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Mathematics in STEM in the context of conservation: Exploration in mathematics learning

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Abstract
This study systematically reviewed the literature linking mathematics learning to STEM education in the context of conservation. An in-depth analysis of 200 scientific articles revealed a significant correlation between STEM and conservation efforts. However, research specifically exploring the central role of mathematics in conservation-based learning was relatively limited. The study successfully identified several best practices, such as using mathematical modeling to analyze complex environmental phenomena and developing problem-based projects that integrate multiple STEM disciplines. However, there was a significant knowledge gap regarding optimal learning design, selection of relevant conservation topics, and comprehensive evaluation of the impact of this learning on students' conceptual understanding and behavioral changes. To fill this gap, further research was needed to develop a more comprehensive framework integrating mathematics into conservation-based STEM learning. This framework was expected to guide educators in designing effective and meaningful learning experiences and allow for more systematic evaluation of learning outcomes. In addition, future research should also explore the role of digital technologies in supporting conservation-based mathematics learning, as well as the challenges and opportunities faced in implementing this approach across cultural and social contexts.

Keywords: conservation**,** mathematics, mathematics learning, STEM

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INTRODUCTION

Recent research has explored the relationship between STEM (Science, Technology, Engineering, and Mathematics) education and conservation science, focusing on STEM identity development and integrating emerging interdisciplinary fields. The Conservation Science and Technology Identity (CSTI) instrument was developed to measure STEM identity in informal learning programs, revealing that youth and adults significantly improved their science and technology competencies through such programs (L. S. Rodriguez et al., 2020). Intergenerational collaborative partnerships have been shown to promote STEM identity by providing opportunities to demonstrate competency, engage in STEM practices, and receive recognition (L. Rodriguez et al., 2023). These partnerships are influenced by social and cultural norms, with STEM positioning and identity formation mutually reinforcing (Campbell *et al*., 2021). While there is potential to integrate emerging fields such as conservation physiology, technology, and biomechanics into conservation science, their incorporation in current research remains low, suggesting opportunities for further integration to address complex conservation challenges (Schulz et al., 2024).

Mathematics in STEM also plays a critical role in improving conservation efforts. Optimization techniques can help select reserves, control invasive species, and maintain genetic diversity (Billionnet, 2013). These methods help conservationists achieve more with limited resources by combining structured decision-making, mathematical programming, and market forces (Hiebert, 2021). Complex ecological systems benefit from creative approaches at the intersection of ecology, statistics, mathematics, and computational science, using new information technologies to develop and test detailed models (Green et al., 2005). Mathematical bio-economics provides tools for analyzing resource harvesting, investment decisions, and regulatory strategies, incorporating concepts such as dynamic optimization, supply and demand, and uncertainty (Colin, 2010). By applying these mathematical techniques, conservationists can make more informed decisions, improve cost-effectiveness, and address challenges in biodiversity protection and resource management across spatial and temporal scales.

The significance of mathematics in conservation can be effectively integrated into STEM-based mathematics education, which aims to enhance conservation awareness and environmental decision-making skills. Combining STEM with chemical entrepreneurship strengthens students' conservation values and entrepreneurial interests (Ruliyanti et al., 2020). Mathematical modeling serves as a useful tool for teaching students about making environmentally conscious decisions, such as those related to isolation choices (Yanik & Memis, 2014). A comprehensive approach to professional development in environmental STEM has been shown to significantly enhance mathematics instruction and influence teachers' beliefs regarding teaching and learning in mathematics (Livers, 2022). Additionally, there is a growing call to rethink STEM education from Indigenous and ecological perspectives, framing it as a “place” rather than a strictly human-centered approach. This perspective highlights the interconnectedness of mathematics, STEM, and nature, which could redefine success in terms of “survival” (Nicol et al., 2023). Collectively, these approaches underscore the potential of STEM-based mathematics education to cultivate environmental awareness and conservation skills.

Recent research emphasizes the importance of developing STEM-based mathematics education to enhance problem-solving abilities and foster conservation awareness among elementary and secondary school students. Studies have demonstrated that the integration of science, technology, engineering, and mathematics through the Engineering Design Process offers an engaging learning experience and boosts interest in mathematics (Firdaus et al., 2020). Additionally, STEM-based modules that incorporate elements of chemical entrepreneurship have proven effective in cultivating students' conservation values and entrepreneurial interests (Ruliyanti et al., 2020). Furthermore, problem-solving tasks grounded in integrated STEM contexts—such as health, energy efficiency, and environmental quality—have been designed to strengthen problem-solving skills among secondary school students (Tasir et al., 2018). This approach aims to prepare students for future challenges by linking classroom learning to real-world problems and promoting interdisciplinary thinking, ultimately addressing the gap between educational outcomes and industry demands (Firdaus et al., 2020; Tasir et al., 2018).

Based on the literature review above, it is clear that there is great potential in integrating mathematics into STEM education to improve conservation awareness and environmental decision-making skills. By combining mathematics with other sciences, we can develop more accurate models to predict environmental change, optimize conservation strategies, and inform better policies. STEM-based mathematics education can also equip young people with the skills needed to address complex environmental challenges and build a more sustainable future. However, further research is needed to identify best practices in integrating mathematics into STEM learning from previous studies. Thus, the purpose of this study is to understand the integration of mathematics within a STEM framework with a focus on conservation issues from previous studies.

METHODS

This study was aimed at mapping and analyzing existing research that integrated mathematics education within a STEM framework, with a particular emphasis on conservation issues. Through a thorough literature review, the study sought to identify best practices, challenges, and opportunities in merging mathematical concepts with conservation principles in educational contexts. The initial phase involved searching for relevant literature using the "publish or perish" platform. A total of 200 scientific articles were identified using the keywords "mathematics learning," "STEM," and "conservation." Following this, a more focused screening was conducted on articles that explicitly addressed the relationship between mathematics and conservation, utilizing the "VosViewer" tool for mapping purposes.

The article screening process was conducted meticulously, focusing on the titles and abstracts of each publication. The goal was to identify studies that specifically explore the application of mathematical concepts in addressing conservation-related challenges. In light of the extensive nature of STEM, this review deliberately narrowed its focus to articles that explicitly included the keywords "mathematics" alongside conservation-related terms. This approach was designed to ensure that the selected studies were directly pertinent to the objective of this research, which aimed to integrate mathematics education within the context of conservation.

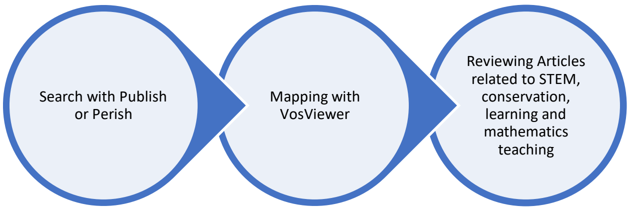

Figure 1. Review flow

RESULTS AND DISCUSSION

An extensive analysis of 200 articles sourced from "publish or perish" was conducted using Vosviewer software, aimed at uncovering research patterns and trends related to the integration of mathematics within the contexts of STEM and conservation. By establishing a minimum threshold of five occurrences for each term, the analysis yielded 684 unique terms. After filtering, 23 terms were identified that met the specified criteria. The results of the keyword network visualization, as illustrated in Figure 2, reveal numerous clusters represented by various colors. Notably, the green cluster—designated as cluster 2—houses key terms such as "STEM," "conservation," "math," "learning," and "teaching," which were closely interconnected. This finding suggested that the studies represented in the green cluster primarily focused on the development and implementation of STEM education that integrated mathematical concepts to foster conservation efforts.

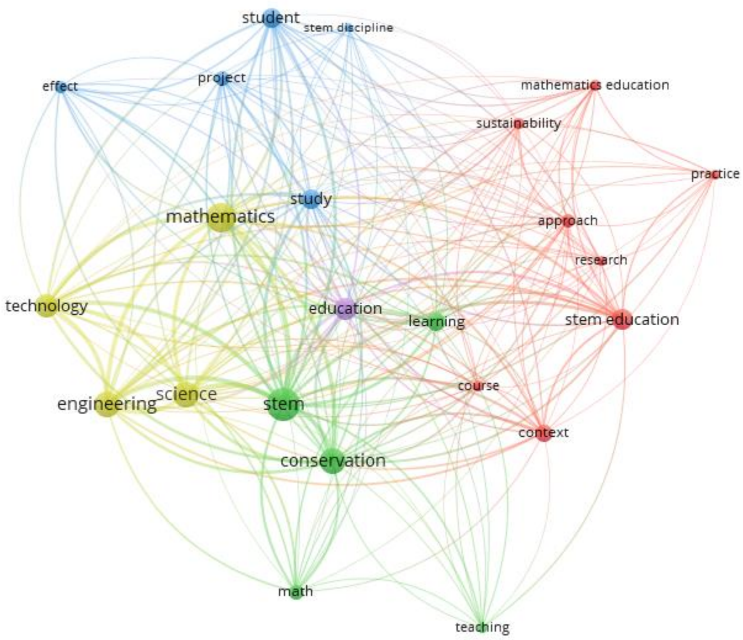

Figure 2. Term clusters from 200 article titles and abstracts of STEM, mathematics, and conservation keywords

The results of literature mapping conducted through VosViewer (Figure 3) revealed a notable gap in research at the intersection of STEM and conservation. While numerous studies establish a connection between STEM and conservation initiatives, there was still a significant lack of research specifically focused on the role of mathematics in conservation-based education. This discrepancy was evident in the prominent yellow density observed in the STEM and conservation sector, which reflected a wealth of prior research in this domain. Conversely, the area concerning mathematics and mathematics teaching about conservation appeared underdeveloped, highlighting insufficient attention to the integration of mathematical concepts within conservation learning contexts.

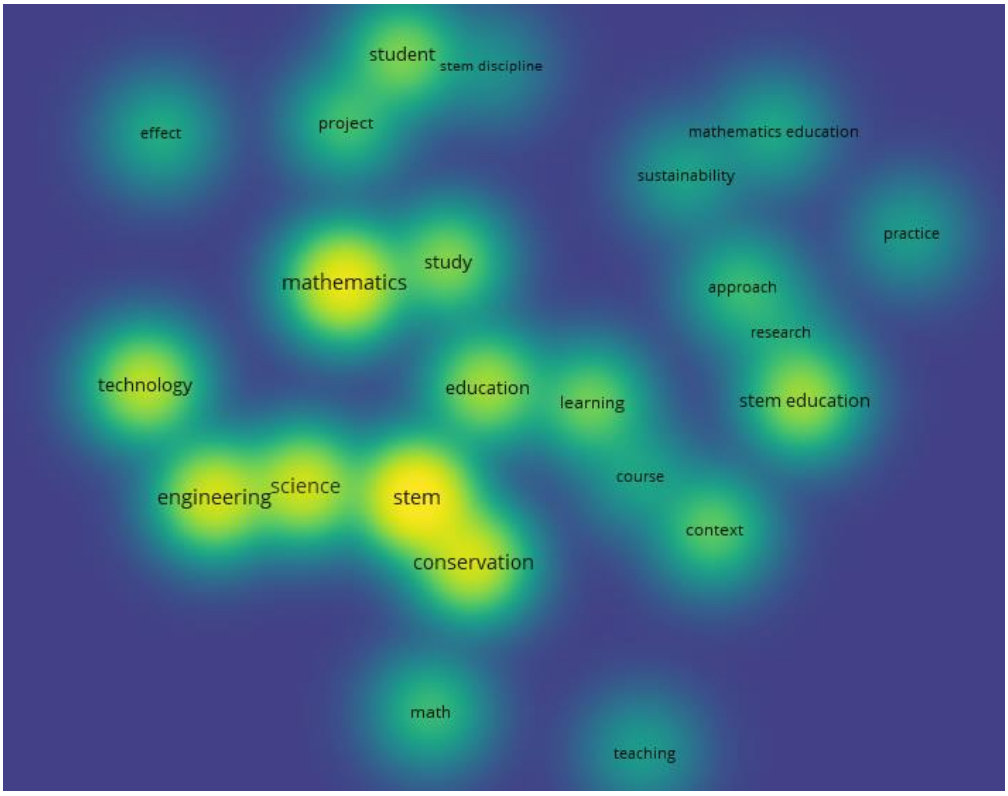

Figure 3. Density of terms

A closer examination of the clusters identified in Vosviewer (Figures 2 and 3) revealed a more nuanced understanding of the relationships between concepts. The term "STEM" emerged as having the most robust connections, featuring 22 links and a link strength of 360. This suggested that STEM concepts were pivotal within the knowledge network established. Similarly, the term "conservation" also played a crucial role, with 22 links and a link strength of 209. The strong connection between STEM and conservation underscored that numerous studies had associated STEM approaches with environmental and sustainability challenges.

Furthermore, a detailed analysis revealed that the concept of "mathematics" held a significant position within this knowledge network, albeit with a slightly lower number of connections compared to STEM and conservation. Specifically, it was associated with 18 links and a link strength of 64. The concepts of "learning" and "teaching" also played vital roles, with 22 and 14 links, respectively. These findings suggested that existing research had focused on how mathematical concepts could be integrated into the STEM learning process, particularly in the context of conservation.

Next, a more in-depth review of the articles in Table 1 informed the development of a STEM-based mathematics learning framework within the conservation context.

Table 1. Reviewed articles

Correlation Theme	Article Title	Author
Mathematics and STEM	The role of mathematics in interdisciplinary STEM education	(Maass et al., 2019)
	Problematizing teaching and learning mathematics as "given" in STEM education	(Li & Schoenfeld, 2019)
	Mathematical Modeling: A Bridge to STEM Education	(Kertil & Gurel, 2016)
	Mathematics Teachers' Practices of STEM Education: A Systematic Literature Review	(Rahman et al., 2021)
STEM and Conservation	STEM education in secondary schools: Teachers' perspective towards sustainable development	(Nguyen et al., 2020)
	Problem-based learning integration in STEM education to improve environmental literation	(Widowati et al., 2021)

The study conducted by Maass et al. (2019) delved into three interconnected perspectives that highlighted the central role of mathematics in an interdisciplinary STEM approach. Firstly, STEM instruction that integrated multiple disciplines proved to be an effective means of fostering the 21st-century skills that were highly sought after in today's globalized landscape. Skills such as critical thinking, complex problem solving, creativity, and collaboration—all deeply rooted in mathematical foundations—were essential competencies for individuals aspiring to succeed in both their personal and professional endeavors. Secondly, mathematics served as a universal language that enabled us to comprehend and predict both natural and social phenomena. By applying mathematical concepts to model real-world situations, students not only enhanced their understanding of scientific principles but also cultivated the ability to think analytically and systematically. Lastly, mathematics played a crucial role in equipping students with the necessary skills to become responsible citizens. By exploring contemporary issues that possessed significant mathematical dimensions—such as climate change, social inequality, and technological advancement—students were encouraged to think critically, assess information, and make decisions that positively influence society. Consequently, mathematics-centered STEM education not only prepared students for careers in STEM fields but also provided them with the tools essential for actively contributing to a better future.

Li & Schoenfeld (2019) emphasized the necessity of transforming our approach to teaching mathematics and STEM subjects to prioritize conceptual understanding and the cultivation of critical thinking skills. Mathematics was often perceived merely as a series of formulas and procedures to be memorized. However, it should be viewed as a process of inquiry and discovery. Rather than just serving as a tool for other scientific fields, mathematics was an essential component of the scientific process itself. By focusing on conceptual understanding and meaning-making, we could enhance the connection between mathematics and other STEM disciplines. Teachers play a vital role in fostering a learning environment that nurtures students' mathematical thinking.

Kertil & Gurel (2016) explained that mathematical modeling offered a powerful bridge connecting mathematics to other STEM disciplines. By providing students with opportunities to apply mathematical concepts to real-world problems, mathematical modeling fostered critical thinking, problem-solving, and creativity. While mathematical modeling had been studied extensively in mathematics education, its potential for integration with other STEM subjects was increasingly recognized. By emphasizing the process of mathematizing, interpreting, and verifying real-world situations, mathematical modeling aligned with the goals of STEM education, which aimed to develop students' ability to apply knowledge and skills across disciplines.

Rahman *et* al. (2021) explained that Mathematics played a central role in STEM education, acting as a foundation that united science, technology, engineering, and mathematics. Mathematical skills such as critical thinking, problem-solving, and data analysis were at the heart of STEM practices. Integrating mathematics into STEM allowed students to apply mathematical concepts in real-world contexts, develop creativity, and solve complex problems. Effective instructional design in STEM involves the use of project-based learning, technology integration, and consideration of cultural relevance. While there were challenges in implementing STEM, such as accessibility and teacher professional development, the potential benefits were enormous. By integrating mathematics into STEM, we could prepare future generations to face the challenges of the 21st century and contribute to technological advancement.

Nguyen et al. (2020) emphasized the significance of innovative pedagogical approaches in STEM education as a means to tackle sustainable development challenges. The teachers participating in this study exhibited a strong commitment to integrating environmental and social issues into STEM learning. They employed student-centered learning methods, such as problem-based and project-based learning, to foster critical thinking, collaboration, and the pursuit of innovative solutions to real-world problems. However, to unlock the full potential of these approaches, it is essential to provide stronger support for teachers through training and professional development. Additionally, increased investment in infrastructure and resources is necessary to ensure equitable access to STEM education for all students, particularly those in remote areas or from disadvantaged backgrounds. Consequently, STEM education could serve as a powerful catalyst for achieving Sustainable Development Goal (SDG) 4, which aims to ensure inclusive and quality education for all.

Widowati et al. (2021) Highlighted the potential of integrating STEM education with Problem-Based Learning (PBL) to improve environmental literacy in elementary education. By combining the interdisciplinary nature of STEM with the student-centered approach of PBL, this model empowered students to identify and address real-world environmental challenges. Through active learning and collaborative problem-solving, students developed critical thinking, creativity, and problem-solving skills. This integrated approach has been shown to enhance knowledge acquisition, character development, and the ability to design and implement solutions to environmental problems. Ultimately, STEM-based PBL could foster a generation of environmentally conscious citizens who were ready to make a positive impact on the planet.

Based on the results of the review of these articles, STEM-based mathematics learning, especially in the context of conservation, offered an innovative approach to preparing future generations to face global challenges. By integrating mathematics into problem-based projects (PBL) that focused on environmental issues, students not only honed their numerical skills but also developed critical thinking, creativity, and collaboration skills that were much needed in the 21st century. Through PBL, students could be actively involved in solving complex environmental problems, such as designing sustainable solutions for waste management or analyzing the impact of climate change on local ecosystems. Thus, mathematics learning was no longer just memorizing formulas but became a valuable tool for understanding the world around them and contributing to environmental conservation. For this approach to be successful, strong support was needed from various parties, including teachers, schools, and the government, to provide adequate resources and create a conducive learning environment.

CONCLUSION

A comprehensive analysis of the literature revealed that the integration of mathematics within STEM contexts—especially in support of conservation efforts—represented a vibrant field of research with significant untapped potential. While several studies have established connections between STEM and conservation, investigations that specifically explored the role of mathematics in conservation-based learning remain relatively scarce. Results from keyword network visualizations indicated a close relationship among STEM concepts, conservation, and mathematics; however, gaps still exist in our understanding of how mathematics can be effectively employed to tackle environmental challenges.

Existing research highlighted the crucial role of mathematics as a foundational aspect of STEM learning. Mathematics not only equipped learners with tools for data analysis and model creation but also enhanced critical thinking and problem-solving skills essential for addressing complex environmental issues. To fully harness the potential of STEM learning in conservation contexts, further research was required to develop effective teaching materials, learning designs, and evaluations. Additionally, it is vital to engage teachers in ongoing professional development to enable them to implement this innovative learning approach successfully in their classrooms.

Limitations and Future Direction

The analysis presented in this study has several limitations. Firstly, the research was confined to 200 article titles sourced from the Publish or Perish database, a sample that may not adequately represent the entirety of existing literature on mathematics, STEM, and conservation learning. Secondly, an in-depth analysis was conducted on only six articles. These constraints highlight the necessity for further research that encompasses a broader scope.

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Declarations

Both authors of this article have jointly contributed to all stages of preparation, from data collection, and analysis, to writing.

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