education sciences

Communication

Revitalizing Sustainability in Mathematics Education: The Case of the New Norwegian Curriculum

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Abstract: This paper aims to discuss the revitalization of education for sustainable development (ESD) in mathematics education, particularly in relation to mathematics curricula for grades 1–10, using the example of the new Norwegian curriculum, LK20, which came into effect at the beginning of the 2020 school year. Several studies in the past two decades have identified disengagement of sustainability learning (SL) within mathematics education and called for a change in the philosophy of mathematics education to integrate sustainability into the teaching and learning of mathematics. Using the qualitative content analysis method, we examined three types of documents: the core curriculum, the mathematics curriculum, and one Norwegian mathematics textbook series called Matemagisk. We find that sustainable development (SD) is one of the interdisciplinary issues addressed in LK20. Even though the mathematics curriculum does not explicitly incorporate terms such as 'sustainability' or 'sustainable development', indicating that mathematics and sustainability are unconnected, its six core elements—exploration and problem-solving, modeling and applications, reasoning and argumentation, representation and communication, abstraction and generalization, and mathematical fields of knowledge—provide opportunities for integrating sustainability learning (SL). On the other hand, looking at one of the mathematics textbook series, Matemagisk, for grades 4, 7, and 10, it appears that tasks that use sustainability contexts were included implicitly or explicitly, indicating another opportunity to facilitate sustainable learning. By including sustainability contexts in tasks and mathematical activities, it is possible to boost the process of embedding ESD in mathematics education without compromising content.

Keywords: sustainability; sustainability learning; education for sustainable development; curriculum; mathematics education; mathematics curriculum

Citation: Tesfamicael, S.A.; Enge, O. Revitalizing Sustainability in Mathematics Education: The Case of the New Norwegian Curriculum. *Educ. Sci.* **2024**, *14*, 174. https://doi.org/10.3390/educsci14020174

Academic Editor: Eila Jeronen

Received: 3 January 2024
Revised: 1 February 2024
Accepted: 5 February 2024
Published: 7 February 2024

1. Introduction

In this age, humankind is engaged in enormous economic development and competition, which has affected the ecological system in a way that could expose future generations to extinction [1,2]. Since the development trends are not sustainable, "many experts on environmental issues have called for changes in human behavior towards ways of living that are ecologically, economically, socially, culturally, and personally more sustainable" [3]. In September 2002, at the Johannesburg Earth Summit, education for sustainability or sustainable development was suggested to be integrated into the mainstream curriculum in order to prepare students for the needs of the Earth in the twenty-first century [4]. Later that year, in December 2002, the United Nations General Assembly declared the years 2005–2014 as a Decade of Education for Sustainable Development (DESD) [5].

What is sustainability or sustainable development? The widely used definition of the term reads, "Sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [6]. It depends on the interrelationships between four systems, called the "pillars" of sustainability: ecological, economic, social, and political systems [3]. According to UNESCO, education for sustainable development (ESD) empowers "learners of all ages with the knowledge, skills, values, and agency to address interconnected global challenges including climate change, loss of biodiversity, unsustainable use of resources, and inequality. ESD empowers learners of all ages to make informed decisions and take individual and collective action to change society and care for the planet" [7], and it is part of an integral part of the sustainable developmental goals (SDGs) [8–10]. Through education, future orientation is possible [11]. According to [2], ESD implementation demands several things, including redesigning policies, curricula, pedagogy, and educational training. Adapting and integrating ESD into education systems is seen as one aspect of boosting quality education, and whole institution approaches (WIA) to sustainability are recommended by various studies [1,3,7,12]. However, "the consistent transfer of ESD into learning environments through whole system approaches within specific educational organizations remains a considerable challenge" [2].

In general, across curriculums of various education systems, sustainability is considered to be a cross-cutting or cross-curriculum issue, and it is handled across several disciplines, including mathematics [3,12]. In this communication, we focus on how sustainability is embedded in the new Norwegian curriculum for primary schools (grades 1–10). Particularly, we are interested in looking at the opportunities to revitalize ESD in mathematics education since ecological sustainability and mathematics education remain unconnected, in general, across education systems [1,4,11–19]. Therefore, the questions shaping this study are as follows:

i. What does the Norwegian curriculum for grades 1–10 say about sustainability?
ii. How does the mathematics curriculum deal with the topic of sustainability?
iii. What could be done further in this regard so that ESD is embedded in the teaching and learning of mathematics?

Hence, the current status of the relationship between sustainability and mathematics education, as well as the conceptualization and realization of ESD in mathematics curriculum, are discussed first.

2. Literature Review—Sparse and Smart

In this section, we provide a sparse but smart literature review on how sustainability is embedded in mathematics education. It is sparse because we have selected only a few articles to represent recent research and positions on the theme among mathematicians. This approach is effective in avoiding redundancy. It is smart since we have utilized AI-powered search engines such as Elicit (https://elicit.com/?workflow=table-of-papers accessed on 2 December 2023) and ResearchRabbit (https://www.researchrabbit.ai/ accessed on 2 December 2023), in addition to the usual search engines like Google Scholar and ERIC, to map out the interconnectedness of these studies. When using Elicit for searching, this versatile tool provides an intelligent literature review and a summary of four papers highly correlated with the search phrases or words. We searched for "sustainability in mathematics education" and "sustainability and mathematics education curriculum". In both cases, ref. [12] was among the selected four articles. Additionally, Elicit offered a list of many other related articles. On the other hand, ResearchRabbit, an innovative "citation-based literature mapping tool", allows users to visualize the network of literature related to the selected article(s) quickly, including other authors and timelines, among other features. It assisted us in selecting the articles.

Further, three articles have been selected to explore how sustainability is incorporated into the teaching and learning of mathematics [4,12,15]. These articles span two decades, reflecting the period during which the cross-cutting issue of ESD has gained importance worldwide. We believe that these articles capture the essence of the matter discussed in this study. We have chosen these articles not only for their representation of different time periods but also because they address the same concern that sustainability is not yet integrated into mathematics curricula globally. Furthermore, we have found the frameworks and recommendations presented in these articles highly relevant for revitalizing sustainability or sustainable development in mathematics education not only in Norway but also beyond.

The main aspects of these articles that will be utilized in this communication are presented in the following order.

2.1. Petocz & Reid [4]: What on Earth Is Sustainability in Mathematics?

Even the title is telling. It captures the appealing nature of sustainability and the curiosity of mathematicians and mathematics educators "to incorporate the notion of sustainability into mathematics courses without compromising the mathematics content" [4] (p. 141). The researchers conducted a phenomenology study by interviewing university academics involved at a postgraduate level about their courses and sustainability. The rationale for engaging with individual academics is that institutional policy is implemented by individuals who dare to incorporate the ideas of sustainability and sustainable development to help their students grasp the issue well. Their findings were discussed using two different dimensions, each with three qualitative conception levels. The first deals with the teaching practice of academics in relation to sustainability: disparate, overlapping, and integrated. The first conception claims the two are unrelated ideas; the second considers the overlap, while the third emphasizes that the notion of sustainability is an essential (integral) component of the teaching and learning of mathematics. The other dimension deals with the ideas or thinking of the academics, with three different qualitative conceptions: distance, resource, and justice. In short, these can be summarized as follows: using the dictionary definition of the word and keeping sustainability at a distance; approaching it using various resources like material, biological, and human; or conceptualizing it by focusing on the notion of "fairness" in the context of within and beyond a generation.

Furthermore, Petocz and Reid used the results of another study that investigated undergraduate mathematics students' conceptions of mathematics, finding a range of views from the narrowest and most limiting to the broadest and most holistic: components, models, and life [4]. Some students view mathematics as a subject made up of different individual components, others view the subject as building and using models, while others view mathematics as an approach to life and a way of thinking. Based on this, Petocz and Reid argued that the integration of sustainability in mathematics education depends on academics' conceptualization of sustainability and students' perception of mathematics [4]. The broader and more holistic conceptions and views provide opportunities to engage with sustainability, while the narrow and limiting conceptions and views minimize or avoid engagement with ESD in general.

2.2. Renert [15]: Mathematics for Life—Sustainable Mathematics Education

Renert recognized the large-scale ecological problem humans face and added ecology as one aspect in addition to social, cultural, and cognition in mathematics education. Eight years after the article by [4], Renert expressed the disconnect between mathematicians and mathematics educators regarding the issue of ecological sustainability [15]. He reflects that the sustainability issue did not receive enough attention in mathematics education research as well as in mathematics curricula. He attributed this to the legacy of the Platonism philosophical position of mathematics, which perceives mathematics as "a pure body of knowledge independent of the environment and value-free" [15] (p. 20). He built upon the ideas of social constructivist and critical mathematics education, which added social, cultural, and political dimensions to the teaching and learning of mathematics [20,21] and argued for the inclusion of environmental issues such as climate change. He believed that integrating the environmental issue into the mathematics classroom discourse is more genuine to reality than abandoning it.

Renert adapted two-stage models by Sterling [22] and Edwards [23] to anticipate responses to sustainability in mathematics education. Only Sterling's model of educational response to sustainability is presented here since the two overlap. Sterling's model of educational response to sustainability has three stages: accommodation, reformation, and transformation. The accommodation stage refers to education about sustainability. It assumes that knowledge about sustainability is uncontested and can be codified and transmitted. The reformation stage deals with education for sustainability. It involves some reformation of the existing paradigm but leaves it essentially intact. The final stage, transformation, takes education as sustainability. It involves transformative epistemic learning response by the educational paradigm. Furthermore, Renert took two examples, large numbers and chaos, to shed light on these three-stage models so that mathematicians and mathematics educators can learn to integrate sustainable mathematics education in mathematics classrooms. According to [15], "sustainable mathematics education is the project of reorienting mathematics education towards environmentally conscious thinking and sustainable practices" (p. 24).

2.3. Li & Tsai [12]: Education for Sustainable Development (ESD) in Mathematics Education: What Could It Look Like?

Exactly one decade after Renert's [15] communication and about two decades since Petocz and Reid's [4] recommendations on integrating ESD in mathematics education, Li and Tsai [12] (p. 1) have confirmed that "sustainability and mathematics education remain largely unconnected in actual classrooms". They [12] (p. 2) reported that ESD-related studies "for teachers of mathematics in particular, and for mathematics education in general, are small and disproportionate to the number of studies" in the context of ecological problems and solutions. They call for a rethinking and re-envisioning of the teaching and learning of mathematics for the 21st century by challenging the traditional boundaries of the philosophy of mathematics. The authors acknowledge the paradigm shift from drill theory to meaning theory in mathematics teaching and learning [24–28]. They advocate for the philosophy of mathematics to accommodate social, economic, and environmental dimensions in the sense of ESD, which "requires a mindset shift, and success lies largely in a fundamental reconfiguring and expanding of the traditional boundaries of the philosophy of mathematics" [15] (p. 7). Furthermore, they propose embedding ESD perspectives in mathematics education within mathematics teacher education to support teachers in developing knowledge about ESD [16,17,19].

2.4. ESD in Mathematics Curriculum

Vásquez and colleagues conducted a systematic review study that provides an overview of the current status of the integration of ESD into mathematical education and statistical education [18]. Their finding showed that, among the 32 studies that were indexed in Scopus and Web of Science databases published between 2010 and May 2023 included in their analysis, most of the studies mainly focus on teacher training [29]. Only two of the studies were on integrating ESD into curriculums [30,31], and two others on textbooks [32,33]. In [30] (p. 108), Su and colleagues examined if "the Chilean primary education curricular bases offer learning opportunities and contexts for students at this stage to develop their awareness, knowledge and skills in a sustainable way" in relation to mathematics, natural and social science. They reported that natural and social sciences provide learning opportunities in ESD. Meanwhile, in [31], Vásquez and colleagues focused on investigating teachers' knowledge that can be found in the curricular guidelines of primary teachers' mathematics knowledge in the three Latin American countries belonging to the OECD, which is somehow at the college level. Their finding shows that the curriculum for teacher training is not aligned to foster ESD.

Among the studies that focus on integrating ESD in mathematics textbooks, Kim and Pang explored how contents related to SL were embedded in Japanese, Korean, and Singaporean elementary mathematics textbooks [32]. Their findings show promising integration of sustainability in terms of problem-solving in connection to the mathematics content domains of numbers and operations, patterns, and data and possibilities in all the third- or fourth-grade mathematics textbooks [32]. On the other hand, Vásquez and colleagues investigated how SL is embedded in a collection of primary school mathematics textbooks in Chile (6–14 years old) focused on statistical and probability tasks [33]. They reported that the textbooks are not aligned with education for sustainable development (ESD).

Urválková and colleagues studied the nature, quality, and availability of teaching materials available for Czech teachers in STEM education to foster ESD. They used SD indicators (SDI) and analyzed available documents with a full-text search, identifying 1376 records. Their findings showed that most of the records (95%) do not contain SDIs in teaching materials; only 59 records mentioned SDIs [34]. Already, there are some endeavors to fill the lack of resources for SL. For example, Roe and colleagues provided a textbook that can foster SL for college students [35]. They aimed to allow learners to model sustainability on local, regional, and global levels by focusing on concepts like measurement, flow, connectivity, change, risk, and decision-making [35]. In fact, as Brundies and Wiek reported, "Over the last decade, higher education institutions have introduced sustainability research education in different ways" [36]. For instance, engineering education across the institutions of Europe has embedded ESD in a more robust way [37]. These studies [34–37] are not at the primary and lower secondary education level, which is the focus of this study. However, it is quite possible to extend their work at lower levels.

The above recent studies [30–35], as well as the three main articles presented above [4,12,15], point out that ESD was and still is not yet well integrated into mathematics education, even after two decades of recognizing the vital importance of education for sustainability at the Johannesburg Earth Summit in September 2002. For effective and consistent SL, national curriculums should reflect "knowledge, skills, perspectives, and values related to sustainability" [38] (p. 46). According to [2], the literature on WIA calls for integrating sustainability as a cross-cutting and cross-disciplinary concept rather than adding it to some subjects and courses. Petocz and Reid reflect that the notions of sustainability can be incorporated into mathematics curricula without compromising the mathematical content [4]. Furthermore, ref. [17] emphasizes "the need to advance in the integration of ESD in the different areas of the mathematics curriculum" (p. 12). The question remains on how to integrate ESD in mathematics education at the primary and lower secondary levels.

Jenkins discusses the question of how one can fit sustainability into a program or subject, particularly in the context of Australia and New Zealand, even with the issue of a crowded curriculum [11]. According to Jenkins, rich concepts pertaining to sustainability include the following:

> "citizenship, ecological sustainability, human rights, justice, well-being, conflict and cooperation, war, resources, social justice, needs and wants, diversity, relationships, spirituality, work and leisure, imagining and constructing a future, thinking critically, energy, change, power and control, inequity, the global society, time and so on" [11] (p. 40).

Textbooks with mathematical activities based on these rich contexts can provide opportunities for students for SL. Serow provided mathematical activities within the different mathematics sub-strands for different school levels (lower/middle/upper) in connection to different sustainability contexts [39]. In their recent endeavor to connect ESD with elementary school mathematics teaching, Tim and Pang acknowledged Serow's pioneer work in this regard [32]. Table 1 summarizes such activities and corresponding target strands in Australia and New Zealand's mathematics curriculum. We only selected those activities for the lower/middle schools, which span from grades 1 to 10, since we are currently looking at the curriculum from grades 1 to 10 (ages 6–16). We intend to use this further since we think that such a way of integrating sustainability or sustainable development across the mathematics strands might be the way forward.

Table 1. Summary of mathematical activities for sustainability context according to [11].

Mathematics Substrand	Activity	Target Level	Focus Concept	Sustainability Context
Number	Around the world in 20 hands	Middle	Fractions, percentages, and decimals	Water conservation sustainability context
Space and geometry	Travel Comparisons	Lower	Position	Modes of transport and purchasing local food
	Solar passive home design	Middle	3D construction and Properties of 3D figures	Solar energy
	Dynamic geometry software floor plans	Middle	Quadrilateral figures and properties	Solar passive housing
Measurement	Worldmapper	Middle	Formal area units	Wealth, poverty, population
	Toilet roll timeline	data	Timelines	Environmental impact/ Indigenous issues
Patterns and algebra	Glacier melts	Lower/ middle	Relationships among variables concerning rates	Greenhouse effect
	Fuel consumption of your dream car data	Middle	Connection between variables of consumption and distance travelled	Making an informed choice concerning fuel consumption
Statistics	Survey	Middle	Statistical design and investigation	Water management
	Wastage audit	Lower/ middle	Collection and display of data	Reducing waste

3. Methodology

Since we aim to investigate what the new Norwegian curriculum says about sustainability and how the mathematics curriculum deals with sustainability, we looked at three documents: core curriculum, subject curriculum, and a textbook series (see Table 2). This is a qualitative content analysis study on curriculum. According to Valverde and colleagues, there are three main categories of curriculum: intended, implemented, and attained [40]. Both the core curriculum and the subject curriculums are intended ones developed by the policy makers and experts in the nation. Meanwhile, textbooks called potentially implemented curriculums [40], are developed by authors and publishers. And in Norway, there are several textbooks, both digital and paper, for each grade level.

Table 2. List of documents (texts) analyzed.

Document (Text)	Description	Towards Research Q.
The new core curriculum (grades 1–10) (LK20)	The new curriculum for grades 1–10 (6–16 years old) is part of the main focus of this study.	(i)
The old core curriculum (1–10) (LK06)	The older curriculum (LK06) is included for comparison.	(i)
The curriculum for mathematics (grades 1–10)	The subject curriculum, which is part of the main focus of this study, is included.	(ii)
The curriculum for natural Science	Two subject curriculums are included for comparison.	(ii)
The curriculum for social studies		
A mathematics textbook	The mathematics textbooks series called Matemagisk for grades 4, 7, and 10 are included to support the current study.	(iii)

In addition, we looked at the older curriculum (LK06) and the new natural science and social studies curriculum just for cross-checking (comparison). In order to address the third research question, one textbook series is included. The textbook series Matemagisk, developed after LK20, was selected due to its online availability for all grades 1–10. In addition, the publisher, Aschehougs (https://aschehoug.no/), is one of Norway's three leading producers of mathematics textbooks. Furthermore, we selected grade 4 for grade levels 1–4, grade 7 for grade levels 5–7, and grade 10 for grade levels 8–10 to limit the scope of this preliminary study. We intend to compare the different mathematics textbooks concerning ESD produced by various publishers in depth. However, in this study, we looked for particular examples across the textbooks for varying levels of the school system in Norway to find opportunities to embed sustainability contexts. The summary of the qualitative data collection is given in Table 3.

Table 3. Summary of data collection.

Curriculum Type	Documents/Texts	ESD Related Concepts/Contexts/Words
Intended Curriculum	Core Curriculum - LK20 - LK06	Sustainable (Sustainability) Sustainable development (SD)
	Subject Curriculum (LK20) - Mathematics - Natural Science - Social Science	Sustainable (Sustainability) Sustainable development (SD) Environment Nature
Potentially Implemented Curriculum	Textbook - Matemagisk	Water conservation/management Modes of transport Purchasing local food Solar energy Wealth/poverty Population Environmental impact Indigenous issues Fuel consumption Reducing waste Greenhouse effect

We used summative content analysis to analyze the data. Summative content analysis is a method "wherein keywords are selected based on previous research or the researcher's research interest", [41] (p. 674). Keywords related to sustainability are used in both the core curriculum and the subject curriculums, while rich contexts [11] and concepts [39] (see Table 1) were used to gather evidence of affordance for ESD in the selected textbooks. In addition, we have added one more column that shows the mode of embedding the sustainable context: explicit and implicit, referring to the direct usage of the sustainability context and a potentially rich context that provides an opportunity for SL, respectively.

4. Finding and Analysis

4.1. Sustainability in the Norwegian Core Curriculum

The Norwegian core curriculum includes three interdisciplinary topics: health and life skills, democracy and citizenship, and sustainable development [13]. The third cross-cutting and cross-disciplinary topic deals with sustainable development, and it reads as follows [13]:

> Sustainable development as an interdisciplinary topic in school shall help the pupils understand basic dilemmas and developments in society and how they can be dealt with. Sustainable development refers to protecting life on Earth and providing for the needs of people who live here now without destroying the

> possibilities for future generations to fill their needs. Sustainable development is based on the understanding that social, economic, and environmental conditions are interconnected. Our lifestyles and resource consumption have local, regional, and global consequences.

The text includes three of the four pillars of sustainability [3]: social, economic, and environmental (ecology). Furthermore, it emphasizes the importance of learners developing competence in relation to sustainability issues, including "issues relating to the environment and climate, poverty and distribution of resources, conflicts, health, equality, demographics, and education". Technological competence and knowledge are also added to enhance this endeavor. Interpreting the text in terms of the SDGs, it is possible to connect to SDG1 (zero hunger), SDG 3 (good health and well-being), SDG6 (clean water consumption), SDG 7 (affordable and clean energy), SDG11 (sustainable cities and communities), SDG 13 (climate action) and so on as in [35].

The word "sustainable" is found eight times in the whole document in general (one under contents, one under the section interdisciplinary topics, and six under the sustainable development subsection, sec 2.5.3). Considering the ecological aspect of sustainable development and searching for "nature" or "environment", we found 9 and 40 references, respectively (see Tabel 4). Around 20 of those references to nature and environment relate to ESD. For instance, Section 1.5 of the core curriculum, "Respect for Nature and Environmental Awareness", states, "Schools shall help the pupils develop an appreciation of nature so they can enjoy and respect nature and develop climate and environmental awareness". Even at the start of the core curriculum, among the statements that describe the purpose of education, we found the following statement: "The pupils and apprentices shall learn to think critically and act ethically and with environmental awareness".

In general, the new Norwegian core curriculum has integrated the general guide for the issue of sustainable development. Additionally, we examined the older curriculum from 2006 (LK06), which made approximately ten references in connection to subjects such as geography, social studies, and food and health. Compared with LK06, LK20 explicitly incorporates sustainability as an interdisciplinary issue, which is understandable considering that the popularization of ESD issues was at an early stage (see Table 4).

Table 4. Summary of words related to ecological aspect of sustainable development in the core curriculums.

Document	"Sustainable" or "Sustainable Development (SD)"	"Nature" and "Environment"
LK20	7	9 + 40 = 49
LK06	0	3 + 6 = 9

In fact, LK20 embeds ESD in a similar way to the Australian curriculum, which is explained as follows, as reported by [3]:

> Education for sustainability develops the knowledge, skills, values, and world-views necessary for people to act in ways that contribute to more sustainable patterns of living. It enables individuals and communities to reflect on ways of interpreting and engaging with the world. Sustainability education is future-oriented, focusing on protecting environments and creating a more ecologically and socially just world through informed action. Actions that support more sustainable patterns of living require consideration of environmental, social, cultural and economic systems and their interdependence.

In the Australian curriculum, we noticed that the term education for sustainability (EfS) is used instead of the phrase sustainable development or sustainability. Petocz and Reid argue that EfS emphasizes "the deliberate use of Education for Sustainability and recognizes that action which supports sustainability is an imperative for quality of life and survival of generations", [4] (p. 3). Otherwise, we understand that there is not much difference between the two national texts in embedding the issue of ecological sustainability discussed above except for the phrase "sustainable patterns of living". As mathematics is the study of patterns, it is possible to capitalize on it to integrate sustainability [3].

4.2. Affordances of Sustainability in the New Curriculum for Mathematics Year 1–10

We searched for "sustainability" or "sustainable development" in the new Norwegian curriculum for mathematics for grades 1–10. Somewhat unexpectedly, there were none. We also checked the new natural science [42] and social studies curriculum [43]. The curriculum for natural science had eight mentions of SD and thirty-three mentions of "nature" and "environment". While the curriculum for social Studies had six mentions of "sustainable" or SD and twelve mentions of "nature" and "environment". The results are summarized in Table 5.

Table 5. Summary of words related to ecological aspect of sustainable development in the subject curriculums.

Document—Subject Curriculum (LK20)	"Sustainable" or "Sustainable Development (SD)"	"Nature" and "Environment"
Mathematics	0	3 + 1 = 4
Natural Science	8	19 + 14 = 33
Social Science	6	5 + 7 = 12

The fact that "sustainable" or SD is not mentioned in the mathematics curriculum (1–10) is intriguing. Hence, we looked closely for the three references to 'nature' and 'environment' in the mathematics curriculum, and it reads as follows:

> Mathematics is an important subject for understanding the patterns and relationships within society and nature through the use of modeling and applications [33] (p. 2).
>
> In mathematics, the interdisciplinary topic of democracy and citizenship refers to giving the pupils the competence to explore and analyze findings from real datasets and data collected from nature, society, working life, and everyday life [44] (p. 4).
>
> Exploring numbers, sets, and counting through play, nature, visual art, music, and children's literature; represent the numbers in different ways and translate between the different representations [44] (p. 6).
>
> In relation to the latter, we only found one reference.
>
> Explore, draw, and describe geometric shapes from one's own local environment and argue for ways to sort them by properties [44] (p. 6).

These references to nature and the environment could provide the opportunity to connect ESD. Another significant aspect of the new Norwegian curriculum for mathematics grades 1–10 is that it has six core elements: exploration and problem-solving, modeling and applications, reasoning and argumentation, representation and communication, abstraction and generalization, and mathematical fields of knowledge. The first five are called process standards, according to [45], while the last one refers to specific mathematical contents such as arithmetic, algebra, geometry, statistics, and probability.

4.3. Affordances of Sustainability in Mathematics Textbooks in Norway

Searching for rich contexts, activities, and tasks in mathematics textbooks that can allow us to connect SL, three Matemagisk mathematics textbooks for grades 4, 7, and 10 were closely examined. Jenkins's rich contexts [11] and Serow sustainability concepts [39] (see Table 1) served as lenses to gather evidence of affordance for ESD in the selected text-books. We have added one column that shows the mode of embedding the sustainable context: explicit and implicit, referring to the direct usage of the sustainability context and a potentially rich context that provides an opportunity for SL, respectively. Six examples are provided and summarized in Table 6.

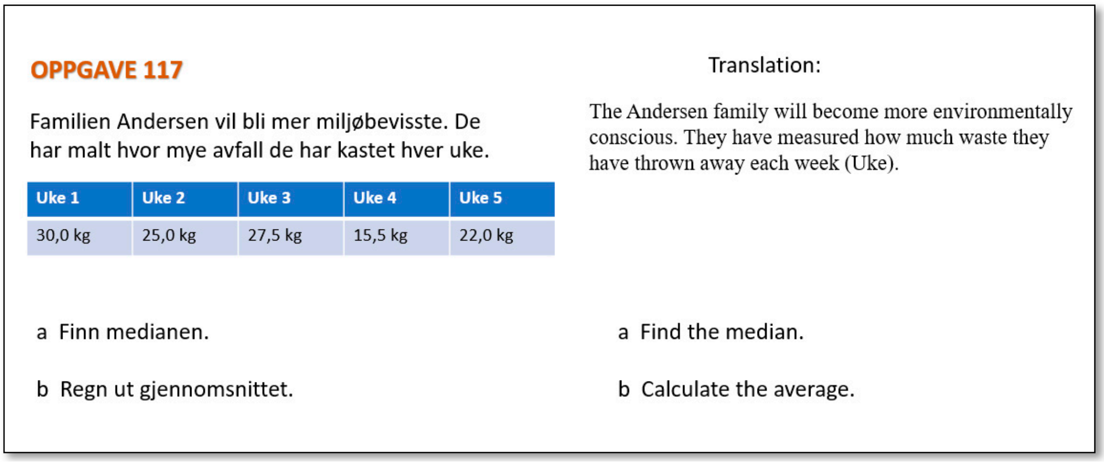
Table 6. Affordances for SL—Matemagisk mathematics textbook (grades 4, 7, and 10).

Mathematics Substrand	Activity	Target Level	Focus Concept	Sustainability Context	Mode of Embedding
Arithmetic	Collecting bottles	Grade 4	Fair-share model	Waste management	Implicit
	The kitchen garden	Grade 4	The four operations	Growing local food	Implicit
Statistics	Survey	Grade 7	Mean, mode and median	Waste management	Explicit
Algebra	Mountain trip	Grade 10	Variables, system of equations	Purchasing local food	Implicit
	Construction works	Grade 10	Pattern/ Generalization	Ecological sustainability	Implicit
Numbers (Fractions)	Travel Comparisons	Grade 10	Percentages, proportionality	Modes of transport and use of diesel	Implicit

In the grade 4 Matemagisk mathematics textbook, under the mathematics-sub strand—arithmetic—two activities are selected as potential contexts for SL: collecting bottles and the kitchen garden activity on pages 55 and 80–87, respectively (see Table 6). The collecting bottles activity is given in connection to one of the meanings of the division of natural numbers, the fair-share model, and it has the potential to provide knowledge about waste management. The kitchen garden activity has nineteen tasks in reference to the four operations in arithmetic in connection to growing local food, which can provide an opportunity to learn responsibility for the Earth and ethical conservation via mathematical reasoning [15]. The activities do not mention SL explicitly, which is why we used the term "potential for SL".

Figure 1 shows Task 117 in the grade 7 Matemagisk mathematics textbook, which explicitly uses a sustainability context (waste management, see Table 6). The Andersen family is involved in measuring the amount of waste they throw out each week in kilograms. The table provides data for five weeks. The students are asked to calculate the median and mean of the given data. This task is not open-ended and contributes to instrumental understanding [46]. It can also be categorized as a traditional exercise that uses real-life contexts, according to Skovsmose's milieus of learning [21]. Teachers can utilize this context and develop it into an open task, providing opportunities for students to explore, reason, and solve problems as they build their sustainability competence. It is interesting to see how the textbook developers are aware of ESD even though it was not explicitly included in the mathematics curriculum.

Three tasks in the grade 10 Matemagisk mathematics textbook are included in this analysis: a mountain trip, construction works, and travel comparison activities on pages 79, 84–85, and 104, respectively (see Table 6). These three contexts provide an opportunity to explicitly implement ESD if teachers deliberately pose the tasks as sustainability problems. Furthermore, there is one subsection that deals with SD context-based tasks under the mathematical domain of algebra, specifically in the sub-domain of modeling. The data set-based tasks are centered around five different sustainability contexts: equity, trade and cheaper consumer goods, greenhouse gas emissions, energy production, and the oil fund. One may find more tasks and activities to help integrate sustainability contexts and issues across the Matemagisk mathematics textbook series from grades 1 to 10. However, a thorough investigation is deferred for another study. Here, we have only selected a few tasks to demonstrate the affordances within the textbook and the potential for implementing a sustainable curriculum.



OPPGAVE 117

Familien Andersen vil bli mer miljøbevisste. De har malt hvor mye avfall de har kastet hver uke.

Uke 1	Uke 2	Uke 3	Uke 4	Uke 5
30,0 kg	25,0 kg	27,5 kg	15,5 kg	22,0 kg

a Finn medianen.

b Regn ut gjennomsnittet.

Translation:

The Andersen family will become more environmentally conscious. They have measured how much waste they have thrown away each week (Uke).

a Find the median.

b Calculate the average.

Figure 1. Task 117 in grade 7 Matemagisk mathematics textbook using ecological context.

5. Discussion—ESD in Mathematics Curriculum

The new Norwegian core curriculum, LK20 (what Valverde et al. name as the intended curriculum), explicitly embeds ESD as a cross-curricular issue [13]. In contrast, the mathematics curriculum has avoided the mentioning of it. However, there are references to the words like 'nature' and 'environment' in the mathematics curriculum. Actually, in connection to RME, people learn mathematics by actively investigating realistic problems, [47] which includes problems taken from the nature around the learner. Now the question is, why did mathematics educators and policy makers who took responsibility for drafting the document avoid 'sustainability' explicitly in the curriculum? It is already in the core curriculum. This needs further investigation.

Of course, it is possible to reflect, based on the existing literature [1,4,12,14,15,19,48], that the same trend exists among mathematicians, mathematics educators, and mathematics teachers across the world. There could be many reasons for the disengagement with ESD. First, it might be due to the root philosophical positions of mathematicians that mathematics is a value-free subject [15]. In this case, a paradigm shift is needed. In this study, we are joining researchers like Petocz and Reid [4], Renert [15], and Li and Tsai [12] in a call to include aspects of sustainability in mathematics education. As 'sustainability im-migrants' [the grown up generation], we are expected to train the 'sustainable natives' [the new generation], which requires rethinking and re-envisioning mathematics teaching and learning [19]. The task of teaching/training sustainability to sustainability natives by sustainable immigrants could be challenging [37]. For learners who perceive mathematics as an approach to life, the subject can also contribute to thinking of ways to understand and solve sustainability problems. The subject can help apply different models to reason out and justify future trends. The sustainability context must be available to them so they can mathematize with it, as we adhere to the student-centered pedagogy these days. In fact, [1] argues that critical mathematics education can offer a perspective with which mathematics teaching and learning might embed ESD to equip future citizens with sustainability competence.

Second, integrating ESD into mathematics is not a simple matter. How can SL be embedded in the doing of mathematics? Some create distance between sustainability and mathematics and see no way of integrating the two. Meanwhile, others find overlap, as Figure 1 shows. But, others see that sustainability is essential and can be seamlessly embedded in the subject without compromising content [4,19]. It is possible to conceptualize SL with the notion of 'fairness'. It is popular in Norway, for example. Future generations demand us to be fair and just. That is why ESD is well integrated as an interdisciplinary topic in most subjects in Norway [48]. Could that be enough? Why exclude ESD in mathematics, then? As discussed above, core elements in LK20 provide a possible way to integrate ESD in the teaching and learning of mathematics. It is possible to accommodate or assimilate it, or even better, envision mathematics education for sustainability and re-form the existing paradigm [14,21]. In fact, the best way is to see education as sustainable, and mathematics education contributes to enabling learners to realize their visions for a sustainable future [11].

Third, finding activities and tasks promoting SL could be complex. In this study, we looked for opportunities and examples to embed ESD into the mathematics curriculum. We started by examining mathematics textbooks, as they play a vital role in the teaching and learning of mathematics [11]. According to [40], textbooks are potential curricula facilitating teachers' daily work and providing students with learning opportunities. Genuine engagement with ESD in mathematics education should include the development of mathematics textbooks that incorporate sustainability contexts in connection with mathematical strands, rich concepts, activities, and tasks at different levels and grades [15,19]. We found some examples in Matemagisk by adapting the works of [15] and [11]. However, more work is needed to enrich that list further.

Opportunity to Integrate ESD into the Mathematics Curriculum

Integrating sustainability across the curriculum and across disciplines is the usual practice across nations [11,32–34,38]. Kim and Pang investigated how Japanese, Korean, and Singaporean elementary mathematics textbooks embedded SL. They reported that "sustainability-related contents were used both to introduce and apply mathematical concepts or principles" [32] (p. 1) in problem-solving. The model, in the context of the Australian and New Zealand education system, allows "to cover essential content, skills, attitudes, values, and behavioral outcomes from the humanities and social sciences, the natural sciences, and health and physical education, while concurrently addressing literacy, numeracy, and creative arts outcomes. This concurrence is achieved by identifying 'rich concepts' and addressing them in a cross-curricular manner" [11,38]. Jan recommends taking into consideration the different levels of the curriculum when dealing with it [49]. One possible distinction is the supra (international) level, macro (system/society/nation/state) level, meso (school/institution) level, micro (classroom) level, and nano (individual/personal) level [49]. The SDGs are at the supra level, while SD is embedded at the macro level in the Norwegian curriculum context, within the core curriculum and some subject curriculums (see Table 5) [42,43,48].

Furthermore, within the context of the Norwegian education system and the teaching and learning of mathematics, it is possible to incorporate SL into the mathematics curriculum, particularly by utilizing the six core elements. This approach presents a significant opportunity to integrate ESD (see Figure 2). The six core elements allow ESD to be integrated (see Figure 2). First, one considers the SDGs, then the core curriculum. Furthermore, even if the subject curriculum does not mention sustainability or SD, it is possible to capitalize on the statements referring to nature and the environment and actively create content and contexts that promote SL, from meso to nano levels of the curriculum, using the six core elements as a guiding framework.

One potential activity could involve students exploring the number of plastic bags used within their family, community, district, and country and reflecting on the environmental impact. They can then analyze why this practice is not sustainable and propose various solutions, supporting their reasoning with mathematical concepts, procedures, and models. Such activities can be tailored to the learning objectives of each grade level. In this specific example, we have utilized the first three core elements outlined in the new mathematics curriculum for grades 1 to 10. Textbook authors and developers can enhance SL by incorporating sustainable contexts, as demonstrated in the Matemagisk mathematics textbook series (see Table 6). While an implicit reference to sustainability context may suffice to some extent, engaging students with explicit mentions of sustainability is recommended, as the problem of sustainability is evident and urgent in our current global population of almost eight billion individuals [35].

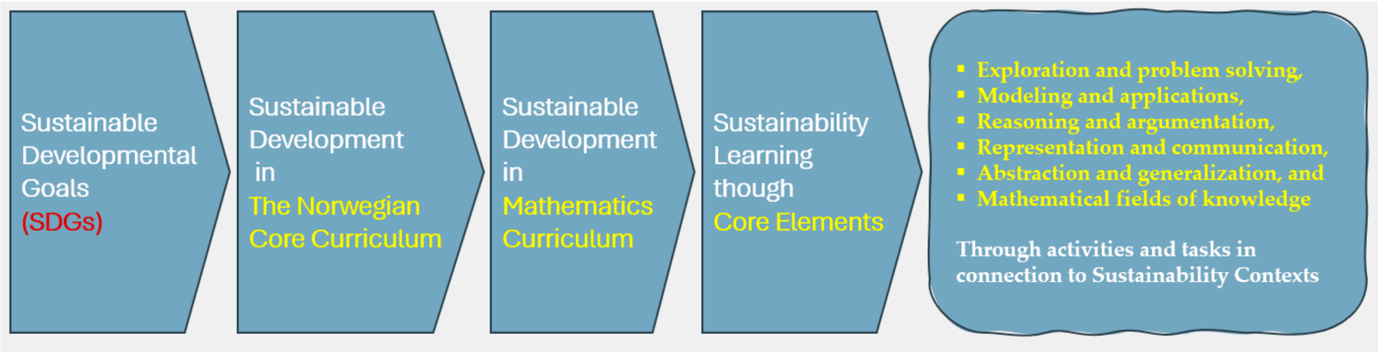


Figure 2. A possible model of integrating sustainability across the curriculum in the Norwegian context. The Red color (SDGs) is at the supra level while the Yellow colors are at the macro level.

6. Conclusions

According to Roe and colleagues, "Sustainability is the ability of a social, economic, or ecological system to meet the needs of the present generation without compromising the ability of future generations to meet their own needs" [35] (p. 11). This means that the current generation takes responsibility for the ecosystem around itself responsibly for the sake of future generations. ESD aims to empower learners with the knowledge, skills, and understanding to make smart decisions in connection to problems related to sustainability, and many nations have used SDGs as a guiding framework to educate their citizens [7–10,35]. This study focuses on the ecological aspects of SD in mathematics education, particularly the mathematics curriculum in the context of Norway. However, the study has implications for other nations across the globe.

ESD is considered an interdisciplinary issue in various national curricula, including in Norway [11,13,14,19,30–34,39,48]. A clear trend exists to integrate SD into the natural and social sciences curricula [31,42,43,48]. However, more work must be carried out to incorporate SL into the mathematics education curriculum (intended, implemented, and attained) at different levels. DESD (2005–2014) has passed away, and the impact of engagement with SD has gained momentum globally but at a slower rate. Holst takes sustainability as a core paradigm of the quality of education [2] (p. 1015) and calls for a more robust approach: WIAs—meaning "all learning is embedded within its socio-physical contexts" [2] (p. 1015), which includes the curriculum. Li stated that over the past two decades, there has been preparation to integrate ESD in school subjects and systems; however, there is still limited progress regarding embedding it in curricula [24]. Specifically, many mathematics textbooks, as potential curricula, offer minimal, if not zero, opportunities for SL. Li joins others who call for the philosophy of mathematics and mathematics education to be reconfigured or re-envisioned to appropriately integrate the relevant aspects of ESD into mathematics and mathematics education [12,15,19].

In this study, we argue that in an educational context, SL should be integrated not only into the general curriculum and subject curricula but also into teacher training, professional development programs, research contexts, the whole school system, and so on [2,12,16,17,19]. We dare to say the same to mathematicians, mathematics educators and teachers, and mathematics textbook developers, like [4,12,15], to actively engage in this regard in Norway and globally. Many authors and publishers develop mathematics textbooks, both paper and digital versions, in Norway. However, our study considers only one textbook series, Matemagisk, and only three of its books (grades 4, 7, and 10). That limits the scope of our study. A more comprehensive survey on integrating ESD into mathematics textbooks using sustainable contexts and concepts was not the focus of this study. As stated before, it is deferred for future work. However, we have indicated the opportunity in the new mathematics curriculum to embed ESD: to use the six core elements in the subject curriculum and include tasks/activities that use sustainability contexts in textbooks.

Author Contributions: Conceptualization, S.A.T. and O.E, methodology, S.A.T. and O.E.; writing—original draft preparation, S.A.T.; writing—review and editing, S.A.T. and O.E.; All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data are contained within the manuscript.

Acknowledgments: The authors acknowledge the discussion with the Textbook research group at the Department of Teacher Education, NTNU.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

DESD	Decade of Education for Sustainable Development
EfS	Education for Sustainability
ESD	Education for Sustainable Development (ESD)
LK06	Kunnskapsløftet 2006 (Curriculum 2006)
LK20	Kunnskapsløftet 2020 (Curriculum 2020)
RME	Realistic Mathematics Education (RME)
SDGs	Sustainable Developmental goals
SL	Sustainability Learning
WIA	Whole Institution Approaches (WIA)

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