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Education for Sustainable Development (ESD) in Mathematics Education: A Systematic Literature Review

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Abstract

Education for Sustainable Development (ESD) is an effort to encourage people to be constructive and creative in facing global challenges and to create a resilient and sustainable society. ESD incorporates key issues of sustainable development into teaching and learning. Mathematics is the key to other fields of science and plays an important role in realizing ESD. Almost all competencies in the dimensions of ESD can be integrated into the curriculum of mathematics. This article aims to examine ESD especially on mathematics education. A systematic literature review (SLR) was conducted using established and robust guidelines. We follow the preferred reporting items for systematic reviews and meta-analyses (PRISMA). We searched Scopus, ERIC and ProQuest, for 15 studies about ESD on mathematics education published between 2019 and 2023. The findings of the SLR indicate that: (1) interest in ESD research especially on mathematics education has grown over time and is evenly distributed across different countries; (2) most of the reviewed studies used qualitative research methods; (3) most of the research is for teachers or pre-service teacher education level; (4) there are various ways to integrating ESD into mathemathics curriculum. This understanding may increase the quality of mathematics practices within ESD domain.

Keywords: *Education For Sustainable Development, Sustainability, Mathematics Education, Systematic Literature Review.*

Introduction

Education for Sustainable Development (ESD) is currently being developed in many countries. Every country must ensure that its people live sustainability-oriented (Onoshakpokaiye, 2021). The United Nations (UN) Conference held in Brazil in 2012 discussed a sustainable development agenda called the Sustainable development goals (SDGs). UNESCO as an organization at the forefront globally, coordinates the implementation of the global action program (GAP) on ESD, as a follow-up to the UNs decade of ESD 2005-2014. The 17 goals of Sustainable Development Goal's which includes three main domains of economic, social, and environment through several approaches such as Education for Sustainability.

The inclusion of ESD in Target 4.7 of Sustainable Development Goal 4 highlights the importance of quality education in addressing sustainable development challenges. According to (UNESCO, 2017), target 4.7 states that UN member states must "ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including through ESD." Quality education that includes ESD can be a significant factor in achieving the remaining 16 SDGs, which address sustainability from social, economic, and environmental perspectives. ESD enables every human being to acquire the knowledge, skills, attitudes and values needed to shape a sustainable future (Glavič, 2020; Holfelder, 2019; Latchem, 2018; Novidsa et al., 2020; Valencia, 2018; Violanda & Madrigal, 2021). ESD incorporates key issues of sustainable development into teaching and learning; for example, climate change, disaster risk reduction, biodiversity, poverty reduction, and sustainable consumption (Anderson, 2012; Choi, 2018; del Sol, 2019; Glavič, 2020; UNESCO, 2012).

The aim of this paper is to investigate, evaluate, and categorize the literature that has been written about ESD in mathematics education. This comprehensive review examines the how ESD develop in teaching and learning curriculum. The study (Corres et al., 2020; Pegalajar-Palomino et al., 2021) reviewed ESD in teacher training. While (Lim et al., 2022) studied comprehension ESD implementation and/or integration

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into higher education institutions. On the other hand, (Husamah et al., 2022) reviewed and compared investigations of sustainable development researches on articles published by EJMSTE.

Table 1 illustrates the frameworks of some of the previous *ESD* researchers. Based on the existing works in Table 1, it appears that a comprehensive and thorough analysis of the particular theme has not yet been presented.

Table 1. Comparison With Existing Work

Corres et al.	Husamah et al.	Lim et al.	Pegalajar-Palomino et al.
Review methodology			
-	-	-	PRISMA
Identification, screening, eligibility, and inclusion	Identifying, evaluating and analyzing	Scoping, planning, identification, screening and eligibility	Identification, screened, suitability, and inclusion
Year of publication			
2020	2022	2022	2021
Year of article database			
November 2019 and May 2020	2005-2021	2014-2019	2010-2020
Search database			
Scopus, Eric	Scopus	ScienceDirect, WoS and IEEE Xplore	WoS and Scopus
Final set of articles			
14	22	148	21
Research questions			
Context, conceptual and pedagogical approaches, t types of educators' competences, e pedagogical strategies	Trend, theme, country, method, keywords, contribution	The accomplishment of SD, awareness and commitment, evaluation and commentary, structural transformation, course coordination and university management.	Year, articles publisher, research methodology, attitudes and skills of future teachers towards sustainability
Keyword			
competencies; education for sustainable development; environmental education; teachers; transformation	sustainable, sustainability, education for sustainable development, curriculum reform	education sustainable development (ESD); sustainable development (SD); sustainable education (SE); higher education institution/s (HEIs); Sustainable Development Goals (SDGs); environmental education (EE)	sustainability, higher education, teacher training, teacher education for sustainability, social responsability, Education for Sustainable Development

Based on Table 1, the similarities observed between this study and previous research lie in the selection of keywords. However, the most prominent difference is related to the research questions posed. In the previous research, ESD was explained based on education in general, while in this research we will look for how to apply ESD to mathematics education.

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Mathematics Education for Sustainable Development is efforts to inculcate the value of character, skills, attitudes, and knowledge through the application of mathematics learning in the field of environment, social, culture, and economics so that learning mathematics becomes more useful in sustaining their lives sustainably and support the achievement of Sustainable Development Goal's. SLR is a scientific technique for collecting all accessible information according to established criteria to address a specific research problem (Gough et al., 2017). In addition, SLR is also a systematic and appropriate method of classifying, selecting and critically analyzing various studies or research documents (Tikito & Souissi, 2019). Compared to traditional literature reviews, SLRs enhance review validity, reliability, replicability, and consistency (Xiao & Watson, 2019). An author's claim of accuracy can be clarified by a methodical review, allowing gaps and directions for further research to be identified (Mansoor et al., 2022).

Research Questions

- How is the ESD in mathematics education distributed in terms of publication year?
- How is the development of ESD in mathematics education based on the distribution of their demographics?
- How is ESD in mathematics education distributed in terms of the research methodology?
- How is ESD in mathematics education distributed in terms of the educational level study sample?
- What are the recommendations for integrating ESD into mathemathics curriculum?

Theoritical Foundation

Education for Sustainable Development (ESD) is an educational concept for sustainable development. ESD consists of 3 words, each of which has a meaning, that are: (1) Education, meaning education, both moral and immaterial education, covering basic to advanced education, and a way to inform (educate) other people about something according to a method. (2) Continuous, meaning continuously or continuously, has the meaning of a thing or activity that is carried out in earnest for a period of time to achieve maximum results. (3) Development, meaning development, development, or develop, has the meaning to expand existing functions by not removing the main elements (Putra & Nurcahyono, 2022).

Education for sustainable development (ESD) is an effort to encourage people to be constructive and creative in facing global challenges and to create a resilient and sustainable society (Asikainen & Tapani, 2021; Seikkula-Leino et al., 2021; Weicht & Jónsdóttir, 2021; Zulkarnaini et al., 2020). The basic question "How can mathematics contribute to realizing a sustainable life?". Philosophically, mathematics can be interpreted in various ways. For example, Hersh (1997) views mathematics as a human activity. Meanwhile (Harel, n.d.) defines mathematics as Ways of Understanding (WoU) and Ways of Thinking (WoT). Understanding mathematics as a human activity opens up opportunities for how mathematics can support or underlie sustainable development. Bishop (1988) identifies mathematics as a human activity in the form of counting, measuring and locating. These activities indicate a clear relationship between humans and their environment. Through activities like this, humans are enabled to design ways to meet their needs as efficiently as possible. In this context, mathematics can be seen as a tool for realizing sustainable development.

Mathematics learning is expected to be able to provide solutions to social problems that exist in society. Besides that, the mathematical ideas raised in the learning process are adapted to social awareness, the principles of mutual cooperation and mutual assistance as well as the formation of a long-term mindset which is part of ESD.

Methodology

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Research Design

We conducted a comprehensive SLR to answer our research questions. SLR is a method of gathering appropriate data on a certain topic that meets pre-determined eligibility criteria (Mengist et al., 2020). This review was performed utilising PRISMA with the goal of thorough reporting (Page et al., 2021). It allows readers to evaluate the appropriateness of the methods and hence the result's trustworthiness. Moreover, presenting and summarising study aspects leading to a synthesis assists policymakers in evaluating the findings' applicability with respect to their own situations. PRISMA creates a uniform, peer-reviewed technique that makes use of checklists of best practices to help ensure the quality and reproducibility of the revision process (Conde et al., 2020). Identification, screening, eligibility, and inclusion are the foundational elements of PRISMA.

PRISMA has three main benefits (Sierra-Correa & Cantera Kintz, 2015). First, it provides precise research questions that allow systematics study. Second, it develops exclusion and inclusion criteria, and thirdly, it strives to analyse a massive scientific database publication within a certain time constraint. Finally, the PRISMA statement enables a comprehensive search for terms relating to innovative teaching.

Figure 1. PRISMA Flow Diagram

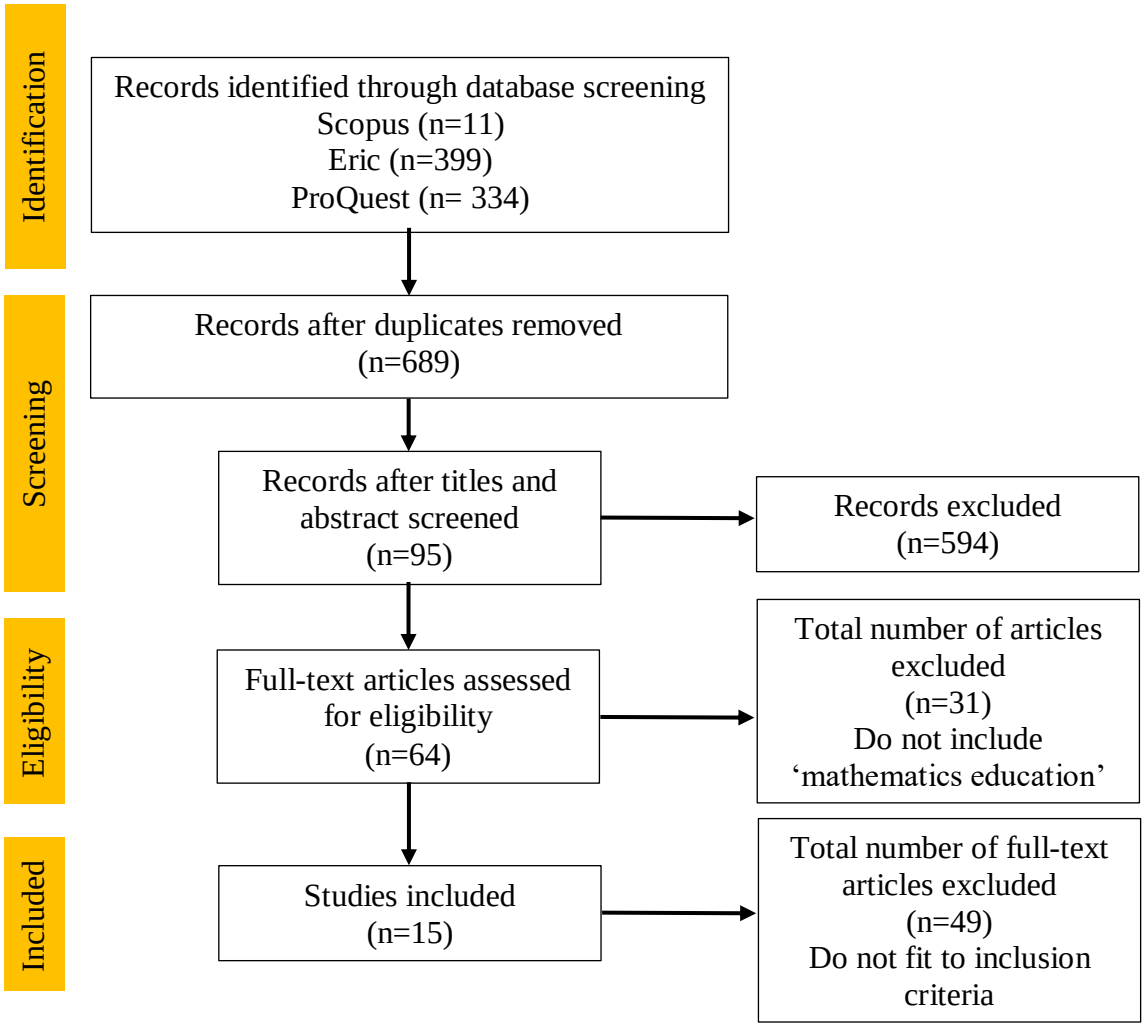

Figure 1. Displays The PRISMA Flow Chart in This Study Adapted and Modified from Moher Et Al. (2009)

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Table 2. Synonyms and Alternatives Terms for Main Search Terms

Education for Sustainable Development	Math
ESD	Maths
Sustainable Development	Mathematics
SD	Mathematical
Sustainable Development Goals	Mathematics education
SDGs	Learning mathematics
	Teaching mathematics

Table 3. Inclusion and Exclusion Criteria

Criteria	Inclusion criteria	Exclusion criteria
Article title and content	An appropriate title that complied with the study's requirements	Did not match the requirements of the study and had an irrelevant title
Year of publication	Publications from 2019 to 2023	Publications outside the range specified
Type of publication	Solely for journal articles	Reviews, editorials, and non-empirical studies
Language	English	Others
Field of article study	Mathematics education	Others than mathematics education
Accessibility	Full-text articles or open access	Preview articles and required a payment

Systematic Review Process

Identification

The search took place on Scopus, ERIC and ProQuest database. We came up with two mains search terms based on our fundamental research topics: Education for Sustainable Development and mathematics education. We compiled a list of synonyms and alternate terms based on the most popular search terms (Table 1).

Therefore, we expanded our search terms and strategies in exploring as many potentially relevant studies as possible. To search, we used a key search term that was created by combining the words discovered from (Table 1), as follows: TITLE-ABS-KEY (("Education for Sustainable Development" OR "ESD" OR "Sustainable Development" OR "SD" OR "Sustainable Development Goals" OR "SDGs") AND ("math" OR "maths" OR "mathematical" OR "mathematics" OR "mathematics education" OR "learning mathematics" OR "teaching mathematics")). Through Scopus, ERIC and ProQuest database, 744 results were identified using search strategies.

Screening

The subsequent step is screening. As displayed in Figure 1, the selection process followed the PRISMA principles (Moher et al., 2009). We used a variety of inclusion and exclusion criteria in this approach (Table 2). Here, the first step includes eliminating journals (systematic reviews), novels, book series and chapters as well as conference proceedings from being considered. The screening procedure was then restricted to items published between the years 2019 and 2023, considering (Kraus et al., 2020) 'research field maturity' concept. Because the amount of published research was sufficient to conduct a representative review, this timeline was taken into consideration. Consequently, the author decided to exclusively examine empirical research papers written in English. But there were no exclusions for specific countries or regions. In the final stage of the screening process, we focused their attention on publications that contained atleast one

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reference to mathematics. Following the screening phase, 744 papers were identified as not meeting the study's criteria, while 55 articles were identified as duplicates. Additionally, there are just 689 articles remaining.

Eligibility

As illustrated in Figure 1, the eligibility procedure follows the screening method. The author personally examined the articles extracted to guarantee that all of the remaining articles met the requirements. This was achieved by reading the titles, abstracts, and complete contents of the papers. First, journal articles that did not meet the criteria for Education for Sustainable Development in mathematics were rejected. Then, to ensure that all 689 articles fit the study's selection criteria and objectives, each article's title, abstract, methodology, results, and discussion were thoroughly reviewed. At this point, 674 articles have been rejected because they do not fully explain Education for Sustainable Development in mathematics education or do not clearly explain and review the findings data in the study findings section. As a result, 15 articles were selected for publication in the final stage of the review process (see Figure 1).

Inclusion and Exclusion Criteria

After gathering all of the results from all identified sources, we used the selection criteria such as timeline, document type, language, and subject area to filter out the articles that were not relevant to our research. When selecting pieces for inclusion and exclusion, the inclusion and exclusion criteria must be clearly defined to ensure that the studies selected are relevant to the primary research purpose. (Table 2) shows the inclusion and exclusion criteria for this review study and the findings of the research. It was determined that 15 articles were relevant, and the full-text articles of these publications were obtained. The research's goals were all linked to Education for Sustainable Development in mathematics education.

Findings

The papers selected for this SLR were obtained from the Scopus, ERIC and ProQuest databases, as mentioned in the methodology section. These databases were chosen because they comply with protocol requirements and have a filtering feature that automates specific parameters set. Finally, a total of 15 articles was analyzed. All articles (n=15) were analyzed to gather the information we needed to answer our research topic. The following subsection provides answers to the research questions.

The Distribution of Research Study by Publication Year

The first question relates to the year of publication which the research was conducted (Figure 2). In 2023, just one article published (Sakaria et al., 2023). Compairing to other years, 2022 is the year with the most publications, because 6 articles have been published (Kim & Pang, 2022; Li & Tsai, 2022; Moreno-Pino et al., 2022; C.-S. Su et al., 2022; Vásquez et al., 2022). Articles published as in 2021 has decrease (3 articles) (Aslam et al., 2021; Doğan, 2021; Santamaría-Cárdaba et al., 2021). In the previous year, in 2020, 5 articles have been published (Jeong & González-Gómez, 2020; A. Su & He, 2020; Szabo et al., 2020; Vásquez et al., 2020). In 2019, no articles were published regarding ESD in mathematics education.

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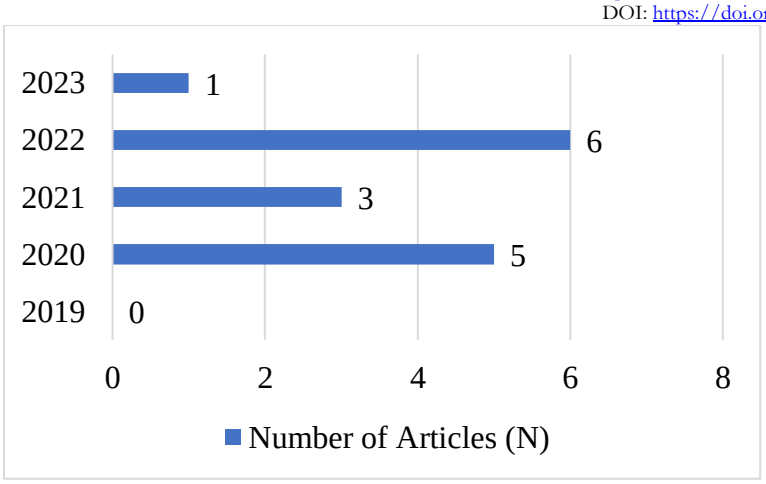

Figure 2. Distribution of Research Studies in Term of Publication Year

The Distribution of Research Studies in Term of Country

The geographic distribution of the authors was the subject of the second research question. Figure 3 shows the categorization of the selected studies according to the countries they were carried out. Even though our systematic review only included publications published in English, the research was carried out in various cultural contexts throughout the world. According to the established criteria, Spain has the highest number of publications (n=4) (Jeong & González-Gómez, 2020; Moreno-Pino et al., 2022; Santamaría-Cárdaba et al., 2021), followed by Chile (n=3) (C.-S. Su et al., 2022; Vásquez et al., 2020, 2022) and China (n=2) (Aslam et al., 2021; A. Su & He, 2020).

In contrast, ESD in mathematics education is the least frequently discussed among scholars in various countries, such as United Kingdom (Helliwell, 2022), Romania (Szabo et al., 2020), Turkey (Doğan, 2021), Taiwan (Li & Tsai, 2022), South Korea (Kim & Pang, 2022), and Malaysia (Sakaria et al., 2023). As a result of this finding, it is possible that scholars in the Spain and Chile are becoming increasingly interested in exploring the topic of ESD in mathematics education. Therefore, additional research into this topic is still required in other countries, among other things.

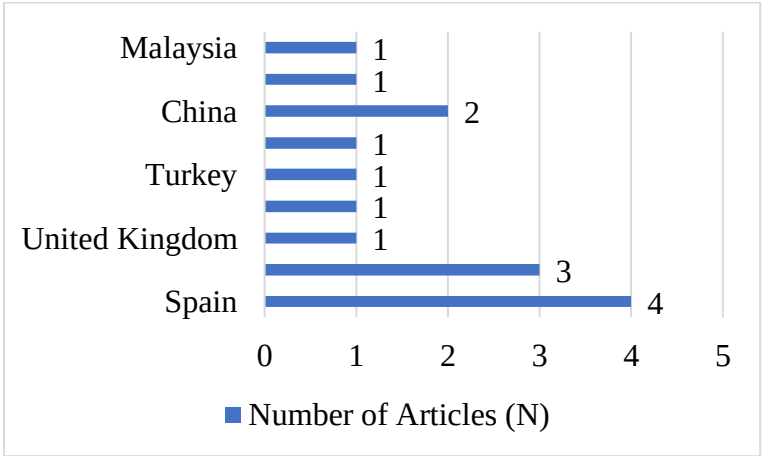

Figure 3. Distribution of Research Studies by Country

The Distribution of Research Studies in Term of Research Methodology

The third research question was about research methodologies. In the present study on the incorporation of sustainability in mathematics education, we considered only the methodology declared by the authors

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of the analyzed articles, with the aim of ensuring the reliability of the obtained results. Figure 4 illustrates the distribution of research methodologies used in the reviewed studies. It is observed that the qualitative methodology is the most widely used in research on this topic, present in most of the analyzed articles (Doğan, 2021; Moreno-Pino et al., 2022; C.-S. Su et al., 2022; Vásquez et al., 2020, 2022). On the other hand, the use of quantitative methodology is evidenced in two articles (Santamaría-Cárdaba et al., 2021; A. Su & He, 2020). Regarding article (Lechuga et al., 2020), the research methodology used is not declared. Meanwhile, other methods used to analyze ESD in mathematics education, such as mixed-methods (Kim & Pang, 2022), quasi-experimental (Aslam et al., 2021), action research (Helliwell, 2022), theoritical synthesis (Li & Tsai, 2022), critical literature review (Szabo et al., 2020), systematics literature review (Sakaria et al., 2023), and Multi-criteria decision analysis/fuzzy-decision-making trial and evaluation laboratory (MCDA/F DEMATEL) (Jeong & González-Gómez, 2020). The various data collection methods in the findings of this study show that the researchers use a variety of data collection methods to ensure that the study does not have high errors on the data obtained and the information obtained is appropriate according to the topic of study.

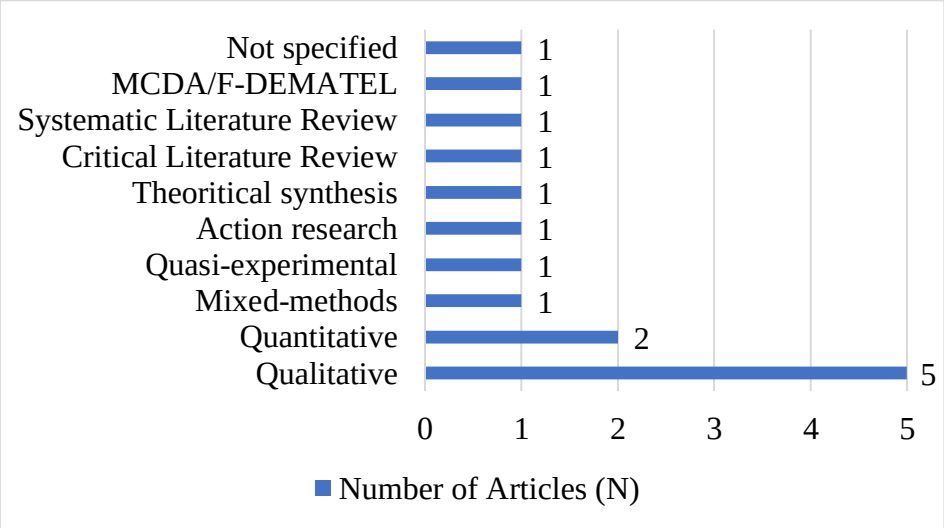

Figure 4. Distribution of Research Studies in Term of Research Methodology

The Distribution of Educational Level Study Sample

The fourth research question was concerned with distribution ESD in term of educational level study sample (Figure 5). The most research is in pre-services teacher education with 7 articles (Doğan, 2021; Jeong & González-Gómez, 2020; Moreno-Pino et al., 2022; Szabo et al., 2020; Vásquez et al., 2020, 2022). Followed by research conducted at elementary schools with 2 articles (Kim & Pang, 2022; C.-S. Su et al., 2022). On the other hand, each one research articles at Junior high schools (Aslam et al., 2021), senior high schools (A. Su & He, 2020), and college students (Lechuga et al., 2020). There is also one research conducted on teacher (Santamaría-Cárdaba et al., 2021). The two others articles are using theoretical synthesis (Li & Tsai, 2022) and systematics literature review (Sakaria et al., 2023), so the educational level study sample not given.

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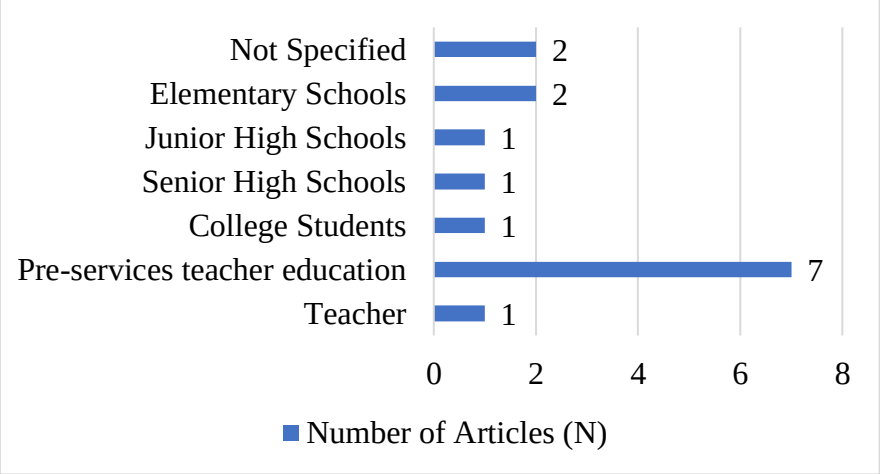

Figure 5. Distribution of Research Studies in Term of Educational Level Study Sample

Recommendations for Integrating ESD into Mathemathics Curriculum

Education is a fundamental tool to make a country's society equitable, just, and respectful of the environment. Education allows building knowledge and skills to promote sustainable development, in this sense, it is necessary to examine whether the curricular bases offer learning opportunities and contexts for students at this stage to develop their awareness, knowledge and skills in a sustainable way. In mathematics education, in line with (RENERT, 2011) we note that ESD which encourages or allows learners to engage in interdisciplinary activities and discussions about sustainability is rather uncommon in mathematics. One reason for this deficit, in our view, is that the integration of ESD into mathematics education would require a redefinition of the scope of mathematics. Despite increasing awareness of the importance of sustainability, there is no clear rationale for ESD in mathematics education.

Integrating ESD into the mathematics curriculum become necessary and important. Based on the articles that have been analyzed, the following are written down some recommendations for integrating ESD into the mathematics curriculum:

- Using flipped e-learning (Jeong & González-Gómez, 2020)
- Using mathematics textbooks with sustainability-related contents were used both to introduce and to apply mathematical concepts or principles (Kim & Pang, 2022)
- Using classroom projects work that lead to reflect on environmental issues, addressing ESD through activities like use of recyclable materials, questioning that provokes debate about environmental problems (Vásquez et al., 2020)
- integrating ESD into educational policies, strategies and programs; integrating ESD into curricula and textbooks; integrating ESD into teacher education; teaching ESD in the classroom and other learning settings; and assessing ESD learning outcomes and the quality of ESD programs (Vásquez et al., 2022)
- Practical questions have been proposed that relate real problems to the contents (Lechuga et al., 2020)
- Various practical strategies in teaching mathematics for sustainable like designed and implemented a set of blended learning activities as complementary and improvements to the task (Helliwell, 2022)

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- Using practical strategies with storytelling method (Doğan, 2021)
- Mixed-class teaching (A. Su & He, 2020)
- Using interdisciplinary link between ESD and stochastic education (C.-S. Su et al., 2022)
- Integrating problem solving based on mathematical content and Using polya's Problem-Solving Strategies (Szabo et al., 2020)
- Using Reciprocal Teaching in Mathematics Education and mathematical word based problems (Aslam et al., 2021)

Discussion

Education for Sustainable Development (ESD) is a learning process based on the objectives and principles that underlie sustainability and relate to all levels and types of education. For over a decade, the incorporation of ESD in all educational disciplines has been internationally driven (UNESCO, 2017). Our findings on ESD in mathematics education in terms of years of publication (Figure 2) indicate that 2022 have the highest percentage of publications, followed there are 5 articles published in 2020. In 2023, because it has only been running for 6 months, only 1 article has been published. However, it should be noted that this figure is still low compared to other research topics. These results suggest that the topic under study is an emerging issue and of growing interest to researchers in the field. The increase in the number of publications in recent years could reflect greater concern for the topic in the scientific community, which in turn could generate new research questions and motivate future studies in this area. Consequently, these findings highlight the need to continue exploring the topic and promote additional research that allows for a deeper understanding of it.

With regard to the distribution of ESD in mathematics education studies by country, based on Figure3, it can be observed that there are publications from selected countries included in this study. The results indicate that the majority of the analyzed studies come from Asian countries such as Malaysia, South Korea, China, Taiwan, and Turkey with a total of 6 publication. On the other hand, 5 from European countries and 4 from American countries. It is possible to observe that the majority of the research on sustainable development is led by Spanish authors, accounting for a total of four publications, which suggests a significant presence of Spain in the field of research on this subject. On the other hand, there is an unequal geographical distribution regarding research in this field, indicating the need to promote greater collaboration between researchers from different countries and continents. Additionally, it is important to highlight that countries such as Chile -who has 3 publications- and others have also stood out for their participation in the study of ESD in mathematics, reflecting a global interest in addressing this critical issues.

A research methodology is a specific process or approach for identifying, selecting, processing, and analyzing information about a specific topic. In the present study on the incorporation of sustainability in mathematics education, we considered only the methodology declared by the authors of the analyzed articles, with the aim of ensuring the reliability of the obtained results. Figure 4 shows the declared methodology in the analyzed articles. The results of the analysis reveal that the type of research related to ESD in mathematics is dominated by qualitative studies and then followed by quantitative studies (with a difference in the number of which is not too large). Qualitative research related to the human dimension, namely conservation and the environment, is growing in quantity (Macura et al., 2019). Quantitative methods used for seeing the correlation and relationship of ESD through studying their attitudes, knowledge, and behaviour towards the area (Marilyn Cordina & Mark C. Mifsud, 2016).

Sustainability is a vital theme that tends to attract many authors from various fields and interests (Hermundsdottir & Aspelund, 2021; Khan et al., 2021). Sustainability research trends emerge in several fields of knowledge and present a variety of methods without showing a tendency towards a qualitative or

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quantitative approach (Amaratunga et al., 2002). This has a positive impact as it results in a more unified, and more diverse theme (Storopoli et al., 2019). Another methodology that find in this articles such as mixed methods, quasi experimental, action research, theoritical synthesis, critical literature review, systematic literature review, and Multi-criteria decision analysis/fuzzy-decision-making trial and evaluation laboratory (MCDA/F DEMATEL).

Regarding the sample or participants of the analyzed studies (Figure 5), a total of 7 articles involving pre-service teachers were counted. This finding suggests that there is greater emphasis on the training of pre-service teachers than on in-service teachers in the area of sustainable development. Therefore, it is essential to involve in-service teachers in research as their experience and practical knowledge are crucial for addressing current education challenges. Additionally, researching in-service teachers can contribute to professional development and improvement in education quality. Deepening the analysis of the current status of sustainability and the relationship with initial teacher education, according to (Salīte et al., 2020) would help create deeper personal meanings for sustainable education. The future teacher must be a committed citizen, capable of leading the new challenges posed by society (Merritt et al., 2018) and must therefore have a series of professional skills related to the development of a fairer, more sustainable and economically viable society (Álvarez-García et al., 2019; Muñoz-Rodríguez et al., 2020; Solís-Espallargas et al., 2019).

The philosophy of mathematics education for sustainable development may be assumed that all of theory and material in mathematics can give more advantages for our environment, economic, and society in order to all of people can love mathematics more and more because they feel any advantages from mathematics for their live (Widiati & Juandi, 2019). Integrating ESD into the mathematics curriculum become necessary and important. Our findings indicated one of the most ways for integrating ESD into the mathematics curriculum that is using mathematics textbooks with sustainability-related contents (Kim & Pang, 2022; Vásquez et al., 2022). There is a close relationship between the conceptualizations of a topic used in mathematics textbooks and the opportunity to learn for students afforded by the textbooks (Charalambous et al., 2010; Choy et al., 2020; Törnroos, 2005). Textbooks, as a concrete embodiment of mathematics curriculum, help make the curriculum intentions specific (Li et al., 2009; Rezat et al., 2021). Both a passive and an active way were employed in connecting mathematics to ESD in the textbooks, such as w hile the former provided opportunities for students to encounter sustainable development while learning mathematical concepts and principles, the latter provided opportunities for them to understand and take account of ESD in depth beyond solving the given problems.

Our findings also indicated that recommendations for integrating ESD into the mathematics curriculum that is using real problems for the questions (Lechuga et al., 2020; Szabo et al., 2020). It is gives opportunities for students not only to solve related problems mathematically but also to connect them to sustainability. The other recommendations that is using classroom projects work that lead to reflect on environmental issues, addressing ESD through activities like use of recyclable materials, questioning that provokes debate about environmental problems (Vásquez et al., 2020). Students are directed to think about and plan alternative solutions to everyday life. The habit of doing mathematical activities can support students in making sustainable discoveries of new knowledge.

An equally important factor in integrating ESD into the mathematics curriculum is from the teacher. When teachers come across students trying to obtain knowledge in their specific fields and academic accomplishments, they strive hard to incorporate various strategies. Based on our findings indicated that teacher can integrating practical strategies in teaching mathematics for sustainable like designed and implemented a set of blended learning activities as complementary and improvements to the task (Helliwell, 2022); Using practical strategies with storytelling method (Doğan, 2021); Using Reciprocal Teaching in Mathematics Education and mathematical word based problems (Aslam et al., 2021); using Mixed-class teaching (A. Su & He, 2020); Using flipped e-learning (Jeong & González-Gómez, 2020); or Using interdisciplinary link between ESD and stochastic education (C.-S. Su et al., 2022).

Not only teachers are required to take an active role in ESD actualization in learning but also need good cooperation with schools including teachers and school citizens presented in the lesson will be more

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complex by emphasizing the interdisciplinary principle. The importance of ESD in mathematics learning is closely related of schools, students, society, and school environment condition.

Conclusion

Education is the primary means for achieving the goal of sustainability. Mathematics is the key to other fields of science and plays an important role in realizing ESD. Arguably, if we are to take up sustainable development challenges, we cannot afford to continue with no or limited progress in ESD in mathematics education. Almost all competencies in the dimensions of ESD can be integrated into the curriculum of mathematics.

All research questions have been evaluated in this study. Throughout this paper, we provide the findings of an analysis of 15 research publications published between 2019 and 2023, which explored how can ESD integrating in mathematics curricullum throughout the teaching and learning process. Integrating ESD in teaching and learning mathematics has spread throughout the country. Most countries use ESD to achieving the goal of sustainability. Compared to other nations, Spain has published the most significant number of publications on the study about ESD in mathemathics education in the last five years.

Integrating ESD in mathemathics curricullum has been carried out at various levels from elementary school to college. The results of the analysis revealed that sample or participants from pre-service teachers made up most of the sample in the review of selected articles. Promoting ESD in higher education or pre-service teachers implies an improvement and quality in the exercise of responsible citizenship, being the key in the training of future teachers as the main agent of change and transition towards sustainability in society.

It is crucial to know how to integrate ESD into mathematics education in various ways. So, ESD can be applied more broadly in the future in mathematics learning. Teachers and students can fully explore the potential of ESD to focus on and enhance their knowledge of mathematics. This understanding may increase the quality of mathematics practices within ESD domain.

Limitation

Each study is limited in some way. There may be limitations to your study due to limitations on the research design or technique, which may affect the study's findings. While this analysis identifies numerous significant trends and application of teaching and learning for ESD in mathematics education, it has several limitations. Only indexed articles in Scopus, ERIC, and ProQuest databases were used to review this investigation and even then it was limited to the last five years' review. Future studies may also be able to use other databases, such as EBSCHO Host, Science Direct, SCCI, WoS, and Springer. In addition, the study is restricted to studies published as articles. Future studies may focus on looking at a larger range of aspects, including conference papers, editorials, theses, and dissertations, as this may help researchers learn more.

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