

Integrating sustainability in mathematics education and statistics education: A systematic review

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Abstract

If we are to understand and address today's social, environmental and economic crises through education, we must introduce education for sustainable development (ESD) into classrooms and approach it from an integrated perspective. In so doing, this study aims to provide an overview of the current status of the still-emerging research agenda on the integration of ESD into mathematical education and statistical education. To this end, we conducted a systematic review of Scopus and Web of Science databases of theoretical and research articles published between 2010 and May 2023. In total, 32 studies were identified, conducted mostly in Europe, followed by South America, which mainly address teacher training. The results suggest that mathematics education and statistics education are an effective means of providing education focused on ESD, but that teachers still have limited knowledge and resistant attitudes. Therefore, initial and ongoing training must move towards characterizing proposals that provide examples and involve teachers in response to this challenge.

Keywords: mathematics education, statistics education, ESD, teacher training, systematic review

INTRODUCTION

Currently, due to environmental problems and social and economic inequality resulting from the excessive exploitation of the planet's natural resources, we are facing an unprecedented planetary emergency that affects the present and future (UNESCO, 2017). In light of this situation, it is urgent that we take measures and focus our efforts in different areas, with the educational field being a key aspect to further identify, understand and communicate these various problems in order to become aware of them, influence them and improve them (Barwell, 2013; Hamilton & Pfaff, 2014; Helliwell & Ng, 2022).

To address this challenge, United Nations (UN) has proposed an agenda with 17 sustainable development goals (SDGs) to be met by 2030, related to the "fight against the threats of climate change, no poverty, quality education, sustainable cities, zero hunger, gender equality, clean air, clean water, renewable energy and responsible production and consumption" (Semiz &

Baykal, 2020, p. 112). In view of this, more and more agencies and governments are proposing the need to promote education for sustainable development (ESD), with the purpose of "integrating the values of sustainable development into every aspect of education with a view to creating more sustainable and just societies" (Li & Tsai, 2021, p. 7).

From this standpoint, it is crucial that this ESD be approached from a broad perspective throughout schooling, including higher education, and be integrated into the different areas of knowledge (UNESCO and Education International, 2021), since promoting ESD is not only about integrating "contents such as climate change, poverty and sustainable consumption [...] it also creates interactive, learner-centered teaching and learning settings" (UNESCO, 2017, p. 7). According to Semiz and Baykal (2020), this holistic, integrative and interdisciplinary approach allows us to "understand our personal responsibilities for the planet, realize the interdependencies between the complex problems that threaten our future, such as poverty, climate change and

Contribution to the literature

- The results of this study suggest that mathematics education is a valuable tool for developing ESD.
- One contribution of the study is that it reveals the importance of initial and ongoing teacher training so that they can integrate ESD into their mathematics teaching and learning practices.
- Another contribution of this research is related to the identification of a future line of research that allows characterizing the mathematics and/or statistics education strategies that favor ESD approach.

inequality, to explore solutions to these problems” (p. 112). Therefore, one of the priorities in the field of education research is to understand how to effectively integrate sustainability into the classroom, into teacher training at different educational levels and into different disciplines (Laurie et al., 2016; Mulà & Tilbury, 2023).

In light of the foregoing, the focus of this study is to analyze how, through the field of research in mathematics education and statistics education, the challenge of integrating ESD from an early age is being met. This perspective assumes that

- (a) the role of teaching mathematics takes on an important role in the promotion of sustainable development, since it provides students with opportunities to develop the skills and knowledge necessary to deal with environmental, social and economic crises and the various problems that result from them and that we face as humanity (Alsina, 2022),
- (b) statistics also plays a relevant role in the promotion of ESD, as pointed out by the Secretary General of UNs, in the midst of the COVID-19 pandemic: “This year, as the world deploys data to face a common challenge, let us use World Statistics Day to spotlight the role of statistics in advancing sustainable development for all” (Guterres, 2020), and
- (c) it further assumes that crises cannot be solved only through mathematics, but through the sum of different disciplines (Alsina & Mulà, 2022), which implies that mathematics teachers progressively develop a literacy of an interdisciplinary nature that allows them to think not only about mathematics, but about mathematics in connection with sustainability (e.g., Alsina, 2022; Barwell, 2013; Bögeholz et al., 2014; Li & Tsai, 2021; Vásquez et al., 2020).

It is thus necessary to pay attention to the contributions of the studies undertaken so far that support the integration of mathematics and/or statistics education with ESD. In this context, some review works are starting to emerge that provide a summary of the research into the links between mathematics education and sustainability. For example, Rodrigues-da Silva and Alsina (2023) have conducted a review of papers from 2007 to 2022 to explore the intersection between interdisciplinary STEM/STEAM educational approaches and early childhood for sustainability,

analyzing 12 research articles. Their results show that most studies focus on the environmental aspect of sustainability and address scientific aspects more frequently.

Specifically in mathematics education, Su et al. (2023) carried out a review of the literature from 2015 to 2021 focused on the scientific output on ESD in mathematics teacher training, analyzing 16 research articles. Their results show the importance of continuing to research and develop effective strategies to integrate ESD into the initial and ongoing training of mathematics teachers. While this review confirms the connection between mathematics education and ESD, it focuses specifically on pre-service teachers. Therefore, a review is needed of the studies that have addressed the way in which mathematics education in general, and statistics education in particular, are integrated and connected with ESD (Vásquez & Alsina, 2021). The purpose of such a review is to provide an overview that yields the knowledge and tools that mathematics teachers need to play an effective role as agents of social change (Alsina, 2022) and allow students to develop sustainability competencies (Semiz & Baykal, 2020; Li & Tsai, 2021).

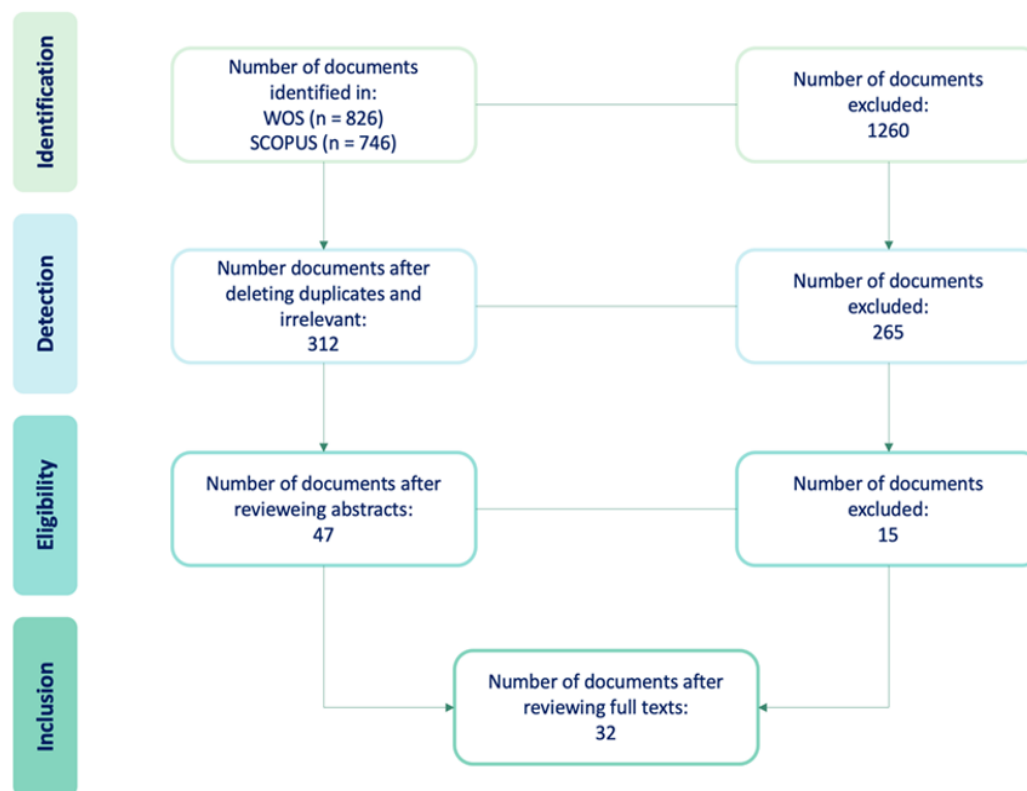
Against this background, we asked ourselves: What studies have been published on integrating sustainability into mathematics and/or statistics education in pre-school, primary and secondary education? What are the characteristics of these studies? What are their main findings? To answer these questions, the goal of this paper is to conduct a systematic review of Scopus and Web of Science (WoS) databases of theoretical and research papers published between 2010 and May 2023, to provide updated data that can be used to explore and characterize the scientific output on integrating sustainability in mathematics and statistics education.

METHODOLOGY

Given the goal of this paper, we conducted a systematic review of the specialized literature based on the model of PRISMA (preferred reporting items for systematic reviews and meta-analyses) statement, updated by Page et al. (2021), which includes a checklist to present the studies more accurately. To carry out the review, we decided to search indexed journals in WoS databases of Clarivate Analytics, and Scopus database of Elsevier, since their respective impact indices are internationally recognized in field of education research.

Table 1. Inclusion & exclusion criteria

Criteria	Inclusion	Exclusion
Language	English, Spanish, or Portuguese	Other languages
Publication period	2010 to May 2023	Before 2010
Type of paper	Theoretical (T) & empirical (E) papers that underwent a peer-review process	Other formats such as conference proceedings, book chapters, other systematic reviews, etc.
Area of research	Education	Other areas
Level	Early childhood, primary, & secondary education	Other levels

**Figure 1.** Flowchart of corpus selection process (Source: Authors' own elaboration)

Search & Selection of Papers

The inclusion and exclusion criteria applied in this systematic review are shown in **Table 1**.

Thus, by using PRISMA model, as a first step we extracted, filtered and processed the data as per the following four stages:

1. Identification of the source of the documents (in our case, papers published in Scopus and WoS databases): based on key terms in the research goals, such as "education for sustainable development", "sustainable development goals" "mathematics education" and "statistics education", using the "AND" connector between each concept. For terms related to the educational level ("early childhood education", "primary education", "secondary education"), the search operator "OR" was used.
2. Detection and review of the resulting documents: any duplicate and irrelevant documents were deleted and the relevant ones, based on their titles

and keywords, were selected, yielding 312 papers of interest.

3. Eligibility: the inclusion and exclusion criteria were applied, and abstracts were reviewed, leading to the selection of 47 papers.
4. Inclusion: the complete papers were carefully and exhaustively reviewed, leading to the final list of 32 papers that comprise the study sample.

Figure 1 shows the process for selecting and excluding the sources found.

Analysis Parameters

For an optimal analysis of the 32 selected articles, a thorough and in-depth reading of each of the papers was carried out to determine the central themes and to identify relationships between the articles in the first instance.

To facilitate this process, the articles were reviewed and summarized according to the analysis parameters shown in **Table 2**.

Table 2. Analysis parameters

Parameter	Definition
Reference	Author(s) and year of publication, sorted in alphabetical order
Country	Country where the research was conducted
Language	English (E), Spanish (S), or Portuguese (P)
Indexing	Type of indexing of the journal, where the article was published
Type of paper	Theoretical (T) and empirical (E) papers
Method	Research methodology, which may be quantitative, qualitative, or mixed
Level	Early childhood (E), primary (P), and secondary education (S)
Subject of the study	Subject on which the study focuses
Instruments	Data collection instruments used
Research questions/goals	Principal goal/s or question/s
Main results	Relevant findings reported in the investigations

Finally, based on the complete and in-depth reading and the identification of the parameters of analysis, interpretative syntheses were made of each article, which were then related to each other. This made it possible to draw up integrative syntheses, resulting in the identification of interrelated aspects that are configured as research focuses (Pearson et al., 2011).

papers are explored, such as indexation, type of article (theoretical or empirical), language, year of publication, geographical distribution, method, object of study, educational level and data collection instrument. We then analyzed specific characteristics related to the identification of the main findings reported by the studies in order to determine the focus of the research.

RESULTS

This section presents the results of the study in relation to the research questions guiding this systematic review. First, the general characteristics of the selected

General Characteristics of the Papers Selected

Table 3 gives an overview of the 32 articles published between 2010 and May 2023 that have been selected for this study.

Table 3. Articles on integrating ESD in mathematics & statistics education published in Scopus & WoS (2010-May 2023)

Authors Country/Language	DB	PT		Method	Level			Study subject(s)	Instrument
		T	E		E	P	S		
Alsina and Mulà (2019) Spain/E	WoS	x		Qualitative	x			48 pre-service teachers	Classroom observation
Alsina and Silva-Hormazábal (2023) Chile/E	Scopus	x		Qualitative	x			23 in-service teachers	Questionnaire
Barwell (2013) Canada/E	Scopus	x		-	-	-	-	-	-
Boeve-de Pauw et al. (2022) Sweden/E	Scopus	x		Quantitative	x	x		414 in-service teachers	Questionnaire
Cardenoso et al. (2015) Spain/S	Scopus	x		Qualitative		x		40 in-service teachers	Rubric
Carmona-Medeiro and Cardenoso-Domingo (2021) Spain/E	WoS	x		Mixed	x			133 pre-service teachers	Reports produced by students
Chin et al. (2019) Japan/E	Scopus	x		Qualitative	x			1 in-service teacher	Interviews & class observation
Coles (2023) UK/E	Scopus	x		-	-	-	-	-	-
Colinas and Arnal-Palacián (2022) Germany/S	Scopus	x		Qualitative	x			20 children	Class observation & questionnaire
García-Alonso et al. (2023) Spain/E	Scopus	x		Mixed		x		15 pre-service teachers	Rubric
Hamilton and Pfaff (2014) USA/E	Scopus	x		-	-	-	-	-	-
Helliwell and Ng (2022) UK/E	WoS	x		Qualitative		x		50 pre-service teachers	Interviews & class observation
Helliwell et al. (2023) UK/E	Scopus	x		Qualitative		x		1 in-service teacher	Interview
Jeong and González-Gómez (2020) Spain/E	WoS	x		Qualitative	x			230 pre-service teachers	Classroom observation
Kim and Pang (2022) Japan/E	Scopus	x		Qualitative	x			Mathematics textbooks	Rubric

Table 3 (Continued). Articles on integrating ESD in mathematics & statistics education published in Scopus & WoS (2010-May 2023)

Authors Country/Language	DB	PT		Method	Level			Study subject(s)	Instrument
		T	E		E	P	S		
Li and Tsai (2021) UK/E	WoS	x		-	-	-	-	-	
Mahlisa and Zubainur (2021) Indonesia/E	Scopus	x		Quantitative			x	54 in-service teachers Questionnaire	
Moreno-Pino et al. (2021) Spain/E	WoS	x		Qualitative	x	x	x	Programs of subjects in area of mathematics Rubric	
Moreno-Pino et al. (2023) Spain/E	Scopus	x		Mixed	x	x	x	105 pre-service teachers Questionnaire	
Mulà and Tilbury (2023) Spain/E	Scopus	x		-	-	-	-	-	
Paredes et al. (2020) Spain/E	WoS	x		Qualitative			x	42 pre-service teachers Reports produced by students	
Pasichnyk et al. (2020) Ukraine/E	Scopus	x		Mixed			x	153 pre-service & in- service teachers Questionnaire	
Rico et al. (2021) Spain/E	WoS	x		Mixed			x	24 pre-service teachers Questionnaire	
Semiz and Baykal (2020) Turkey/E	WoS	x		Qualitative			x	10 pre-service teachers Semi-structured interview	
Suh et al. (2020) South Korea/E	WoS	x		Mixed	-	-	-	28 pre-service teachers Interview	
Su et al. (2022) Chile/E	Scopus	x		Qualitative			x	Mathematics curriculum Rubric	
Uitto and Saloranta (2017) Finland/E	WoS	x		Quantitative			x	442 in-service teachers Questionnaire	
Vásquez & García-Alonso (2020) Chile/S	Scopus	x		Qualitative			x	30 pre-service teachers Reports produced by students	
Vásquez et al. (2020) Chile/S	WoS	x		Qualitative	x	x		145 pre-service teachers Questionnaire	
Vásquez et al. (2021) Chile/E	WoS	x		Qualitative			x	Mathematics textbooks Rubric	
Vásquez et al. (2022) Chile/E	WoS	x		Qualitative			x	Mathematics curricula Rubric	
Vásquez et al. (2023) Chile/E	Scopus	x		Qualitative			x	11 in-service teachers Interview	

Note. Language E: English; S: Spanish; & P: Portuguese; DB: Database; & PT: Paper type

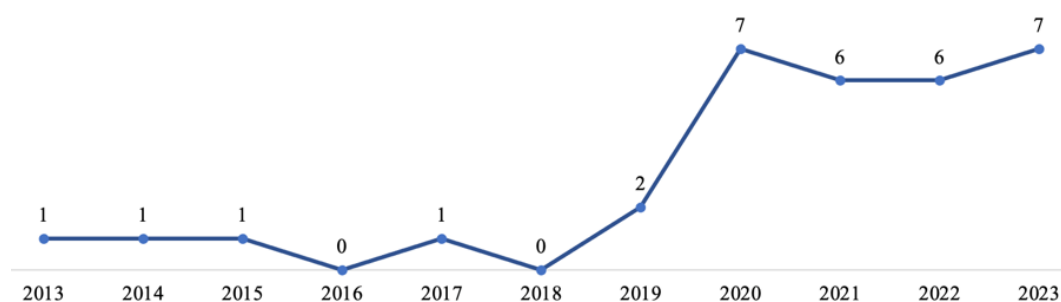


Figure 2. Distribution of papers selected by year of publication (Source: Authors’ own elaboration)

In relation to question what studies have been published on integration of sustainability in mathematics education and/or statistics education linked to early childhood, primary and secondary education levels? As well as characteristics of such studies?

Table 3 shows that 14 articles were published in journals indexed in WoS and 18 in Scopus. Furthermore, 16% of the papers selected are theoretical, while 84% are

empirical. Regarding the language, 87% of the articles are written in English and 13% in Spanish. None of them was written in Portuguese.

Regarding the year of publication, we note that although this review covers from 2010 to May 2023, we only identified articles from or after 2013. We also identified an increase in publications starting in 2020 (**Figure 2**). This shows that integration of sustainability into mathematics and/or statistics education is a recent

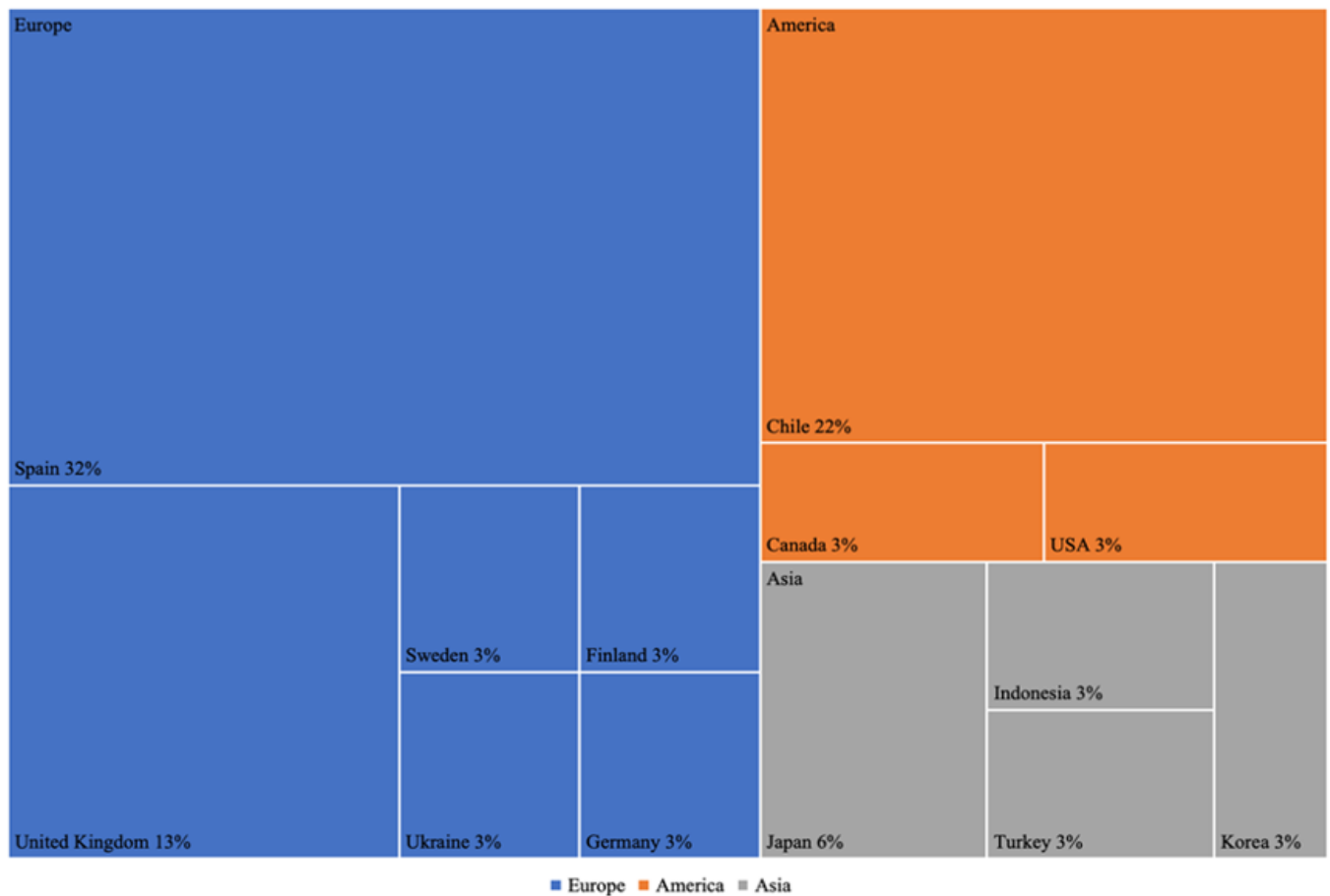


Figure 3. Distribution of papers by continent and country (Source: Authors’ own elaboration)

area of interest, constituting an emerging field of research. Regarding the geographical distribution, 57% of the articles correspond to studies carried out in Europe, 28% in the Americas and 15% in Asia (Figure 3).

Regarding the research method, we observe a predominance of the qualitative approach (67%), followed by the mixed approach (22%) and the quantitative approach (11%). On the other part, it can be seen that a large part of the research (50%) has been carried out on aspects linked to the primary education stage, whether in pre-service and in-service teacher training, analysis of beliefs, textbooks, curricula, and opportunities for professional development of teachers. To a lesser extent, studies focused on secondary education (37.5%) and only 15.6% on early childhood education.

In relation to the areas of study, 64% of the research on the integration of sustainability in mathematics and/or statistics education focused on the training, whether initial or ongoing, of teachers at different educational levels. We found, to a lesser extent, studies focused on curricular analysis (9%), an analysis of primary education textbooks (6%) and an analysis of the implementation of classroom experiences in early childhood education (3%). Finally, 18% correspond to theoretical studies that seek to bridge the gap between

mathematics education and ESD by identifying common ground.

Finally, with regard to data collection instruments, 45% of studies are inclined to apply questionnaires or semi-structured interviews as a collection method. To a lesser extent, 45% of the studies relied on direct observation through rubrics or the analysis of writings, activities or plans carried out by teachers. It is important to note that a paper can exhibit more than one data collection instrument, depending on the authors’ research needs.

Specific Characteristics of the Papers Selected

With the aim of deepening the characteristics of the studies and their main results, an analysis was carried out based both on the parameters of analysis (research questions/objectives and main results) and on a process of elaboration of interpretative and integrating syntheses. This has made it possible to determine that the research areas of the selected articles revolve around three major interrelated aspects:

- (a) need for mathematics education to nurture and be nourished by ESD;
- (b) training of mathematics teachers with a view to promote and include ESD at all school levels; and

(c) statistics education as a key element to enhancing sustainable development.

Need for mathematics education to inspire & be inspired by education for sustainable development

From the review of the selected articles, it is evident that numerous studies relating to the need to move towards mathematics education that feeds into ESD and vice versa.

This is reflected in the fact that, for some years now, studies have begun to establish connections between various research agendas in mathematics education and ESD (Alsina, 2022). These links respond to the call of international institutions and organizations that strongly recommend the incorporation of ESD in the different educational stages, considering it to be one of the main instruments available to public authorities in their attempt to ensure the development of their countries.

From this perspective, they underline that both the meaning and the values of education for sustainability are developed in an interconnected way, based on the contributions of disciplines from different fields: scientific-technological, humanistic, social, etc. Since, unlike other human activities, "education can have a lasting change, since the stakeholders appropriate the change" (Chin et al., 2019, p. 2). Consequently, and given the current planetary emergency, sustainability education emerges as a key tool to achieve SDGs (Semiz & Baykal, 2020). There is thus an urgent need for a ESD transformative, based on active, student-centered teaching and learning processes (Rico et al., 2021). Teaching and learning processes that can raise awareness, provide knowledge and skills for lasting behavioral change in lifestyle, active participation in social issues with the mindset of social needs and economic interests located within the capacity of the Earth's life support system (Chin et al., 2019, p. 14).

Consequently, teaching and learning processes must address the link between the relationships between people and their environment, which requires social and economic development models in which "the human factor is essential" (Carmona-Medeiro & Cardeñoso, 2021, p. 1). In this regard, Cardeñoso et al. (2015) propose that it is necessary to develop sustainability skills in students at different educational stages. To achieve this, the role of teachers as agents of social change is fundamental (Alsina, 2022), given the formative work they carry out in the classroom involving the "world views, knowledge, attitudes and competencies of students towards sustainability" (Semiz & Baykal, 2020, p. 113). This is in addition to the fact that teachers "not only hold the key to promoting understanding and skills in sustainable development, but also to supporting social justice, equity and environmental responsibility in our communities" (Alsina & Mulà, 2019). Therefore, the success of

implementing ESD will be subject to "their opinions, understanding of sustainability and how they incorporate this concept into their pedagogy" (Semiz & Baykal, 2020, p. 113).

There thus arises a need *ESD inspires mathematics education*, that to empower students to make decisions for sustainable development. In other words, students should train in "take informed decisions and responsible actions for environmental integrity, economic viability and a just society, for present and future generations, while respecting cultural diversity" (Li & Tsai, 2021, p. 1).

However, research in this regard exhibits a lack of clarity on how to rethink and reconsider mathematics teaching and learning based on 21st century learning priorities (Li & Tsai, 2021). Thus, this constitutes a challenge for schools and teachers in training and in service, since this means an evolution in the processes of teaching and learning mathematics (Alsina & Mulà, 2019; Vásquez & García-Alonso, 2020). However, this challenge cannot be solved by mathematics education alone as it is "an interdisciplinary concept that requires an interdisciplinary approach to integrate ESD into education at all levels and disciplines" (Semiz & Baykal, 2020, p. 112).

On the other hand, given the nature of mathematics as a scientific discipline, it allows mathematics education to function as an area that facilitates the integration of interdisciplinary knowledge and skills. This helps students to become aware of its role in the development of knowledge and styles of thought. Therefore, mathematics education must be considered as a generalizing and systematizing discipline. Which allows the development of, for example, systemic thinking and provides tools to "guarantee the acquisition of professional skills in the context of application of ESD model" (Pasichnyk et al., 2020, p. 2086).

Therefore, it is imperative that mathematics education make a transition towards a holistic, integrative, and interdisciplinary education in order to "develop students' knowledge in a collaborative and novel way, with the aim of training them to see ESD as a way of being and thinking about the world and its actions" (Li & Tsai, 2021, p. 4). This will facilitate the development of socially meaningful mathematical learning, enabling the application of mathematical knowledge to real-world problem solving (Coles, 2023; Hamilton & Pfaff, 2014). For this reason, as Rodrigues-da Silva and Alsina (2023) note, countries such as South Korea, Spain and the United States have recently incorporated interdisciplinary approaches. In Spain, for example, STEM competence has been introduced into the curriculum from early childhood education to foster an "understanding of the world by using scientific methods, mathematical thinking and representation, technology and engineering methods to transform the

environment in a committed, responsible and sustainable way" (MEFP, 2022, p. 21).

In this approach, the *mathematics education inspires ESD* and provides an opportunity to achieve the objectives it seeks to develop, since "mathematics is one of the most important means to understand and address the climate emergency, since we understand much of the world through mathematical models and representations" (Helliwell and Ng, 2022, p. 129). According to Cardenoso et al. (2015), mathematics education "can lead the sustainable development movement by providing adequate content that allows students to acquire the necessary skills to understand concepts related to sustainable development and aspects of the world around them" (p. 4). However, "moving toward a mathematics education incorporating ESD requires a 'mind shift', and success lies largely in a fundamental reconfiguring and expanding of the traditional boundaries of the philosophy of mathematics" (Li & Tsai, 2021, p. 5). Undoubtedly, this poses a challenge related to the complex interconnection that crosses the limits of the social, economic, and environmental dimensions of sustainable development; the necessary diversity of perspectives and opinions; and the orientation towards problem solving by the students themselves (Boeve-de Pauw et al., 2022). In the words of Li and Tsai (2021), mathematics education in the context of ESD demands a "new key concept for thinking and acting about how we can reorient mathematics toward environmentally and socially conscious thinking to engage the younger generations in ethical action for a better future" (p. 6).

There are studies in this regard that seek to analyze links between ESD and mathematics education at the level of the learning objectives proposed in mathematics curricula (Su et al., 2022; Vásquez et al., 2022), and more specifically in the activities proposed in mathematics textbooks (Kim & Pang, 2022; Vásquez et al., 2021). Regarding the curricular analysis, it is reported that the content areas of statistics and probability, as well as numbers and operations, are those with the greatest number of objectives related to aspects of ESD (Vásquez et al., 2022). While, in the case of textbooks, although some attempts have been made to integrate ESD with mathematics content, and in particular with statistics content (Kim & Pang, 2022), these efforts are still insufficient. Consequently, it is necessary to move towards a mathematics education for sustainability education, focused on issues from real and local contexts, with the aim of empowering students to reflect on issues related to sustainable development (Vásquez et al., 2021).

Emerges the need to educate in sustainability emerges from a mathematics education in context and with meaning. A mathematics education that considers a teaching and learning process based on real-life problem situations (Semiz & Baykal, 2020). Thus,

according to Jeong and González-Gómez (2020), there is a need for mathematics education understood as "long-life educational gatekeeper" (p. 14), in the sense that "[s]tudents with a decent mathematics comprehension are more likely to have enhanced outcomes and to finish with enhanced instructive traces than underperforming mathematics students" (p. 2). This ability of mathematics, in combination with an ESD approach, makes it a decisive tool to train citizens with solid sustainability skills, which connects with what suggests UNESCO (2014). Therefore, teacher training should be headed in this direction, since "the creation of realistic tasks through reflection and communication will stimulate sustainable aspects in education, such as creativity and critical thinking" (Paredes et al., 2020, p. 1). According to Coles (2023), an aspect to consider in this line of a new social contract for education is basing mathematics education on "socioecological" practices that consider the following guiding principles:

- (a) not taking nature (that is, the environmental crisis) as a fixed background for concerns,
- (b) avoiding the epistemological error of taking the individual as the unit of learning,
- (c) questioning what is centered in our work, and
- (d) moving towards a dialogic ethics.

In this way, it will contribute to designing mathematics education that not only contributes to ESD and its competencies, but that also draws from ESD. Through this lens, various research efforts have been made to integrate mathematics education with ESD, with the following focuses of action: examples and classroom proposals aimed at providing clarity on how to integrate ESD and mathematics education (Colinas & Arnal-Palacian, 2022; Hamilton & Pfaff, 2014; Jeong & González-Gómez, 2020; Rico et al., 2021); analysis of mathematics curricula for primary education (Su et al., 2022; Vásquez et al., 2022); and analysis of the presence of ESD in mathematics tasks proposed in textbooks (Kim & Pang, 2022).

Another strong focus, which we will address in the next section, is the training of mathematics teachers as a key agent for the promotion and inclusion of ESD in the classroom.

Training of mathematics teachers in an effort to promote & include education for sustainable development

As noted in the previous section, the studies analyzed conceive of the integration of mathematics education and ESD on several fronts, both at the theoretical level and in the development of classroom proposals, curricular analysis and its presence in textbooks. However, one area that emerges with great strength is the pre-service and in-service training of teachers who teach mathematics.

This still-emerging field of research called training of mathematics teachers for sustainability (Alsina & Mulà, 2019) aims to integrate mathematics with ESD so that, both during pre-service and in-service training, the necessary knowledge and tools are provided to mathematics teachers so they can play an effective role as agents of social change (Alsina, 2022; García-Alonso et al., 2023). In this sense, none of the aspects previously addressed would be possible without teacher training that involves ESD using the tools offered by mathematics and, in particular, statistics. According to Pasichnyk et al. (2020), “education is the most important and necessary condition for achieving SDGs in the world” (p. 2088), so pre-service teacher training plays a decisive role in successfully achieving these goals through education and could even contribute “significantly to overcoming the difficulties of teachers to teach and improve the quality of teaching” (Mahlisa & Zubainur, 2021, p. 6).

In from this perspective, the studies analyzed show a growing interest of the scientific community in research on: the design and implementation of professional development opportunities (Alsina & Silva-Hormazábal, 2023; Boeve-de Pauw et al., 2022; Cardeñoso et al., 2015; Chin et al., 2019; Helliwell & Ng, 2022; Helliwell et al., 2023; Paredes et al., 2020; Vásquez et al., 2020); analysis of beliefs regarding the integration and links between ESD and mathematics education (Mahlisa & Zubainur, 2021; Rico et al., 2021; Semiz & Baykal, 2020; Uitto & Saloranta, 2017; Vásquez et al., 2020); the generation of training models and teacher profiles that integrate ESD and mathematics education in teacher training (Alsina & Mulà, 2019; Carmona-Medeiro & Cardeñoso-Domingo, 2021; Mulà & Tilbury, 2023; Pasichnyk et al., 2020); the analysis of the presence of ESD in the training curricula of teachers who teach mathematics (Moreno-Pino et al., 2021); and the analysis of the level of mastery of sustainability competences in teachers (García-Alonso et al., 2023; Moreno-Pino et al., 2023).

In this respect, it is evident that it is necessary to deploy not only planned activities to improve the practice (professional development), but to carry out actions that entail a change in the practice (professional learning) (Alsina & Mulà, 2019; Alsina & Silva-Hormazábal, 2023; Vásquez et al., 2022; García-Alonso et al., 2023). Even more so if we consider that mathematics teachers could be less aware of their competencies to implement mathematics teaching that connects with sustainability (Uitto & Saloranta, 2017; Vásquez et al., 2020). Therefore, it is necessary to design teacher training plans that incorporate ESD (Alsina & Calabuig, 2019).

The challenge then, is incorporating ESD into both initial and ongoing training “to strengthen their ability to teach it” (Semiz & Baykal, 2020, p. 116). Therefore, “in addition to teaching mathematics, teachers are also responsible for providing opportunities for their

students to engage in learning and participation in broader social, ecological and economic issues” (Li & Tsai, 2021, p. 7), related to the dimensions of sustainability. This responsibility implies changes in “the methodologies and ways of organizing teaching, which implies radical changes in the teaching and learning processes” (Cardeñoso et al., 2015), starting with a reorientation of pre-service teacher training programs that “consider the criteria of the curricular environment proposed by multiple agencies and authors” (Vásquez et al., 2020, p. 28), while transferring them to the mathematical contents and processes of teachers (Jeong & González-Gómez, 2020). By way of example, García-Alonso et al. (2023) notes that “the implementation of training sessions for teachers that promote these connections contributes decisively to holistic and systematic teaching, who also develop their sustainability competencies and learn strategies to implement them in their classrooms” (p. 79). Likewise, “educational programs, curricular guidelines for various levels, textbooks, etc., should be reviewed, since they are key elements to further the development of a sustainability-oriented educational system” (Vásquez et al., 2023, p. 128). The purpose of the above is to provide mathematics teachers with the necessary tools for the development of sustainability skills in the various stages of schooling (Colinas & Arnal-Palacián, 2022; Moreno-Pino et al., 2021, 2023; Suh et al., 2020). This is because approaching the teaching of mathematics from an ESD perspective can be a complex topic for mathematics teachers (Helliwell et al., 2023). In particular if we consider that research, such as that conducted by Semiz and Baykal (2020), details reflections from pre-service teachers who “had never thought that teaching mathematics could be related to the concept of sustainability, that they could establish connections between sustainability issues and many mathematical topics” (p. 124).

Therefore, it is necessary to have clear guidelines that can be used to supplement the training of mathematics teachers of the different educational stages in the pursuit of sustainability (Mulà & Tilbury, 2023).

Statistical education as a key element to enhance education for sustainable development

Finally, the systematic review shows that an emerging area with great potential for integrating ESD in the classroom is statistics education. This connection is based on the idea that statistics education provides tools to understand and respond to problems in real life as well as in other disciplines, also allowing connections to be established between different contexts and problems (Vásquez, Seckel et al., 2022).

In recent years, this has triggered the beginning of a specific line of research that connects statistics education, as part of mathematics education, with ESD.

This approach has led to studies on various issues addressed by statistics education: professional development with primary school teachers (Alsina & Silva-Hormazábal, 2023; Rico et al., 2021; Vásquez & García-Alonso, 2020); the design and implementation of classroom proposals with pre-service teachers (Suh et al., 2020; Vásquez & García-Alonso, 2020); the analysis of statistics and probability tasks in primary school textbooks (Vásquez et al., 2021); the analysis of teachers' beliefs regarding the integration of statistics and ESD (Vásquez et al., 2023); and curriculum analysis (Vásquez et al., 2022).

These studies indicate that statistics education is fertile ground to provide education on sustainability. Because of this, the need to promote sustainable development skills through statistics education is directly linked to ESD, since it "provides a purpose to teach statistics, and in turn statistics becomes a pretext to train on sustainability" (Vásquez & García-Alonso, 2020, p. 132), in learning that transcends mechanical calculation to give way to statistical literacy from a given context (Barwell, 2013).

Accordingly, it is necessary to develop this literacy from an early age, and thus start nurturing the skills needed to consume and produce statistical information, read and critically evaluate information presented in tables, graphs, and reports in the media (Barwell, 2013). Such literacy will enhance the development of statistical thinking, which aims at "understanding why and how statistical research is conducted and the 'big ideas' that underlie statistical research" (Suh et al., 2020, p. 3). Hence the importance of doing work that allows using data from related and significant contexts, becoming aware of their own action in the environment, and making decisions that modify their lifestyle towards one that is sustainable (Vásquez & García-Alonso, 2020). According to Suh et al. (2020), "experience with real data and a thorough consideration of real-world contexts are known to be effective for enhancing statistical thinking ability, even though it is often muddled and leads to no single correct answer" (p. 4). But this, far from being an inconvenience, is part of statistics education, which provides the tools needed to identify relevant information, although this requires "shifting the teaching of statistics towards teaching in a context that allows the citizens of today and tomorrow to adequately understand statistical information in order to face the current and future challenges of a complex and changing world" (Vásquez, 2021, p. 186), and transitioning towards sustainability and taking a more active role in its development.

In this regard, based on the development of a STEAM training program focused on statistical and sustainability issues, Alsina and Silva-Hormazábal (2023) observe the skills that in-service teachers bring to bear when designing and implementing a statistical task involving sustainability, which demonstrates the

potential of statistics in the development of competencies linked to ESD.

However, we must be cautious, because despite the increasing importance that has been given to statistics education, various studies have shown negative attitudes towards it, in addition to a low interest, and poor prior training, both as these relate to teachers and students. For the teachers, Suh et al. (2020) report that, according to their research, a high percentage of them exhibit difficulties in relation to statistics, which they regard as difficult. They also have some misconceptions and they do not feel comfortable teaching it. A similar result was obtained by Vásquez et al. (2020), who found that "97.9% of pre-service teachers surveyed stated that they do not have the necessary (disciplinary and educational) tools to incorporate ESD into the school classroom through mathematics education" (p. 27). Boeve-de Pauw et al. (2022) refer to research that identifies limitations, such as a lack of familiarity with the subject, a shortage of experience, and a lack of knowledge and pedagogical skills, as noted by the teachers themselves.

Among the reasons that the research has detected for this negative attitude towards statistics education, Cardeñoso et al. (2015) note the "institutional and systemic barriers to the integration of sustainability in higher education, indicating that a large part of the teaching staff is 'comfortable' with the teaching they provide and the disciplinary structure of the courses" (p. 124). All this could trace its roots to a method of teaching statistics that is focused on formulas, based on tasks with a low cognitive demand, with no reliance on useful tasks, neglecting conceptual understanding and the development of key competencies, such as interpretation and anticipation using statistics (Suh et al., 2020; Vásquez & García-Alonso, 2020). In a way, "teacher improvement can be made if the problems and obstacles experienced by the teacher are known in the learning process. Therefore, the indicator of teacher perceptions of a context is the first step in increasing professionalism to produce quality learning" (Mahlisa & Zubainur, 2021, p. 6).

As for the students, the challenge is bringing about a change in their mindset, which requires "promoting adequate methodological strategies that entail a change of attitude, methodology and conception of the teaching-learning processes that address the socio-environmental and socio-constructivist dimensions" (Carmona-Medeiro & Cardeñoso, 2021, p. 2). Undoubtedly, this could be facilitated by "working with authentic, open, realistic or highly cognitive tasks" (Paredes et al., 2020, p. 3) that connect mathematics to the reality of students.

All of the above indicates the relevance of pre-service teacher training in the area of statistics for ESD, and the need to design regular and quality content around this theme so that the students' advances in the classroom are

in tune with their needs at the global level (Li & Tsai, 2021; Vásquez et al., 2023).

CONCLUSIONS

This systematic review reports on 32 research papers published between 2010 and May 2023 on the integration of sustainability in mathematics education and statistics education, in order to describe “what happens” in this field. This systematic review was guided by the following research questions: What studies have been published on integrating sustainability into mathematics and/or statistics education in pre-school, primary and secondary education? What are the characteristics of these studies? What are their main findings?

Regarding the first research question, from a purely descriptive point of view, this study has shown that the percentages of papers published in Scopus and WoS databases are very similar, with a large predominance of empirical studies written in English, followed by a smaller number of articles in Spanish and no articles in Portuguese. These studies were published mostly in Europe starting in 2020, which shows that this is still a nascent area of research (Alsina, 2022). Similarly, it can be seen that the vast majority of the articles correspond to empirical studies that mainly use a qualitative methodology and focus mainly on the primary education level, whether analyzing the pre-service or in-service training of teachers, their beliefs, analysis of textbooks, analysis of mathematics curricula for this level of education or the design and implementation of classroom experiences. To a lesser extent, there are studies referring to secondary education and very little to early childhood education.

With concern to the second research question, along with these descriptive data, we also analyzed aspects involving the content, considering parameters such as the objectives of the studies, the aspects of sustainability that were addressed and the main findings. This analysis was based on the relevance of ESD to understand and provide solutions to social, environmental and economic crises (Mulà & Tilbury, 2023; Tilbury, 2011), and the need to develop skills and abilities consistent with the concept of sustainable development, so that students can gradually develop a general understanding of the complexity of social systems and their interaction with nature (Pasichnyk et al., 2020).

With this as our starting point, we identified three main research focuses on the papers:

- (a) connections between mathematics education and ESD,
- (b) training of mathematics teachers on sustainability, and
- (c) connections between statistics education and ESD.

On the integration of sustainability in mathematics education, we identified several studies, mainly

theoretical ones, that assume that while mathematics can provide considerable knowledge and many tools to address different contemporary problems and crises, this effort must be combined with other disciplines (Alsina & Mulà, 2019). In this regard, for example, Vásquez et al. (2020) have pointed out that mathematics provides a valuable tool to incorporate sustainable development topics in the classroom, given the current outlook facing humanity, and through it, create awareness of the problems it can address.

From this point of view, Alsina and Mulà (2019) propose that mathematics teachers of the various stages have to be actively involved in developing their students’ sustainability competencies, thus becoming agents of social change. To this end, these authors propose greening a model for the development of mathematical competence such that mathematics and sustainability competences are developed in parallel and can reinforce each other. The second group of papers analyzed investigates, specifically address issues around teacher training on sustainability (Alsina, 2022). These studies assume that in order to integrate sustainability, it is necessary for teachers to promote a holistic, inclusive and transformative education that considers (UNESCO, 2017):

- (a) learning contents and outcomes (integration of sustainability issues into study plans),
- (b) pedagogy and learning environments (learner-focused, action-oriented teaching and learning through interaction and exploratory learning),
- (c) the fruits of learning (promoting competencies such as critical and systemic thinking, joint decision-making, taking responsibility for current and future generations), and
- (d) social transformation (enabling learners of any age and in any educational environment, to transform themselves and the society in which they live).

Undoubtedly, this is a challenge that requires an evolution from teaching to learning to educate current and future generations in sustainability. In this regard, Tilbury (2011) stresses the need to learn to ask critical questions; clarify one’s values, consider more positive and sustainable futures, think systemically; respond through applied learning and study the dialectic of tradition and innovation (p. 8).

Finally, a third group of studies analyzed investigates, more specifically, the connections between statistics education and sustainability, based on the assumption that it is necessary to “assimilate fundamental statistical ideas, such as an understanding of graphs and the development of statistical reasoning for decision-making, in order to interpret, critically evaluate and, where relevant, express opinions regarding statistical information” (Vásquez, 2021, p. 167). These studies assume that teachers are responsible

for involving their students in understanding and, eventually, solving the challenge that we currently face as humanity by developing skills and abilities through mathematics education in general, and statistics in particular. This requires keeping in mind how “teachers with experience in statistical research not only acquire better statistics knowledge but are also more likely to effectively teach their students” (Suh et al., 2020, p. 5), especially because their perceptions about learning in a given context will have a strong impact on the learning outcomes of their students (Mahlisa & Zubainur, 2021). From this point of view, the goal is to replace an approach to teaching statistics focused on the mechanical application of formulas, with an approach that promotes ESD (Vásquez & García-Alonso, 2020).

Thus, from this systematic review it is evident that the integration of ESD in mathematics education and statistics education is an emerging area of research. Nonetheless, this review shows that a considerable body of research contributions dealing with of: the generation of training models and teacher profiles that integrate ESD and mathematics education and statistics education in teacher training; the design and implementation of professional development opportunities; the analysis of beliefs regarding the integration and links between ESD and mathematics education; the analysis of the presence of ESD in the training curricula of teachers who teach mathematics; and the analysis of the level of mastery of sustainability competences in teachers.

Consequently, this systematic review shows what progress has currently been made with regard to research on teaching, learning and training in mathematics and statistical education in relation to ESD. The research analyzed has taken steps towards answering the fundamental question: “how can mathematics education help learners of all ages to respond to sustainable development challenges, to lead healthy and fulfilled lives, to nurture sustainable livelihoods, and to achieve human fulfilment for all?” (Li & Tsai, 2021, p. 8). Despite the progress made so far, the systematic review we conducted has shown that there is still much to inquire involving ESD and mathematics and statistics education. Although “ESD in mathematics education is complex” (Li & Tsai, 2021, p. 8) and “there is no guarantee that ESD-related contents will be implemented in lessons although they are stated in the curriculum document” (Kim & Pang, 2022, p. 12), research indicates that is needed “more research into the integration of ESD into mathematics education will no doubt contribute further to an understanding of this highly complex and demanding area of education” (Mahlisa & Zubainur, 2021, p. 6). To do so, researchers suggest the need to develop “a specific framework to incorporate ESD more systematically in mathematics textbooks”, that includes, on the one hand, the content “extracted and organized in relation to ESD” and, on the other hand, “how the contents will be presented in the

textbooks” (Kim & Pang, 2022, p. 16). About the mathematical content, investigations agree that it is necessary to address diversity of mathematical contents (Paredes et al., 2020; Vásquez et al., 2022).

But, if there is something that most research insists on, it is teacher training and professional development. “The university must be the center for the development of citizens who will lead the planet in the future, and, in the case of future teachers the responsibility is even greater” (Vásquez et al., 2022, p. 17). It is for this reason why the researchers consider it necessary to continue advancing in “to identify the type of teacher education that contributes to changing teaching and learning cultures at schools, and more scholarly work is required to understand how teachers develop ESD competences and use these to create and facilitate learning experiences and processes that lead to change” (Mulà & Tilbury, 2023, p. 12). For what it is convenient to analyze “the characteristics that primary education teachers initial, and ongoing training programs should have in order to move towards ESD in the school classroom” (Su et al., 2022, p. 130). Some research indicates that they should be promoted “training programs focused on creative learning and critical thinking [...] to foster teachers’ development of Realistic mathematics tasks” (Paredes et al., 2020, p. 13), as well as “to train teachers in the development of competencies for sustainability from the reorientation of the teaching of statistics in the school classroom” (Vásquez & García-Alonso, 2020, p. 143).

The results of the systematic review are relevant in the context of the integration of ESD in mathematics and statistics education, and since they provide an expanded and updated perspective of how ESD is being incorporated in different areas linked to early childhood, primary and secondary education levels, such as teacher training, implementation of classroom proposals, curricula and textbooks. Thus, this systematic review identifies the challenges that must be addressed by training programs in the future, such as delving into content areas that promote ESD in mathematics education and statistics education. It also highlights the need for public policies that promote the design of training programs and professional development opportunities for knowledge development around ESD and its links with mathematics education and statistics education, since there are still few studies that provide these guidelines. It is also important to note that although research has so far begun on the integration of ESD and mathematics education in general and statistics education in particular, there is a need to advance in the integration of ESD in the different areas of the mathematics curriculum. As well as statistics and probability, the areas of numbers and operations, geometry, algebra and measurement have much to contribute to the challenge of integrating ESD and mathematics education at different levels of education.

In the future, thus, it will be necessary to design new studies that inquire on experiences implemented in mathematics and/or statistics education classrooms with a focus on ESD. It would also be desirable to characterize mathematics and/or statistics education strategies that help to focus on ESD, as well as those that facilitate development of sustainability skills. Regarding initial and ongoing teacher training, it is necessary to move towards in to introduce, in curricula, development of sustainability competencies and analyze the practices that are carried out in order to properly characterize them. Given that “for education to be an effective vehicle of social change, teacher education becomes invariably indispensable. Holistic approach in ESD should consider how new teachers are being prepared for real-life tasks in school” (Chin et al., 2019, p. 14).

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