Article

Integrating Sustainability in Mathematics Education: An Approach to the Spanish Primary Curriculum

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ABSTRACT

We analyze how sustainability competences are integrated into the current Spanish primary education curriculum, and specifically in the area of Mathematics. Using the qualitative content analysis method, we have analyzed the presence in the curriculum of keywords that are related to terms involving the GreenComp sustainability competences, organized into four areas: (1) embodying sustainability values, (2) embracing complexity in sustainability, (3) envisioning sustainable futures and (4) acting for sustainability. The results show that: (a) sustainability competences are mainly present in the subject of Understanding Nature, Society and Culture, while they are very scarce in Mathematics; (b) the area of sustainability competences most present in the subject of Mathematics is embracing complexity in sustainability, while the least present is embodying sustainability values. Based on the main findings, we conclude that it is necessary to promote an Agency for Action to increase the presence of sustainability competences in the mathematics curriculum.

KEYWORDS: sustainability; education for sustainable development; sustainability competences; GreenComp; mathematics education; primary education

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INTRODUCTION

Since the first international calls on sustainability to address social, environmental and economic crises began to emerge several decades ago [1–4], Education for Sustainable Development (ESD) has been gradually incorporated into all educational stages, from early childhood education to higher education, to promote the development of sustainability skills [5–9].

To establish a strategy as united as possible, UNESCO [8] initially suggested 17 Sustainable Development Goals (SDGs) linked to economic growth, social inclusion and environmental protection. According to this organization, achieving these goals requires a holistic, inclusive and transformative education that considers: (a) learning contents and outcomes (integration 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 competences such as critical and systems 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). In short, this challenge requires an evolution from teaching to learning to educate current and future generations on sustainability.

This paper aims to delve into the first aspect, that is, how sustainability has been integrated into study plans. More specifically, the focus is on the integration of sustainability competence in mathematics education, as this is an emerging research agenda [10,11] that seeks to investigate the guideline established by UNESCO [8] to provide strategies and resources that turn mathematics teachers into agents of social change [12]. More specifically, the main objective of this study is to analyse the presence of sustainability competences in the Spanish primary school curriculum, particularly in the area of mathematics.

To this end, taking as a starting point various preliminary studies that have analyzed how sustainability has been integrated into the curriculum in general [13,14] and, more specifically, into the mathematics curriculum [15,16], the purpose of this paper is to determine how sustainability competences have been integrated into the current primary education mathematics curriculum in Spain. To this end, the GreenComp European sustainability competence framework [6] has been taken as a reference, as it is one of the pillars on which the MEFP [17] itself is based to promote a certain competency model in keeping with the leading supranational recommendations [14]. GreenComp is the actual European reference framework for sustainability competences, providing a common foundation for learners and guidance for educators. It offers a consensual definition of what sustainability as a competence entails, addressing the growing need for people to develop the knowledge, skills, and attitudes necessary to live, work, and act sustainably. Designed to support lifelong learning programs, it is applicable to learners of all ages, education levels, and learning settings, whether formal, non-formal, or informal. Sustainability competences help learners become systemic and critical thinkers, develop agency, and form a knowledge base for everyone concerned about the planet's present and future.

THEORETICAL FRAMEWORK

Considering the goal of this paper, to provide theoretical support for the study, we first present the main advances on the emerging research agenda on Training Mathematics Teachers on Sustainability (TMTS), a term coined by Alsina [11] to encompass research on mathematics research that provides new knowledge about this issue. We then describe the main findings of various preliminary studies that have analyzed the presence of sustainability in the mathematics curricula of various countries [15,16].

Training Mathematics Teachers on Sustainability

Alsina [10,11] notes that, currently, it does not seem to make much sense to train teachers to teach mathematics if doing so does not have any effect on the great challenges and transformations of our day. Therefore, according to this author, both in the initial and ongoing training of mathematics teachers, the necessary knowledge and tools should be provided so that teachers can play an effective role as agents of social change.

This perspective has already begun to generate various research results in recent years. In the journal Avances de Investigación en Educación Matemática (AIEM), for example, a monograph was published that made relevant contributions on the knowledge and beliefs of pre-service and/or in-service teachers in various stages of integrating sustainability into mathematics education. Briefly, Coles [18] responds to UNESCO's call for a new social contract for education in relation to the training of mathematics teachers. To this end, the author sets out four principles on which "socio-ecological" practices in mathematics education should be based: not taking nature as the fixed background of our concerns; avoiding the epistemological error of taking the individual as a unit of learning; questioning what is central to our work; and moving towards a dialogical ethic. Other authors have investigated the development of sustainability competences mobilized by future mathematics teachers. For example, Moreno-Pino et al. [19] have analyzed the development of sustainability competences in 105 pre-service Spanish mathematics teachers from three different university degrees, showing that the scores of pre-service secondary school teachers are significantly lower than those of kindergarten and primary school teachers in all the competences. García-Alonso et al. [20] have analyzed the impact of a training program for pre-service secondary mathematics teachers that promotes the design of mathematical tasks and ESD. Overall, their results show that after the training, all 15 participants improved the level of achievement in all of the skills. Elsewhere, Alsina and Silva-Hormázábal [21] have analyzed the effect of a previously validated training program, designed from a STEAM approach, involving 23 in-service Chilean pre-school and primary education teachers. The results show that, after the training, over half of the participants reached an advanced level in the SDGs covered by the program (SDG 5 on Gender Equality and SDG 13 on Climate Action). Helliwell et al. [22], based on a case study, show how a secondary mathematics teacher embraces contradictions and resorts to multiple forms of knowledge during his transformation process in relation to the teaching of mathematics and climate justice in the context of a small-scale professional development program. Finally, in this same monograph, Vásquez et al. [16] explored the belief system of 11 Chilean primary school teachers who teach statistics and how it relates to sustainability, showing that for them, it is a challenge in terms of both mastering the content and developing skills.

Other recent studies focused on mathematics education have investigated other issues, such as the role of dialogue as a tool to co-construct knowledge around sustainability or student perceptions. Zhang et al. [23], for example, have revealed how mathematics teachers initiate informal interactions based on shared goals, how they meet expectations of the dual role of teaching and educational research, and how they perceive the effects of informal interactions on their teaching practices to advance toward sustainable professional development. Alsina and Vásquez [24] have analyzed how the teaching agency of a group of in-service mathematics teachers is developing on aspects such as knowledge of sustainability and its connection with the SDGs; sustainability practices; the links between mathematics education and sustainability; and obstacles and challenges. The findings reveal that teachers exhibit a significant lack of knowledge about sustainability and its connection with the SDGs, making a unique association with issues related to the environmental crisis, which is the main focus of the sustainability practices carried out in schools. As for the links between mathematics education and sustainability, most accept the importance of this connection, but point to various obstacles and challenges, such as a lack of knowledge and time, the curriculum itself, and others. The authors conclude that it is necessary to design training programs focused on these aspects in order to contribute to the development of the teaching agency, that is, to the appropriation and reconstruction of new resources to deal with the challenges involved in mathematics education for sustainability.

In general terms, all these studies show that the TMTS research agenda is providing relevant data on professional teacher development or teacher interaction, context and practice, topics that until a few years ago were addressed exclusively through research in mathematics education, and which are currently already being studied from an integrated perspective together with the ESD vision. It is hoped that these findings will provide a guide both to design the training of mathematics teachers (initial and permanent) and to design the curricula.

Sustainability and ESD in the Mathematics Curriculum

As noted in the introduction, various preliminary studies have investigated the integration of ESD into the curriculum in general [13,14] and, more specifically, into the mathematics curriculum, which is the focus of this paper [15,16].

Sáiz [14], for example, notes that the Organic Law amending the Education Law (LOMLOE) [25] aims to establish a renewed legal system that increases educational and training opportunities for the entire population, that contributes to improving the educational outcomes of students, and that satisfies the widespread demand in Spanish society for quality education for all. To this end, the law adopts a number of approaches, some of which recognize the importance of ESD and global citizenship. Additionally, this same author provides an analysis on the presence of aspects related to ESD by educational stage, considering that one of the foundations is, as already noted, GreenComp [6], which is why we used it as a reference for our study. The report is from Science for Policy series of the Joint Research Centre (JRC), the European Commission's science and knowledge service, which aims to provide factual scientific support to the Union's policy-making process. This report provides an update to sustainability competences, which are grouped into four areas: (1) embodying sustainability values, (2) embracing complexity in sustainability, (3) envisioning sustainable futures and (4) acting for sustainability.

Guardeño and Monsalve [13] describe how ESD has evolved in the Spanish educational system through laws from 1985 (LODE) [26] to 2020 (LOMLOE) [25], noting that the latter proposes various updates and brings ESD to light for the first time in the school curriculum, thus responding to the problems facing society involving the SDGs. At the same time, these authors also analyze the curriculum of Ireland, noting the longer history of ESD policies and underscoring the addition of specific subjects, in addition to promoting a cross-cutting approach, as is the case in Spain. From this perspective, they point out that:

In the case of "Mathematics", specific competence number 2 notes that the analysis involved in problem solving enhances critical reflection from both a mathematical and a general perspective, valuing aspects related to sustainability, gender equality, responsible consumption, equity and non-discrimination ([13], p. 40-41).

Other authors who have specifically analyzed the presence of ESD-related competences in the mathematics curriculum include, for example, Vásquez et al. [16]. As indicated, these authors analyze the primary education curricula of four Latin American countries, Colombia, Costa Rica, Chile and Mexico, showing that, in general terms, the teaching-learning process of mathematics is poorly aligned with ESD, with a low presence of key competences for sustainability. Based on these data, the authors conclude that these findings represent a roadmap, both for teacher training institutions and to provide a new educational approach that, through mathematics education, can be used to promote student understanding of the different problems (social, economic and environmental), as well as the measures that must be taken to transform and work for a more sustainable world. Recently, Tesfamicael and Enge [15] analyzed the presence of sustainability in the Norwegian mathematics curriculum, noting that although the mathematics curriculum does not explicitly incorporate terms such as "sustainability" or "sustainable development", which could imply that mathematics and sustainability are not connected, its six basic elements—exploration and problem solving, modelling and applications, reasoning and argumentation, representation and communication, abstraction and generalization, and mathematical fields of knowledge—offer opportunities to integrate sustainability learning.

GreenComp: A Framework for Analyzing Sustainability Competences

As stated, this paper relies on the GreenComp report [6], regarded as one of the foundations of sustainability [14], as a framework for analyzing sustainability competences in the Spanish primary education curriculum. Table 1 shows the two main elements of the framework (scopes and competences) and provides a description of each competency.

Table 1. Adaptation of the European GreenComp framework of sustainability competences.

Area	Competence	Description
Embodying sustainability values	Valuing sustainability	It implies reflecting on personal values and their cultural variability, connecting them to sustainability. It encourages the clear expression of one's own values and critical reflection on thoughts, plans and actions. The goal is to raise awareness of the diversity of values and their relevance in ethical and sustainable decision-making.
	Supporting fairness	It involves supporting equity and justice for current and future generations, learning from past experiences to promote sustainability. It recognizes the interconnection between environmental quality, equity and justice, fostering accountability in collaborative activities and respect for different points of view.
	Promoting nature	It involves recognizing the interdependence between humans and nature, promoting respect and empathy towards other species. It includes knowledge of the components of the natural environment and fosters contact and connection with nature to cultivate a healthy relationship and a sense of personal connection.
Embracing complexity in sustainability	Systems thinking	It involves addressing sustainability issues by considering multiple perspectives and contexts. It facilitates an understanding of the interaction between elements within and between systems, in different scales and subject areas. It serves as a tool for evaluating options, making decisions and intervening, recognizing that parts of a system can behave differently when separated from it.
	Critical thinking	It involves critically evaluating information and arguments, identifying assumptions, and questioning the status quo. It includes reflection on how personal, social and cultural contexts influence thinking, especially in relation to sustainability. It empowers learners to be responsible and cooperative in creating a sustainable world.
	Problem framing	It involves formulating challenges as sustainability issues, considering their difficulty, people, time and place. It focuses on identifying approaches to prevent, mitigate or adapt to existing problems, assessing their complexity and key components and defining measures to address them.

Table 1. *Cont.*

Area	Competence	Description
Envisioning sustainable futures	Futures literacy	It involves planning for sustainable futures, developing alternative scenarios and identifying actions to achieve them. It requires imagination, creativity, and assessing the necessary steps. It involves training to face the challenges of the 21st century, addressing sustainability. Individuals have to visualize different future perspectives and design strategies to achieve a desirable future.
	Adaptability	It involves promoting the ability to manage transitions and challenges in complex sustainability situations, making decisions in the face of uncertainty and ambiguity, while considering risk. Adaptability requires flexibility to adjust to changes. It empowers us to face sustainable commitments, weigh options and make decisions, even in the face of contradictions and future risks.
	Exploratory thinking	It involves adopting relational thinking by linking various disciplines, using creativity and experimentation with innovative methods. It fosters creativity to plan alternative futures, requiring cognitive processes and the use of intuition, and it contributes to the development of creative thinking.
Acting for sustainability	Political agency	It involves navigating the political system, identifying responsibility and accountability for unsustainable behavior, and demanding effective policies for sustainability. It empowers us to positively influence the collective future, mobilizing us at the political level and promoting institutional and market changes towards sustainability.
	Collective action	It involves promoting the ability to act collaboratively with other agents to promote change. This requires coordination, collaboration and cooperation among peers. Working together towards a common goal facilitates the achievement of meaningful results for change.
	Individual initiative	It involves identifying one's potential for sustainability, recognizing what actions can be taken. It is related to the desire to act, and it promotes an entrepreneurial mindset, empowering people to take the initiative in their lives and improve community and global perspectives.

METHODOLOGY

In keeping with the goal of our study, which, as indicated, consists of determining how sustainability skills have been integrated into the current primary school mathematics curriculum in Spain, we have adopted a descriptive qualitative approach [27]. We relied on the content analysis method through the use of syntactic units as a research technique [28].

Sample and Procedure

The curricular document analyzed is Royal Decree 157/2022 [17], which lays out the organization and minimum teaching content of primary education in Spain. In this document, for each area of knowledge of primary education (Understanding Nature, Society and Culture, Art Education, Physical Education, Education on Civic and Ethical Values, Spanish Language and Literature, Foreign Language, Mathematics and Religion), specific competences and basic knowledge are defined for the different cycles: first cycle (ages 6 to 8); second cycle (ages 8 to 10); third cycle (ages 10 to 12).

The following phases were considered over the course of our research:

1. Establish the syntactic units through a set of exclusionary keywords that are related to the terms related to sustainability and terms associated with the four areas of competence of the GreenComp described in Table 1. To select these keywords, the following were considered:

a) Propose an initial list of keywords related to the topics addressed. Keywords were selected from the description given in the GreenComp document for each of the 12 competencies. The criteria established for this selection were a maximum of 10 words for each competency and a minimum of 5 excluding synonyms.

b) Review of the keywords by three European experts in the field of ESD.

c) Analyze the curriculum to ensure consistency between it and the keywords. After the review with the experts, some key words were eliminated since they did not correspond to the meaning from the sustainability field. For example, the word “complexity” in the mathematics curriculum has the meaning of “higher difficulty” while from sustainability it means “more relationships between elements”.

d) Iincorporate some keywords that were not considered in the first list and involve the topic in question. The experts recommended revising the list of words to add synonyms to the selected terms. For example, initially only the keyword “system thinking” was chosen, but at this stage other terms such as “systematic perspective” were added.

The final list of words, which constitute the syntactic units used, is shown in Figure 1.

2. In-depth analysis of Royal Decree 157/2022.
3. Identify in the document the keywords established in phase 1.
4. Analyze the context in which these keywords are used in the document and the meaning of the sustainability competences that are evidenced in the area of primary education mathematics.
5. Provide evidence for the descriptive analysis by selecting written extracts that exhibit the keywords.

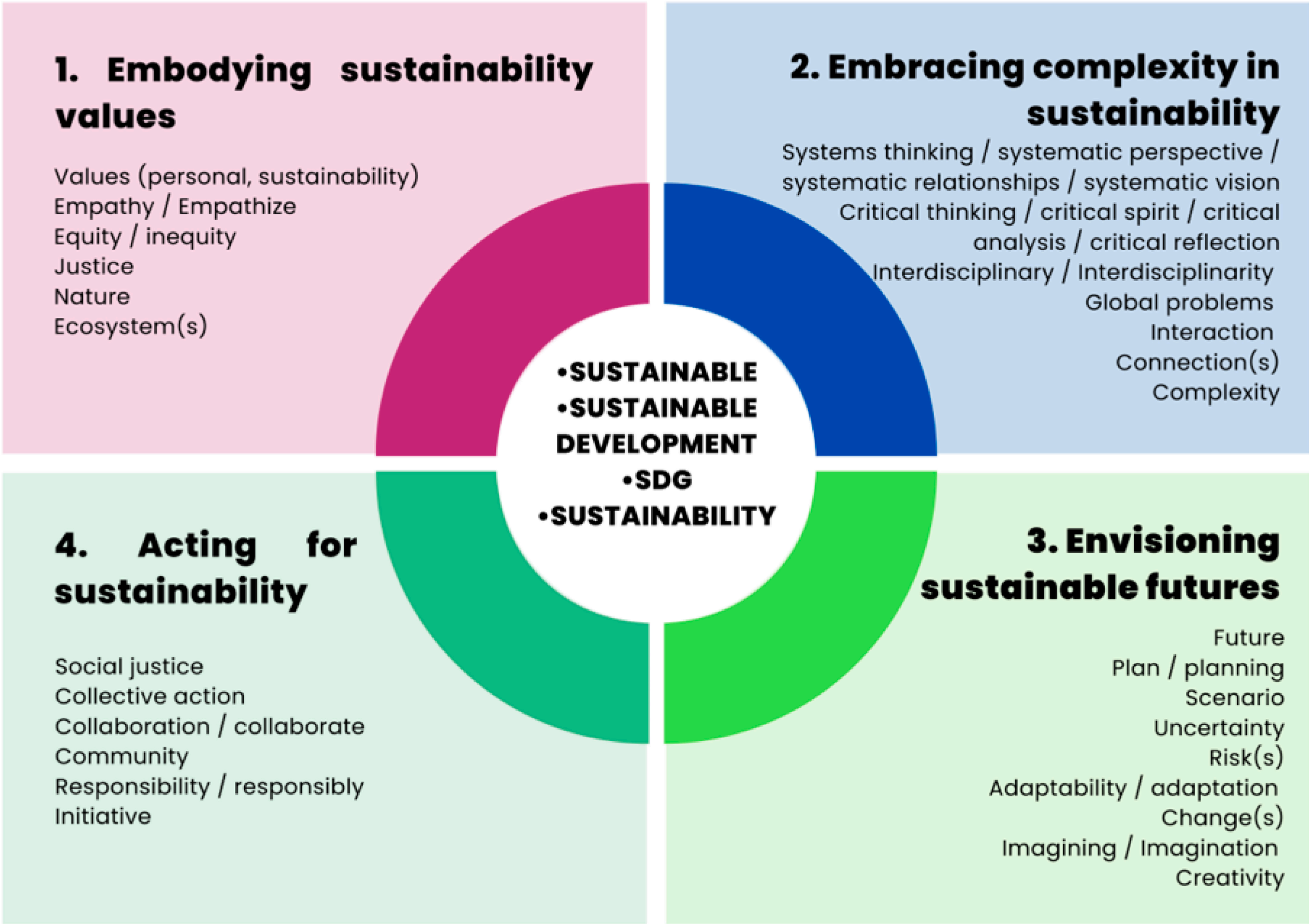

Figure 1. Syntactic units used in the coding process.

Data Analysis

The data analysis considered the coding of the syntax unit, with scores assigned based on presence (1) or absence (0). These encodings were recorded in an MS Excel® spreadsheet to subsequently analyze the contexts in which they are used in Royal Decree 157/2022 [17].

To ensure the reliability of the coding process, the authors conducted joint coding sessions.

RESULTS

In keeping with the goal of our study, we first analyzed the presence of sustainability competences in the curriculum to obtain an initial overview of their presence in the different areas. We then focused our analysis on the area of Mathematics.

Sustainability in the Spanish Primary Education Curriculum

The new law, as indicated in the theoretical framework [13,14], incorporates ESD at every stage of compulsory education. The contents to be presented in the classroom cover concepts such as education for peace and human rights, international understanding and intercultural education, and education for the ecological transition.

First of all, it should be noted that one of the pedagogical principles of the curriculum states that in all areas, “equality between men and women, education for peace, education for responsible consumption and sustainable development, and education for health, including affective-sexual health, will be promoted” [17].

Secondly, Annex I of the Spanish curriculum show the exit profile of students at the end of basic education, a tool that specifies the principles and purposes of the Spanish educational system for this period, and where the key competences that students are expected to have developed upon completing this phase of their training itinerary are defined. This profile includes “the Sustainable Development Goals of the 2030 Agenda adopted by the United Nations General Assembly in September 2015” [17]. In fact, there are references to both sustainability and education on sustainability in five of the eight key competences included in the exit profile: Competence in mathematics and science, technology and engineering; Digital competence; Personal, social and learning to learn competence; Citizenship competence; Entrepreneurial competence. For example, “Mathematical competence and competence in science, technology, and engineering (STEM) involves understanding the world using scientific methods, mathematical thinking and representation, technology, and engineering methods to transform the environment in committed, responsible, and sustainable ways” [17].

By way of summary, Table 2 shows the frequency of sustainability-related terms that were identified in the Spanish curriculum.

Table 2. Distribution of terms related to sustainability in the Spanish primary education curriculum.

Term	***f***
Sustainable	66
Sustainability	13
Sustainable Development	9
SDG	12

In addition to incorporating sustainability across the key competences, it also incorporates ESD in all areas through the specific competences and basic knowledge.

Table 3 shows the terms related to sustainability present in each of the areas of primary education.

Table 3. Distribution of terms related to sustainability in the areas of primary education.

Area	Sustainable	Sustainability	Sustainable development	SDG	Total
Understanding nature, society and culture	37	1	3	4	45
Art education	1	0	0	0	1
Physical education	13	2	0	1	16
Civics and ethics	12	1	3	2	18
Spanish language and literature	4	1	0	0	5
Foreign language	1	2	0	1	4
Mathematics	0	0	0	1	1

Table 3 shows that, although references are found in every area, the primary education curriculum mainly integrates sustainability into the subjects of Understanding Nature, Society and Culture, Physical Education and Civics and Ethics. In Mathematics, only one reference was identified:

Of particular interest at present are elements related to data and information management and computational thinking, which provide effective tools to face the new scenario posed by the challenges of the 21st century. In this sense, mathematics plays an essential role in response to the current social and environmental challenges that students will have to face in their future, as an instrument to analyze and better understand the local and global environment, social, economic, scientific and environmental problems, and to evaluate viable ways of solving them, thus contributing directly to the Sustainable Development Goals proposed by the United Nations ([17], p. 92).

Sustainability Competences in the Area of Mathematics of the Spanish Primary Education Curriculum

As indicated earlier, we have identified the presence of the terms related to the sustainability competences defined in GreenComp (Figure 1) throughout the curriculum, and in the area of Mathematics (Table 4).

Table 4. Distribution of terms related to sustainability competences.

GreenComp Area	Term	All the curriculum *f*	Mathematics area *f*
1. Embodying sustainability values	Values (personal, sustainability)	54	1
	Empathy/Empathize	29	1
	Equity/Inequity	6	0
	Justice	9	0
	Nature	19	0
	Ecosystem(s)	7	0
	TOTAL	**124**	**2**

Table 4. *Cont.*

GreenComp Area	Term	All the curriculum *f*	Mathematics area *f*
2. Embracing complexity in sustainability	Systems thinking/systematic perspective/systematic relationships/systematic vision	7	0
	Critical thinking/critical spirit/critical analysis/critical reflection	38	8
	Interaction	49	1
	Connection(s)	22	15
	Interdisciplinary/Interdisciplinarity	13	2
	Complexity	0	0
	Global problems	1	0
	TOTAL	**130**	**26**
3. Envisioning sustainable futures	Future	10	5
	Plan/planning	0	0
	Scenario	1	1
	Uncertainty	18	7
	Risk(s)	18	1
	Adaptability/adaptation	6	1
	Change(s)	20	1
	Imagining/imagination	2	0
	Creativity	23	1
	TOTAL	**98**	**17**
4. Acting for sustainability	Social justice	2	0
	Collective action	0	0
	Collaboration/collaborate	18	1
	Community	29	0
	Responsibility/responsibly	36	6
	Initiative	9	3
	TOTAL	**94**	**10**

The data in Table 4 show that the competences in the field of acting for sustainability are the least present in the Spanish primary education curriculum. In the area of Mathematics, the scarce (or almost zero) presence of terms related to the field of embodying sustainability values is striking, while the field with the greatest presence in both the entire Spanish primary education curriculum and in the area of mathematics is related to embracing complexity in sustainability.

Analysis of the Content of the Terms of Sustainability Competence in the Area of Mathematics

Below, we present an example of a math curriculum excerpt that showcases each of the terms that have been related to the GreenComp sustainability competences.

Embodying sustainability values

Table 5 shows some fragments of the primary curriculum corresponding to the area of Mathematics related to the competences in the field of "embodying sustainability values".

Table 5. Examples of fragments of the mathematics curriculum related to the fields "Embodying sustainability values" in the area of primary mathematics.

Term	**Fragments**
Values (personal, sustainability)	"The goal of this specific competence is for students to work on the values of respect, equality and peaceful conflict resolution, while solving the mathematical challenges proposed, developing skills of effective communication, planning, inquiry, motivation and trust, in order to create healthy relationships and work environments, for example, through participation in diverse teams with assigned roles. This allows building healthy, supportive and committed relationships, strengthening self-confidence and normalizing situations of coexistence in equality" ([17], p. 105)
Empathy/ Empathize	"Active, respectful and responsible teamwork, showing initiative, communicating effectively, valuing diversity, showing empathy and establishing healthy relationships based on respect, equality and peaceful conflict resolution" ([17], p. 113)

The terms "values" and "empathy", which are only found once each in the mathematics curriculum, are related to the supporting fairness competence. The values promoted are respect, equality and peaceful conflict resolution, which contribute to the support of equity and justice for current and future generations. There are no terms related to the other competences in this field.

Embracing complexity in sustainability

Table 6 shows some fragments of the primary curriculum corresponding to the area of Mathematics related to the competences involved in embracing complexity in sustainability.

Table 6. Examples of fragments of the mathematics curriculum involving "Embracing complexity in sustainability".

Term	Fragments
Critical thinking/critical spirit/critical analysis/critical reflection	"Ensuring the validity of the solutions requires reasoning about the process followed and evaluating them in terms of their mathematical correctness. However, critical reflection must also be encouraged regarding the adequacy of the solutions to the proposed context, and the implications they would have from various points of view (responsible consumption, health, environment, etc.)" ([17], p.103)
Interaction	"Active participation in teamwork: positive interaction and respect for the work of others" ([17], p. 108)
Connection	"Knowing a variety of strategies makes it possible to confidently deal with challenges and it facilitates engagement Recognizing the connection between mathematics and other areas, with real life or with one's own experience, increases the mathematical toolkit of students. It is important that students have the opportunity to experience mathematics in different contexts (personal, school, social, scientific, humanistic and environmental) to become accustomed to identifying mathematical aspects in multiple situations" ([17], p. 104)
Interdisciplinary/ Interdisciplinarity	"Learning situations facilitate interdisciplinarity and promote reflection, criticism, the elaboration of hypotheses and the research task" ([17], p.102)

The terms "interaction", "connections" and "interdisciplinarity" in the area of Mathematics relate to the competence of systems thinking. The curriculum acknowledges that connections between different mathematical ideas, as well as identifying the mathematics involved in other areas of everyday life, contributes to interpreting diverse situations and contexts, providing a global and interrelated view of the world. Such a vision helps us understand that mathematical ideas are not isolated elements, but are rather related with one another, giving rise to a whole.

The terms "critical thinking" and other related terms of the mathematics curriculum are associated with the critical thinking competence. On the one hand, it encourages observation and reflection in the understanding of random phenomena in everyday situations; on the other, it promotes analysis and adaptation of solutions to the proposed context and the implications they would have from various points of view. There are no terms related to the sustainability competence of problem framing.

Envisioning sustainable futures

Table 7 shows some fragments of the primary curriculum corresponding to the area of Mathematics related to the competences involving envisioning sustainable futures.

Table 7. Examples of fragments of the mathematics curriculum related to "Envisioning sustainable futures".

Term	Fragments
Future	"Mathematics plays an essential role in response to the current social and environmental challenges that students will have to face in their future, as an instrument to analyze and better understand the local and global environment, social, economic, scientific and environmental problems, and to evaluate viable ways of solving them, thus contributing directly to the Sustainable Development Goals proposed by the United Nations" ([17], p. 100)
Scenario	"In addition, of particular interest at present are elements related to data and information management and computational thinking, which provide effective tools to face the new scenario posed by the challenges of the 21st century" ([17], p. 100)
Uncertainty	"Probability as a subjective measure of uncertainty. Recognition of uncertainty in everyday situations and by conducting experiments" ([17], p.112)
Risk	"The choice of strategy and its periodic review during problem-solving involves making decisions, anticipating the response, following established guidelines, taking risks and transforming an error into a learning opportunity" ([17], p.103)
Adaptability/ Adaptation	"Cognitive flexibility, adaptation and change of strategy if necessary. Assessment of an error as a learning opportunity" ([17], p.116)
Change	"Cognitive flexibility, adaptation and change of strategy if necessary. Assessment of an error as a learning opportunity" ([17], p.116)
Creativity	"Mathematics integrates characteristics such as the mastery of space, time, proportion, resource optimization, analysis of uncertainty, and the use of digital technology; and promotes reasoning, argumentation, communication, perseverance, decision making and creativity" ([17], p. 100)

The term "scenario" is related to the futures literacy competence in order to contribute to the ability to anticipate alternative scenarios, face the challenges of the 21st century and achieve more sustainable futures.

In relation to the adaptability competence, the terms "uncertainty", "risk", "adaptation" and "change" have been identified within the mathematics curriculum. All of them contribute to the development of personal skills that help adapt to new situations, take risks and accept error or changes as part of the learning process, and adapt to situations of uncertainty in everyday situations.

Finally, on the subject of exploratory thinking, the term "future" was identified more frequently, and "creativity" only once. Of note is the presence of computational thinking in the mathematics curriculum as one of the key skills in the future of students, with abstraction being necessary to identify the most relevant aspects, and decomposition into simpler tasks to arrive at possible solutions. Bringing computational thinking into daily life involves relating the fundamental aspects of computing to the needs of students. This way, they are prepared for a future that will likely be more technological, improving their intellectual abilities and making use of abstractions to solve complex problems.

Acting for sustainability

Table 8 shows some fragments of the primary curriculum corresponding to the area of Mathematics related to the competences in the field of acting for sustainability.

Table 8. Examples of fragments of the mathematics curriculum related to the fields "Acting for sustainability".

Term(s)	**Fragments**
Collaboration/ collaborate	"Collaborate in the distribution of tasks, assuming and respecting the individual responsibilities assigned and using simple teamwork strategies aimed at achieving shared goals" ([17], p. 113)
Responsibility/ responsibly	"Collaborate in the distribution of tasks, assuming and respecting the individual responsibilities assigned and using simple teamwork strategies aimed at achieving shared goals" ([17], p. 113)
Initiative	"Active, respectful and responsible teamwork, showing initiative, communicating effectively, valuing diversity, showing empathy and establishing healthy relationships based on respect, equality and peaceful conflict resolution" ([17], p.113)

The terms related to the field acting for sustainability that are found in the mathematics curriculum are related to the competences of collective action and individual initiative, but none in relation to the political agency competence.

On the one hand, the terms "collaborate", "responsibility" and "responsibly" contribute to collective action by fostering coordination, collaboration and cooperation among peers to solve problems more effectively. On the other, whenever the term "initiative" is found in the mathematics curriculum, it is in relation to individual initiative, sensing one's own potential and showing initiative to seek solutions or strategies to the problems posed.

DISCUSSION AND CONCLUSIONS

This paper has analyzed how sustainability and sustainability competences are integrated into the current Spanish primary education curriculum [17] and, more specifically, into the area of Mathematics. On the one hand, this analysis reflects the fact that, in recent decades, there has been a growing interest in integrating sustainability into all the curricular subjects at different educational levels, as a government response to the need to address social, environmental and economic crises through educational policies [1–4], and thus promote the development of sustainability skills in the public [5–9]. On the other hand, the field of research in mathematics education has been approached for some years based on the TMTS research agenda, which assumes that, in the current context, mathematics teachers should have the knowledge and tools needed to play an effective role as agents of social change [10,11].

It is from this dual perspective that we have analyzed how the Spanish primary mathematics curriculum is integrating sustainability competences, since the curriculum is (or should be) a frame of reference that guides the teaching activity of teachers. To carry out the analysis, we used the GreenComp report [6] as a reference. This is one of the foundations of the Spanish curriculum, by relying on the mainstreaming of sustainability in all areas and educational stages [14].

From this analytical perspective, the first relevant finding is that, in the current Spanish primary education curriculum, sustainability is promoted mainly in the subject of Understanding Nature, Society and Culture. Specifically, a total of 45 references to the syntactic units used in the study relating to sustainability have been identified in this curriculum, while in the area of Mathematics, only one such reference was identified. This fact demonstrates, on the one hand, a clear mismatch between the leading international guidelines on the presence of sustainability in the curriculum [4–8], which advocate for its presence in all areas; and, on the other hand, also some discrepancy with the guidelines of the Spanish curriculum itself on ESD, since the preamble of the LOMLOE indicates that:

“Education for sustainable development and global citizenship must be embedded in the educational plans and programs of all compulsory education, incorporating the knowledge, skills, values and attitudes that all people need to live a fruitful life, make informed decisions and play an active role—both locally and globally—when addressing and solving the problems common to all citizens of the world” ([25], p. 122871).

Although the curriculum indicates that ESD must be present in all educational plans and programs of compulsory education, the analysis carried out shows that in some areas, such as Mathematics, this presence is anecdotal, which matches the findings in curricula from countries such as Colombia, Costa Rica, Chile and Mexico [16].

A second representative finding is that, in an effort to try to comprehensively identify how the GreenComp sustainability competences are integrated [6] into the subject of Mathematics, we have identified embracing complexity in sustainability as the most present area of the sustainability competences, with the most recurrent terms being associated with “critical thinking” and “connections”. This result is not surprising, since, on the one hand, the Spanish curriculum has a specific mathematical competence on “solving problem situations”, which seeks to, among other purposes, promote “critical reflection on the adequacy of the solutions to the proposed context and the implications they would have from various points of view (responsible consumption, health, environment, etc.)” [17]. On the other hand, there is another specific competence on “recognizing and using connections between different mathematical ideas, as well as identifying the mathematics involved in other areas or in everyday life” ([17], p. 104). By contrast, the least present field is embodying sustainability values, which is surprising, especially if we take into account that in the new mathematics curriculum, specific competences of a socio-affective nature have been added, which describe the skills to be achieved personally, emotionally, and socially. However, these competences focus mainly on helping to identify and manage emotions when confronted with mathematical challenges and building a positive identity as a mathematics student, but they do not sufficiently consider other issues such as the role that mathematics plays in solving problems beyond mathematics; that is, they omit the relevance of its social value [29].

The third and final finding of our study is that, when conducting an even more in-depth analysis of the integration of the 12 GreenComp sustainability competences in the area of Mathematics, we determined that, from the sum of frequencies of all the terms related to each competence, eight of them are represented. Those that are most represented are systems thinking, critical thinking and adaptability; those that are represented less are supporting fairness and futures literacy; and, finally, those that are not represented are valuing sustainability, promoting nature, problem framing and political agency.

In light of these findings, on the one hand, we conclude that the area of Mathematics can contribute to the development of some sustainability skills, due to the very nature of mathematical skills, in line with the data from [15] based on their analysis of the Norwegian mathematics curriculum. Thus, there is a practically natural relationship between learning mathematics and sustainability skills related to critical thinking, systems thinking and the ability to establish connections, both between knowledge in the area of mathematics, but also in relation to other areas of knowledge. Similarly, the skills needed to solve mathematical challenges allow adaptability, a key competence within the ESD framework, to be developed simultaneously. In this way, we want to explain and reinforce the existing relationship between the development of mathematical competences and sustainability competences, and also establish the need to design new studies that analyze these relationships more thoroughly so as to provide the educational community with tools that allow this link to be reinforced.

The study also exhibits certain deficiencies, specifically in terms of values and their connection with action: although we identified the presence of terms related to the sustainability competences of both areas (values and action), these are scarce or appear with meanings different from those attributed from the ESD framework. Thus, sustainability appears as a pretext to solve certain mathematical questions. It is presented as context, a backdrop against which to solve a challenge, but the values themselves are not discussed in depth, nor is the students' ability to propose or carry out actions that contribute to the development of sustainability reinforced. It is in this sense that it is necessary to lay out guidelines that allow the establishment of an Agenda for Action, i.e., a set of previously planned actions aimed at promoting a greater presence of these sustainability competences in the mathematics curriculum of all educational stages, since the decisions of the present will determine the future.

This study has some limitations that should be acknowledged. Firstly, the analysis is confined to the Spanish primary school curriculum, limiting the generalizability of the findings to other educational contexts. Future research could expand this scope by comparing the presence of sustainability competences in primary school curricula from different countries, providing a broader perspective on how sustainability is integrated globally. Additionally, while this study focuses on the curricular presence of sustainability competences, further research could delve into practical applications by offering detailed examples and pedagogical strategies for effectively teaching these competences within the mathematics classroom. Such examples would provide valuable insights for educators seeking to incorporate sustainability into their mathematics teaching practices.

DATA AVAILABILITY

All data generated from the study are available in the manuscript.

AUTHORS' CONTRIBUTIONS

AA and PL designed the study. AA and MG developed the theoretical framework. NP was in charge of the methodology. PL and MG analyzed the data and wrote the paper with input from all authors.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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