé & González-Martínez, 2021).
- The role of technology in supporting sustainable mathematics education is further illustrated by those who explored technology-based teaching methods in higher education. Their research highlights how digital tools facilitate embedding sustainability concepts within mathematics curricula, particularly in the context of the Fourth Industrial Revolution (4IR) (Naidoo & Reddy, 2023). This aligns with the findings of those who utilized Bayesian networks to integrate mobile learning and ethnomathematics, demonstrating how technology enhance sustainability in mathematics education by making learning more relevant and contextualized (Johnson et al., 2022).

- Moreover, the use of project-based learning (PjBL) in STEM education is a significant strategy for promoting sustainability. 's study on the prototype of a greenhouse effect project illustrates how PjBL improve students' problem-solving skills while addressing sustainability issues. This approach engages students in hands-on learning and encourages them to consider the environmental implications of their mathematical applications (Solihah et al., 2023). In alignment with project-based approaches, Meylani (2025b) conducted a systematic review on gamification in mathematics education, highlighting its utility in fostering learner motivation and sustainability-oriented thinking through engaging, goal-driven tasks. Similarly, emphasize the importance of early childhood education in fostering sustainability awareness through technology, suggesting that integrating STEM education at a young age lay the foundation for sustainable practices in future generations (Crisostomo & Reinertsen, 2020).
- The integration of sustainability into mathematics education is also supported by the findings of Gamage et al. (2022), who discuss lessons learned from embedding sustainability in STEM higher education programs. Their research indicates that a holistic approach to education, which includes sustainability principles, significantly enhance student engagement and learning outcomes (Gamage et al., 2022). This is echoed by, who highlights the importance of dialogic instruction in mathematics, suggesting that such pedagogical strategies lead to improved student motivation and achievement in sustainability-related topics (Hwang, 2022).
- In a more specific context, the study by demonstrates how real mathematics problems used to stimulate strategic thinking about the Sustainable Development Goals (SDGs). Their research underscores the potential of mathematics education to raise awareness about global challenges and encourage students to engage with sustainability issues through mathematical reasoning (Domínguez-González & Delgado-Martín, 2022). This aligns with the work of Vintere (2018), who argues that mathematics is a crucial tool for sustainable development, as it helps individuals develop strategies to meet their needs while considering environmental impacts.
- Furthermore, the integration of sustainability into mathematics education is not limited to theoretical frameworks; it also extends to practical applications in the classroom. For instance, the research conducted by on air quality education illustrates

how interdisciplinary teaching effectively combine mathematics and science to address real-world environmental issues. Their findings suggest that such integrative approaches enhance pre-service teachers' understanding of sustainability while improving their pedagogical skills (Rico et al., 2021).

- The significance of teacher training in this context cannot be overstated. As highlighted by Moreno-Pino et al. (2021), effective integration of sustainability into mathematics education requires a shift in teacher training paradigms. Their study emphasizes the need for educators to collaborate and share perspectives on sustainability to foster a more cohesive approach to teaching mathematics (Moreno-Pino et al., 2021). This is further supported by the work of Lafuente-Lechuga et al. (2024), who explore the role of mathematics in higher education institutions' efforts to incorporate the SDGs into their curricula.
- Moreover, the importance of contextualized learning experiences is emphasized by the research of Hsiao and Su (2021), who found that STEAM education for sustainable development significantly impact student motivation and learning outcomes. Their study suggests that integrating technology, such as augmented reality, enhance engagement and understanding of sustainability concepts in mathematics education (Hsiao & Su, 2021). This reflects a broader trend in education that seeks to leverage technology to create more interactive and meaningful learning experiences.

In conclusion, the integration of mathematics education with technology and sustainability is a multifaceted endeavor that requires collaboration among educators, researchers, and policymakers. The case studies discussed illustrate the potential for mathematics education to contribute to sustainable development by fostering critical thinking, problem-solving skills, and awareness of environmental issues. As the field continues to evolve, it is essential to prioritize the development of pedagogical strategies that effectively integrate sustainability principles into mathematics curricula, ensuring that future generations are equipped to tackle the challenges of a rapidly changing world.

Discussion

Implications for Mathematics Education

The IMETS Framework significantly transforms traditional mathematics education by making it more relevant, interdisciplinary, and future-oriented. Historically, mathematics education has been perceived as abstract and disconnected from real-world applications. However, the IMETS Framework addresses this gap by integrating sustainability directly into the mathematics curriculum, thereby equipping students with the tools to tackle pressing global challenges, such as climate change and resource management. This integration enhances student engagement and the meaningfulness of mathematics learning, as students recognize the practical implications of their education in solving real-world problems (Barwell & Hauge, 2021; Steffensen, 2019). The pedagogical transformation proposed in the IMETS Framework mirrors Meylani's (2024b) call for adaptive instructional models that foreground critical thinking and sustainability in online mathematics environments.

The interdisciplinary nature of the IMETS Framework further enhances its transformative impact on mathematics education. By connecting mathematics with fields such as environmental science and technology, the framework fosters a holistic understanding of complex issues. This approach promotes the application of mathematical concepts across various contexts, thereby enhancing students' critical thinking and problem-solving skills (f et al., 2021). Technology plays a pivotal role in this transformation by providing interactive and personalized learning experiences that cater to diverse student needs, thus improving their engagement and comprehension (Bray & Tangney, 2017; Temel & Gür, 2022).

Taken together, these all underscore the originality of the IMETS framework as both a conceptual and theoretical contribution. By grounding its structure in bibliometric evidence, validating it through DBR logic, and addressing the deficiencies of prior interdisciplinary models, IMETS offers the academic community a framework that is both innovative and theoretically rigorous. Its capacity to align mathematics education with sustainability imperatives and technological advancements ensures that it contributes not only to classroom practice but also to the broader theoretical discourse on how education can respond to global challenges in the twenty-first century.

The potential of the IMETS Framework to enhance student outcomes, particularly in critical thinking and problem-solving, is substantial. Engaging students with real-world problems through mathematics not only develops their analytical abilities but also prepares them to become proactive citizens who contribute meaningfully to sustainable development (Barwell & Hauge, 2021). The framework's emphasis on technology further supports this by offering dynamic tools that allow students to visualize complex concepts and collaborate with peers on problem-solving tasks (Drijvers, 2015).

Contribution to Sustainable Development Goals

The IMETS Framework aligns with and supports several of the United Nations' Sustainable Development Goals (SDGs), emphasizing the interconnectedness of education, sustainability, and technological innovation. Notably, SDG 4 (Quality Education) is directly supported by the IMETS Framework as it promotes inclusive and equitable education. By integrating sustainability into the mathematics curriculum, the framework equips students with the knowledge and skills to address contemporary global challenges (Prendergast et al., 2019).

Furthermore, the emphasis on technology in the framework aligns with SDG 9 (Industry, Innovation, and Infrastructure) by fostering innovation in teaching and learning practices. This helps enhance educational experiences and prepares students for the technological demands of the modern workforce (Kalaitzi, 2024). Similarly, the framework supports SDG 11 (Sustainable Cities and Communities) by teaching students how to apply mathematical concepts to urban planning and environmental conservation, preparing them to contribute to sustainable urban development (Barwell & Hauge, 2021). The promotion of responsible consumption and production as outlined in SDG 12 is also integral to the IMETS Framework, where students learn to utilize mathematical models for sustainable resource management (Barwell & Hauge, 2021).

Challenges and Limitations

Implementing the IMETS Framework will encounter several challenges, including resource constraints and resistance to change. Educators will face limitations in accessing necessary resources, such as technology and training required for successful implementation (Kalaitzi, 2024). Additionally, the transition from traditional mathematics education to an interdisciplinary, technology-enhanced approach will face resistance from educators accustomed to conventional teaching methods, stemming from a lack of familiarity with new processes or concerns regarding effectiveness (f et al., 2021).

Overcoming these challenges necessitates strategic planning and support. Professional development for educators is vital to equip them with the skills and knowledge needed for effective implementation (Steffensen, 2019). This includes workshops, training sessions, and ongoing support to help educators integrate sustainability and technology into their teaching practices. Moreover, prioritizing resource allocation, including digital tools and materials, is crucial for supporting the IMETS Framework's implementation. Building a community of practice where educators share experiences and best practices w, further help mitigate resistance and foster an environment conducive to change (Gravemeijer et al., 2017).

Conclusion

Summary and Significance of the IMETS Framework

The IMETS Framework represents a novel and transformative approach to mathematics education, integrating sustainability and technology to create a curriculum that is more relevant, interdisciplinary, and future-oriented. The framework’s key components include the integration of sustainability principles into the mathematics curriculum, the use of technology to enhance learning, and a focus on developing critical thinking and problem-solving skills. These components are guided by principles such as interdisciplinary integration, real-world relevance, and inclusivity, making the framework adaptable to various educational contexts.

The significance of the IMETS Framework lies in its ability to address the evolving needs of modern education. By preparing students to meet the complex challenges of the 21st century, the framework not only enhances student outcomes but also contributes to the broader goal of sustainable development. Its alignment with global educational goals, such as the Sustainable Development Goals, further underscores its importance in shaping the future of education.

Future Research Directions

Future research should explore the development of new technological tools that further enhance the implementation of the IMETS Framework. This will include investigating the use of artificial intelligence to create personalized learning experiences tailored to individual student needs. Additionally, longitudinal studies are needed to assess the long-term impact of the framework on student outcomes, particularly in terms of critical thinking, problem-solving skills, and sustainability awareness. Such studies could provide valuable insights into the framework's effectiveness and identify areas for improvement.

Research should also explore the scalability of the IMETS Framework across different educational settings and levels. Investigating how the framework should be adapted to diverse cultural, institutional, and curricular contexts would ensure that it remains relevant and effective in various environments. Case studies of schools or districts that have successfully implemented the framework will serve as models for others, offering practical insights into best practices and strategies for implementation.

Final Remarks

The IMETS Framework has the potential to profoundly shape the future of mathematics education by making it more relevant, interdisciplinary, and aligned with the needs of a sustainable world. By integrating sustainability and technology into the mathematics curriculum, the framework not only enhances student learning but also prepares them to be responsible global citizens who contribute to solving the complex challenges of our time. The framework represents a forward-looking approach to education, anticipating the skills and knowledge students will need to thrive in the future, making it a critical tool for educators and policymakers alike.

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Author Contribution Statement

Ruşen MEYLANİ: *Data curation, methodology, implementation, data analysis, original draft, language editing, organization, and writing*

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