On Integrating Mathematics Education and Sustainability in Teacher Training: Why, to What End and How?

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Abstract

This chapter presents a line of research which examines the integration of mathematics education and sustainable development in teacher training with the aim of enabling both pre-service and in-service teachers to gain the necessary knowledge, understanding and skills in order to contribute towards building a more inclusive, sustainable and resilient future for people and the planet. First of all, via an approach which promotes sustainable development in university education as a key strategy for the transformation of policies, investment and practice in the field of education, a description is provided of the main challenges in advancing towards the integration of sustainable development in teacher training in the field of mathematics and the elements of a profile of a mathematics teacher in who is connection with sustainable development. Secondly, sustainable development is integrated into the Model of Mathematical Literacy in Childhood with the aim of offering guidelines to teachers so that they can plan and carry out mathematics teaching practices in connection with sustainable development and, in this way, play their part as agents of social change.

Keywords

Mathematics education · Sustainable development · Connections · Teacher training · Teaching practices

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Introduction

The skills-based approach to mathematics [1–4] assumes that knowledge of mathematics is necessary, but it also stresses that knowing how to use mathematics appropriately whilst applying values in different contexts is essential. So, what does this perspective of mathematics and its use imply?

Mathematical competence requires thinking and doing mathematics more than memorising definitions and procedures [5]. In this regard, the Council for the Curriculum, Examinations and Assessment (CCEA) considers that using mathematics is one of the cross-cutting skills which form the nucleus of the curriculum, as it makes it possible to develop the ability to suitably apply mathematical knowledge, understanding and skills in different contexts and in different ways in order to communicate, manage information, think critically, resolve problems and take decisions. In order to achieve this aim, it is desirable for teachers to use relevant real-life situations which require mathematical thinking and to give children the possibility to transfer their knowledge, where appropriate, to other contexts [6].

This is, without a doubt, a challenge which extends beyond mathematics. On a global level, for example, social, economic, environmental and, recently, health crises coexist, which can be better understood via mathematics. However, these crises cannot be solved with mathematics alone, but rather via the sum of different disciplines. In other words, knowledge of different kinds must be integrated in order to confront and resolve these challenges. For this reason, the skills-based approach to mathematics refers to connections, one of the standards of processes which demonstrate how mathematical contents are acquired and used. Specifically, in Principals and Standards for School Mathematics, the National Council of Teachers of Mathematics refers to two types of connections [4]: (1) the connections between mathematical ideas, in order to understand how they interconnect and build upon each other to produce a coherent whole (intradisciplinary connections); (2) the recognition and application of mathematics in non-mathematical contexts, which may arise in topics from other subjects and also in the children's daily lives (interdisciplinary connections).

This chapter focuses on the latter type of connection and, more specifically, on the integration of mathematics and sustainability in teacher training, with the aim of providing teachers with the necessary knowledge, understanding and skills to be able to advance in this direction. Therefore, the intention is to actively participate, from mathematics education, in the acquisition of the Sustainable Development Goals and the Competencies for Sustainability [7, 8], in order to contribute towards a more inclusive, sustainable and resilient future for people and the planet.

The structure of this chapter is as follows: In the first section it is asked why it is necessary to integrate mathematics education and sustainable development in teacher training and what purpose this serves, taking into consideration the recommendations of organisations such as: the United Nations, the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the European Union, which have published documents with guidelines of considerable impact in

the promotion of sustainable development [8–17]; international networks such as the COPERNICUS Alliance [18], which aims to help people and institutions in a higher education environment to creatively address the challenges of tomorrow in a collaborative way, to jointly build the knowledge and competences needed for global sustainable development, and to actively engage with policy-makers and community stakeholders; and also authors who have, for some time, been promoting sustainable development as a key strategy in transforming policies, investment and practice in the field of education, not only with the aim of seeking a change in education, but also in the quality of life of many people around the world [19–21]. The second part of the chapter addresses how to integrate mathematics and sustainable development into teacher training based on a line of research which has been developed by the Grup de Recerca en Educació Científica i Ambiental (Scientific and Environmental Education Research Group, GRECA in its Catalan acronym) of the University of Girona (Catalonia, Spain), and which has given rise to doctoral theses, presentations in congresses and both scientific and popular publications [22–26].

Why is It Necessary to Integrate Mathematics Education and Sustainable Development into Teacher Training? What Purpose Does It Serve?

Sustainable Development: A Key Strategy for Transformation

Global calls for initiatives promoting and supporting sustainable development first appeared in the 1980s with the idea of generating collective responsibility in order to make it possible to confront the problems and challenges faced by humanity which seriously threaten its future [20]. For example, in the *Brundtland Report* of the World Commission on Environment and Development (WCED), a first attempt can be noted to promote this objective from the point of view that it is development which satisfies the needs of the present generation without compromising the capacity of future generations to satisfy their own needs [27]. In the present day, it is considered a crucial challenge which must promote practical action so that all of us can build a better future together, making it possible to put an end to poverty and inequality, to achieve peace and justice, to protect human rights and the planet [13]. In this regard, three main dimensions for action in this field are recognised (economic, social and environmental), via which the 17 Sustainable Development Goals (SDG) are suggested [8] covering a broad range of relevant issues concerning relationships with the natural world, personal and collective welfare, a fair and balanced economy and education for a fairer society.

In order to achieve the SDGs, it is necessary for education to be holistic, inclusive and transformative and for it to consider [8]: (a) learning contents and results (integration of topics on sustainability into study plans); (b) pedagogy and learning environments (student-focused teaching and learning, oriented towards

action, based on interaction and exploratory learning); (c) learning outcomes (promoting competencies such as critical and systemic thinking, joint decision-taking, assuming responsibility for current and future generations); and (d) social transformation (empowering students of any age and in any educational environment to transform themselves and the society in which they live). Without a shadow of a doubt, this is a challenge which requires an evolution from teaching to learning in order to educate current and future generations in sustainability. In this regard, [28] states that it is necessary to learn to: "formulate critical questions; clarify one's own values; envisage more positive and sustainable futures; think systemically; respond via applied learning; and study the dialectics between tradition and innovation" (p. 8).

Within this context, [8] highlights the importance of "developing competencies that empower individuals to reflect on their own actions, taking into account their current and future social, cultural, economic and environmental impacts, from a local and a global perspective" (p. 7). In this way, it is hoped that, via education for sustainable development, current and future generations may be able to achieve cognitive, socio-emotional and specific behavioural learning and, above all, to develop key sustainability competencies, which are necessary for contributing towards the understanding and achievement of each of the different challenges of the SDGs. With regard to these competencies, which are key to achieving progress in terms of sustainable development [8, 29–31], proposes eight competencies: systems thinking competency; anticipatory competency; normative competency; strategic competency; collaboration competency; critical thinking competency; self-awareness competency; and integrated problem-solving competency.

Although these competencies are cross-cutting, multifunctional and independent, they should be developed by all students on a worldwide scale (at different levels according to age). They do not replace specific competencies for certain situations and contexts but they comprehend them and have a wider scope [32, 33]. In this regard, target 4.7 of SDG 4 (Quality Education) specifically contemplates that students should acquire knowledge and competencies for the promotion of sustainable development, as education for sustainable development [8] "does not only integrate contents such as climate change, poverty and sustainable consumption into the curriculum; it also creates interactive, learner-centred teaching and learning settings" (p. 7).

In order to achieve the purpose of implementing learning of the SDGs via sustainable development, it is necessary for it to be integrated into public policies, educational programmes, school curriculums, textbooks, etc., as "they are powerful change agents who can deliver the educational response needed to achieve the SDGs. Their knowledge and competencies are essential for restructuring educational processes and educational institutions towards sustainability" [8, p. 51]. From this perspective, taking sustainability criteria into account in the design of the academic curriculums of all fields of knowledge and all stages of education becomes a necessity of social commitment which contributes to a growth in alignment between what is studied in schools, how it is studied and what society demands.

These proposals have encouraged research groups from many universities throughout the world to take sustainability as a reference point and a guide for twenty-first century education. As stated by [19], in spite of all these attempts, the literature continues to show that higher education institutions (HEIs) do not fully understand the true nature of this challenge [11, 18, 34, 35]. The dominant focus has been on integrating content relevant to sustainability into the curriculum of different subject areas, or developing specialist courses on sustainable development, especially for those interested in pursuing careers in this area [21]. However, for [19], the higher education curriculum continues to be engineered and delivered without this questioning or seeking to influence the future capabilities of people to create change towards more sustainable patterns of living [36]. In the opinion of these authors, underpinning ESD is a commitment to reorienting the learning experiences of students so that they understand their professional responsibilities, capabilities as well as personal motivations. According to this, the aim is to enable them to act in support of more sustainable ways of life not just in the domestic sphere, but by influencing change within their professions, industries and wider business environments.

Research into the Integration Between Mathematics Education and Sustainable Development in Teacher Training

Based on the rationale described above and the data of different research on the integration of sustainable development in teacher training [37–41], the GRECA Research Group of the University of Girona is currently carrying out research on the integration of mathematics education and sustainable development in teacher training [22–26, 42]. The purpose of this research is to contribute to the training of mathematics teachers who are competent in sustainability, based on the assumption that initial teacher training can be an important tool for social transformation. Alsina and Calabuig [42] carried out an exploratory study with 30 informants (10 teacher trainers, 10 in-service teachers and 10 pre-service teachers) to whom the previously validated EMS (Educación Matemática y Sostenibilidad—Mathematical Education and Sustainability) Questionnaire was administered with the aim of examining which elements sustainable development is able to contribute in order to improve the initial training of mathematics teachers.

Based on this study, Alsina and Calabuig [42] identified 20 elements of a profile of mathematics teachers in connection with sustainable development, i.e., the actions of the mathematics teacher are defined in order to promote sustainable development (Table 2.1).

With the aim of making progress in this direction, Vásquez et al. [43] have analysed the conceptions of 87 pre-service primary education teachers and 58 pre-service early years education teachers with regard to their competencies for incorporating education for sustainable development into the classroom, specifically into mathematics classes. Based on data obtained via a survey, a lack of clarity

Table 2.1 Elements of a profile of a mathematics teacher in connection with sustainable development [42, pp. 16–17]

1. Establishing in him/herself, and in children, a good relationship with mathematics based on the essence of the discipline
2. Establishing in him/herself, and in children, a good relationship between mathematics and the world
3. Improving day by day his/her own level of general culture and non-academic training, and that of his/her students, which can arise from opening up horizons to the world and its diversity
4. Making use of general culture and non-academic training as an ESD resource when establishing connections with other disciplines and the environment
5. Working on ESD at all times in a globalised and interdisciplinary manner
6. Working on the overall development of the student
7. Providing children with a solid foundation in ESD which will be of use to them at other times in their education
8. Working on ESD in order to improve understanding of information published in the media
9. Promoting children's creativity in order to improve their results in all mathematical processes, particularly in terms of problem-solving
10. Respecting, ensuring respect, appreciating, combining and promoting different ways of reasoning the same mathematical fact both personally and academically
11. Recognising the importance of language in the construction of thinking, both socially and individually, and to work in this direction
12. Understanding and appreciating mathematics in its disciplinary essence and in its role as an agent for both social and cultural change, in order to transmit this to his/her students
13. Understanding and appreciating sustainable development due to what it contributes in terms of responsibility and social commitment, in order to transmit this to his/her students
14. Working on all areas of knowledge, but particularly on that of mathematics in connection with the natural, social and cultural environment
15. Understanding and appreciating all of the mathematical contents of the curriculum in primary education
16. Working on all of the mathematical contents of the curriculum in primary education
17. Knowing how to be critical of the curriculum if the educational situation requires it
18. Continuing with on-going training in an autonomous way
19. Extracting information from publications on ESD and ESD research and experiments which can be applied to his/her own professional reality
20. Knowing (knowledge), knowing how (capacities), knowing how to be (skills and attitudes), knowing how to act (mobilise personal resources), knowing how to feel (emotions) and knowing how to imagine the future (predict)

was observed with regard to education for sustainable development and its scope, in spite of the fact that it was highly valued. In addition, a clear need was revealed for training in this regard, along with the potential of mathematics education as a tool for incorporating education for sustainable development into the classroom. These new data confirmed the results of Alsina and Calabuig [42] regarding the need to incorporate competencies linked to education for sustainable development into initial and on-going teacher training programmes in the field of mathematics with the aim of encouraging and stimulating their inclusion in the classroom.

How Can Mathematics Education and Sustainable Development Be Integrated into Teacher Training?

From a generic point of view, in order to develop the competencies of sustainable development, certain educational strategies and teaching methods should be taken into consideration, along with cross-cutting training processes originating from instances of formal, non-formal and informal education [44]. In this regard, Tilbury [28], in her review of the processes and learning for sustainable development, points out several key processes in which the frameworks and practices are sustained, including the following (p. 10): "processes of collaboration and dialogue (including multi-stakeholder and intercultural dialogue); processes which engage the 'whole system'; processes which innovate issues relating to curriculums as well as teaching and learning experiences; and processes of active and participatory learning".

Alsina and Mulà [22] add that it is essential that knowledge provided by the results of research from different fields of study linked with teacher training, among them sustainable development, should be explicitly included in the teaching of university lecturers who are responsible for teacher training in mathematics. From this perspective, these authors have developed the Transformational Professional Competence Model through Reflective Learning and Sustainability. This model describes certain essential strategies in promoting the transformation of the everyday knowledge of pre-service mathematics teachers (knowledge, experiences and prior beliefs) into professional knowledge from the framework of education for sustainable development and using a realistic and reflexive training model [45].

Taking these frameworks as a reference, these authors have integrated sustainable development into the Model of Mathematical Literacy in Childhood [46], with the aim of providing pre-service and in-service teachers with guidelines to prevent them from only thinking about mathematics, and to concentrate on mathematics in relation to sustainable development [23]. The authors do not claim to offer guidelines to enable teachers to plan the practice of mathematics in contexts of sustainable development or to integrate knowledge of sustainability when they plan and carry out teaching practice in mathematics with the aim of reorienting the learning experiences of students so that they understand their professional responsibilities, capabilities as well as personal motivations [19].

In this regard, the Model of Mathematical Literacy in Childhood contemplates the following phases with a perspective of sustainability:

Analysis of the context: taking into consideration the same theoretical and methodological principles of the Model of Mathematical Literacy in Childhood, mathematical knowledge is determined (contents and processes) along with the ideas of sustainable development (objectives and competencies) which are to be worked on. In this way, the development of interdisciplinary connections between mathematics and sustainable development is encouraged. Ultimately, it is a question of thinking within mathematics and also beyond mathematics in order to enrich mathematical practice from the point of view of sustainable development. In this

regard, whatever the real context selected may be, it should be linked with an appropriate SDG and the sustainable development competencies.

1. *Prior knowledge:* Prior knowledge of mathematics and sustainable development are revealed in a communicative environment in the classroom via the use of good questions and/or other resources and contexts (relating experiences, an article from a newspaper, a story, etc.).
2. *Working in context:* Access to ideas on mathematics and sustainable development is encouraged in the context of the situation and actions are documented for their subsequent analysis.
3. *Co-construction and reconstruction:* Interaction, negotiation and dialogue are encouraged in order to communicate learning in context, both of mathematics and of sustainable development based on the analysis of the documentation. The new co-constructed knowledge is contrasted with the prior knowledge, giving rise to the reconstruction of knowledge regarding mathematics and sustainable development. Possibilities to seek solutions, create alternatives or undertake actions to foster sustainable development in the classroom, in the school, and in the community are encouraged.
4. *Formalisation of learning:* The process concludes with the formalisation of learning acquired in mathematics and sustainable development, using language which is progressively more specific and adapted to the two disciplines.
5. *Systematic reflection:* A self-evaluation of the teacher's practice is carried out with the aim of improving it: What has been taught about mathematics and sustainable development? What has changed? How can it be improved?

In order to assist pre-service and in-service teachers to progressively change their mathematics teaching methods to have a perspective of sustainable development, taking into account all of the elements presented in this chapter, and particularly the model described, it is recommendable to use teaching strategies which guide this transformation. By way of example, one possible strategy may consist of promoting spaces for interaction, negotiation and dialogue based on episodes such as that described below:

From statistics education to statistics education in connection with sustainable development

During their break time, a group of 4–5-year-old children pay great attention to the vehicles using the roundabouts close to their school. Thus, the teacher proposes the following challenge: What type of vehicles go round the roundabouts most frequently? After a conversation in which the children debate different strategies to respond to the question, they decide to gather data by going out to the roundabout. They establish the categories of the statistical variable they wish to study (vans, lorries, cars, motorbikes, tractors and bicycles), collect data over a pre-established period of time in a tally chart, organise the data in a frequency table and, later, represent and interpret the data via a graph, using pieces of wood.

This competency-based mathematical activity makes it possible to identify the type of vehicles going round the roundabout and with which frequency they do so. But what use do these data and the conclusions obtained have? Having reached this point, the pre-service and in-service teachers must integrate the statistical research carried out with sustainable development. In this way, one more step is taken for teachers to research and reflect from the perspective of education for sustainable development and to learn, as stated by Tilbury [28], to ask critical questions, clarify their own ideas, propose more positive and sustainable futures, think systemically, respond via applied learning or study the dialectics between tradition and innovation with the aim of being able to promote the same learning among their own students.

The conclusions of the statistical research carried out based on the vehicles going round the roundabout can be enriched from the point of view of sustainable development by working on aspects connected with SDG 11 on sustainable cities and communities, and SDG 13 regarding climate change. In this framework, the following competencies could be fostered:

- *Anticipatory competency:* Let's imagine and draw what would happen if no vehicles, or mainly bicycles, went round the roundabout. How would the school's surroundings change? What impact would be noted in terms of safety? How would the noise we hear from the school change? What implications would there be in terms of our health and that of the drivers of the vehicles? Which scenario is more sustainable? And which do we prefer: the scenario we have detected or the one we have imagined?
- *Self-awareness competency:* Let's reflect on the route each child takes to come to school, which we can represent in a graph. What type of transport is used? How sustainable is our class in relation to the means of transport we use to travel to school?
- *Strategic competency:* What actions could we promote to encourage sustainable transport? We can present the data and results of the studies to families and to the council and prepare a plan of action in collaboration with older children. During the campaign, data can be collected in order to verify whether the actions taken have an impact, taking into account the need to reflect on the difficulty of changing behaviours and observing them in the short term.

Conclusion

In this chapter, arguments have been presented regarding the importance of establishing connections between mathematics education and sustainable development in teacher training based on an approach which stimulates sustainable development in university education [12, 18]. This approach assumes the proposals of the United Nations Decade of Education for Sustainable Development (DESD) which, as has been stated, is a worldwide movement aspiring to transform policies,

investment and practices in the field of education [10], highlighting not only the transformation of education, but also an improvement in the quality of life of many people throughout the world [28].

From this perspective, the integration of sustainable development into teacher training, which in the literature is called teacher education for sustainability (TEfS), is a growing field which aims to prepare future educators for their role as societal change agents by developing in them specific sustainability competencies [37–41]. The training of teachers in mathematics, as an essential part of teacher training, cannot be marginalised from this aim. Thus, for a number of years, we have been carrying out research on issues such as the definition of a profile of a mathematics teacher in connection with sustainable development [42] and the definition of a model to carry out teacher training in mathematics which is transformative, taking into consideration elements of sustainable development and realistic and reflexive learning [22].

In order for both pre-service and in-service teachers to have at their disposal guidelines for planning and carrying out practical teaching from this perspective, Alsina and Mulà [23] have recently integrated sustainable development into the Model of Mathematical Literacy in Childhood [46]. Via the six phases of which this model consists, from the planning of the context of the competency-based activity to reflection on how it is put into practice, mathematics teachers have at their disposal a tool to foster the development of mathematical and sustainable development competencies in an integrated way [23]. In order to achieve this, both pre-service and in-service teachers must transform the way they plan their teaching and how they put this teaching into practice. As far as the planning of activities is concerned, teachers should ask questions concerning the following aspects:

- Is it an activity which has the aim of providing an answer to a question, addressing a social, economic, environmental or healthcare challenge?
- Does the activity make it possible to apply previously acquired knowledge and to achieve new learning in the fields of mathematics and sustainable development?
- Does it help to relate different knowledge within mathematics and with other subjects from the perspective of sustainable development?
- Is it an activity which can be carried out in different ways and stimulate the students' curiosity and creativity?
- Does it imply the use of tools such as materials which can be manipulated, drawing tools, software, etc.?
- Does it involve collaboration with different agents?

As far as practical teaching is concerning, the following may constitute guiding questions for the transformation:

- Is student autonomy and initiative promoted?
- Is the intervention based more on appropriate questions than on explanations?

- As well as individual work and effort, is work in pairs or in groups employed in order to create dialogue, argue, convince, form a consensus, etc.?
- Does it imply reasoning regarding what has been done and the justification of results?
- Is increasingly accurate progress made in terms of representation?
- Is the most appropriate language of mathematics and sustainable development used?
- Does it promote critical reflection and the questioning of values?
- Does it enable actions in favour of sustainable development to be encouraged?

To sum up, this chapter has provided answers to the questions asked in its title: why, to what end and how can mathematics education and sustainable development be connected in teacher training in such a way that pre-service mathematics teachers can have the necessary knowledge at their disposal in their role as agents of social change [37–42]? Furthermore, this exemplification can serve as a guide for carrying out similar processes of transformation in other areas of knowledge of school curriculums due to the fact that it is based on the sum of changes that we will achieve the common objective of improving the quality of life of people around the world from the field of teacher training. This is an urgent need if the belief is held that teachers have the capacity to shape their countries.

References

1. Niss M (2002) Mathematical competencies and the learning of mathematics: the Danish Kom Project. Roskilde University
2. OECD (2006) Assessing scientific, reading and mathematical literacy—a framework for PISA 2006. OECD
3. OECD (2019) PISA 2018 mathematics framework. In: OECD (ed) PISA 2018 Mathematics framework. OECD, pp 73–95
4. NCTM (2000) Principles and standards for school mathematics. NCTM
5. Alsina Á, Maurandi A, Ferre E, Coronata C (2021) Validating an instrument to evaluate the teaching of mathematics through processes. Int J Sci Math Educ 19:559–577
6. CCEA (2020) Using mathematics. https://ccea.org.uk/foundation-stage/curriculum/using-mathematics
7. Bianchi G, Pisiotis U, Cabrera Giraldez M (2022) GreenComp The European sustainability competence framework. Publications Office of the European Union
8. UNESCO (2017) Education for sustainable development goals. Learning objectives. https://unesdoc.unesco.org/ark:/48223/pf0000247444
9. European Union (2022) Commission calls for environmental sustainability to be at the core of EU education and training systems. https://ec.europa.eu/commission/presscorner/detail/en/ip_22_327
10. UNESCO (2005) UN decade of education for sustainable development 2005–2014. https://unesdoc.unesco.org/ark:/48223/pf0000141629
11. UNESCO (2014) Shaping the future we want: UN decade of education for sustainable development final report. https://unesdoc.unesco.org/ark:/48223/pf0000230171

12. UNESCO (2014) UNESCO roadmap for implementing the global action programme on education for sustainable development. https://sustainabledevelopment.un.org/content/documents/1674unescoroadmap.pdf
13. UNESCO (2015) World education forum 2015. Final report. http://unesdoc.unesco.org/images/0024/002437/243724e.pdf
14. UNESCO (2016) Education for people and planet: creating sustainable futures for all. http://unesdoc.unesco.org/images/0024/002457/245752e.pdf
15. UNESCO (2018) Progress on education for sustainable development and global citizenship education. https://unesdoc.unesco.org/ark:/48223/pf0000266176.
16. United Nations (2015) Transforming our world: the 2030 agenda for sustainable development. https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf
17. United Nations (2020) Shared responsibility, global solidarity: responding to the socio-economic impacts of COVID-19. https://unsdg.un.org/sites/default/files/2020-03/SG-Report-Socio-Economic-Impact-of-Covid19.pdf
18. COPERNICUS Alliance (2012) Rio +20 treaty on higher education. COPERNICUS Alliance
19. Mulà I, Tilbury D, Ryan A, Mader M, Dlouha J, Mader C, Benayas J, Dlouhy J, Alba D (2017) Catalysing change in higher education for sustainable development: a review of professional development initiatives for university educators. Int J Sustain High Educ 18 (5):798–820
20. Orr DW (2013) Governance in the long emergency. In: The state of the world 2013: Is sustainability still possible? W.W. Norton, pp 279–291
21. Tilbury D (2014) Higher education: ESD actions around the World. In: Shaping the future we want: UN decade of education for sustainable development final report UNESCO, pp 113–128. https://unesdoc.unesco.org/ark:/48223/pf0000230171
22. Alsina Á, Mulà I (2019) Advancing towards a transformational professional competence model through reflective learning and sustainability: the case of mathematics teacher education. Sustainability 11:4039
23. Alsina Á, Mulà I (2022) Sumando competencias matemáticas y de Sostenibilidad. Implementar y evaluar actividades interdisciplinares. Uno, Revista de Didáctica de las Matemáticas 95:23–30
24. Calabuig T (2017) Connexions entre educació matemàtica i educació per a la sostenibilitat: definició d'un perfil de mestre de matemàtiques. Doctoral thesis. Universitat de Girona. Girona. http://hdl.handle.net/10803/401745
25. Calabuig T, Alsina Á, Geli AM (2013) Avances en la formación inicial de maestros de matemáticas a través de la educación para la sostenibilidad. Enseñanza de las Ciencias, Núm. Extra: 551–556
26. Calabuig T, Alsina Á, Geli AM (2017) Definición de un perfil de maestro de matemáticas en concordancia con la educación para la sostenibilidad. Enseñanza de las Ciencias, Núm. Extra: 281–286
27. The World Commission on Environment and Development (1987) Report of the world commission on environment and development: our common future. https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf
28. Tilbury D (2011) Education for sustainable development: an expert review of processes and learning. UNESCO
29. de Haan G (2010) The development of ESD-related competencies in supportive institutional frameworks. Int Rev Educ 56(2):315–328
30. Rieckmann M (2012) Future-oriented higher education: which key competencies should be fostered through university teaching and learning? Futures 44(2):127–135
31. Wiek A, Withycombe L, Redman CL (2011) Key competencies in sustainability: a reference framework for academic program development. Sustain Sci 6:203–218

32. Rychen DS (2003) Key competencies: meeting important challenges in life. In: Key competencies for a successful life and a well-functioning society. Hogrefe & Huber Publishers, pp 63–107
33. Weinert FE (2001) Concept of competence: a conceptual clarification. In: Defining and selecting key competencies. Hogrefe & Huber Publishers, pp 45–65
34. Guni (2012) Higher education in the world 4. Higher education's commitment to sustainability: from understanding to action. Palgrave Macmillan
35. Sterling S (2011) Transformative learning and sustainability: sketching the conceptual ground. Learn Teach Higher Educ 5:17–33
36. Ryan A, Tilbury D (2013) Uncharted waters: voyages for education for sustainable development in the higher education curriculum. Curric J 24(2):272–294
37. Brandt J-O, Barth M, Merritt E, Hale AE (2021) A matter of connection: the 4 Cs of learning in pre-service teacher education for sustainability. J Clean Prod 279:123749
38. Ferreira J-A, Ryan L, Tilbury D (2007) Mainstreaming education for sustainable development in initial teacher education in Australia: a review of existing professional development models. J Educ Teach 33(2):225–239
39. Ferreira J-A, Ryan L, Davis J, Cavanagh M, Thomas J (2009) Mainstreaming sustainability into pre-service teacher education in Australia. Australian Government Department of the Environment, Water, Heritage and the Arts
40. Ferreira J-A, Ryan L, Tilbury D (2014) A response to reorienting teacher education towards sustainability. Aust J Environ Educ 30(1):147–148
41. Timm J-M, Barth M (2020) Making education for sustainable development happen in elementary schools: the role of teachers. Environ Educ Res 27(1):50–66
42. Alsina Á, Calabuig MT (2019) Vinculando educación matemática y sostenibilidad: implicaciones para la formación inicial de maestros como herramienta de transformación social. Revista de Educación Ambiental y Sostenibilidad 1(1):1203
43. Vásquez C, Seckel MJ, Alsina Á (2020) Belief system of future teachers on education for sustainable development in math classes. Uniciencia 34(2):1–15
44. Murga-Menoyo MA (2015) Competencias para el desarrollo sostenible: las capacidades, actitudes y valores meta de la educación en el marco de la Agenda global post-2015. Foro de Educación 13(19):55–83
45. Korthagen FAJ (2001) Linking practice and theory: the pedagogy of realistic teacher education. Lawrence Erlbaum Associates
46. Alsina Á (2017) Caracterización de un modelo para fomentar la alfabetización matemática en la infancia: vinculando la investigación con buenas prácticas. AIEM, Avances de Investigación en Educación Matemática 12:59–78

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