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Promoting Mathematics Teacher Education for Sustainability through a STEAM approach

Promoviendo la formación del profesorado de matemáticas para la sostenibilidad desde un enfoque STEAM

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Abstract ∞ The aim of this study is to analyse the effect of a previously validated training program to promote Mathematics Teacher Education for Sustainability (MTEfS). The training program, designed from a STEAM approach and called Pro-STEAM, involved 23 in-service Chilean teachers. For data collection, a questionnaire was administered before and after the Pro-STEAM program; and the design and implementation of a statistical task relating to sustainability, within the practical phase of the program, was analysed. The results show that: 1) following the Pro-STEAM training program, over 60% of the participants reached an advanced level in Sustainable Development Goals involved; 2) by designing and implementing the statistical task, they developed competences linked to the teacher learning objectives to promote Education for Sustainable Development. It is concluded that MTEfS is an emerging research agenda for creating positive social solutions.

Keywords ∞ Mathematics teacher education; Sustainability; STEAM education; Statistics education; Mathematics teacher professional development

Resumen ∞ El objetivo de este estudio es analizar el efecto de un programa de formación previamente validado para promover la Formación de Profesores de Matemáticas para la Sostenibilidad (MTEfS, por su acrónimo en inglés). En el programa de formación, diseñado desde un enfoque STEAM y denominado Pro-STEAM, participaron 23 profesores chilenos en activo. Para la recolección de datos, se administró un cuestionario antes y después del programa Pro-STEAM; y se analizó el diseño e implementación de una tarea estadística relacionada con la sustentabilidad, dentro de la fase práctica del programa. Los resultados muestran que 1) tras el programa de formación Pro-STEAM, más del 60 % de los participantes alcanzaron un nivel avanzado en los Objetivos de Desarrollo Sostenible implicados; y 2) mediante el diseño e implementación de la tarea estadística, desarrollaron competencias vinculadas a los objetivos de aprendizaje docente para promover la Educación para el Desarrollo Sostenible. Se concluye que MTEfS es una agenda de investigación emergente para crear soluciones sociales positivas.

Palabras clave ∞ Formación del profesorado de matemáticas; Sostenibilidad; Educación STEAM; Educación estadística; Desarrollo profesional del profesorado de matemáticas

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1. Introduction

Teacher Education for Sustainability (TEfS) is currently a trend topic, due to the need to provide educational support in the different issues covered by the Sustainable Development Goals (SDGs): poverty, health, education, climate, industry, gender equality, etc. (UNESCO, 2017).

The social, economic and environmental changes associated with these issues have been (and are) the great challenges that the world has been faced with in the last decades of the 20th century and so far in the 21st century. For this reason, public and business policies on sustainable development have been the focus of attention to combat global warming, social conflicts and economic crises (UNESCO, 2020). Within this framework, an increasing number of governments are proposing that sustainability be addressed in a cross-cutting manner throughout schooling, including higher education, and integrated into the different areas of knowledge (UNESCO & Education International, 2021).

This is a major paradigm shift, which requires new ways of thinking about teacher education. In this sense, from research in mathematics education, some authors have started to investigate the integration of education for sustainable development in mathematics teacher training, with the aim that this will have an impact on the training that students at different educational stages will receive in the future. This emerging research agenda, which considers mathematics teachers as agents of social change, has so far addressed a variety of issues such as characterization of a mathematics teacher profile in connection with sustainability (Alsina & Calabuig, 2019); development of training models based on sustainability to promote the transformation of spontaneous knowledge (previous experiences, knowledge and beliefs) into professional knowledge (Alsina & Mulà, 2019); design and validation of training programs for teachers (Silva-Hormazábal & Alsina, 2022); etc. Additionally, more specific research has linked sustainability to a specific mathematical content standard, especially statistics. This link assumes that statistics education requires real contexts to pose challenges that promote the development of statistical literacy (Rodríguez-Muñiz et al., 2022, Alsina et al., 2023). In this sense, for example, the Secretary General of the United Nations pointed out, in the midst of the pandemic caused by covid-19, that "this year, as the world deploys its data to respond to a common challenge, let us use World Statistics Day to highlight the role of statistics in promoting sustainable development for all" (Guterres, 2020, p. 1). From this framework, issues such as strategies to link statistics and sustainability in mathematics teacher education (Vásquez & Alsina, 2021); the presence of sustainability in mathematics textbooks (Vásquez et al., 2021) or the required changes in teachers' knowledge (Vásquez et al., 2022) have been analysed.

In order to foster professional development in the field of Mathematics Teacher Education for Sustainability (MTEfS), a study of 23 in-service teachers which aimed to analyse the impact of a STEAM training program focused on sustainability is described. Specifically, this study has two objectives: 1) to investigate the type of teaching that teachers carry out, or would carry out, concerning the SDGs (specifically, SDG 5 on Gender Equality and 13 on Climate Action) via the administration of a questionnaire before and after the training program; 2) upon completion of the program, to analyse the design and implementation of a statistical task related to sustainability highlighting the two above mentioned SDGs.

2. Mathematics teacher education for sustainability

In order to integrate Education for Sustainable Development (ESD), Tilbury (2011) pointed out that it is necessary to learn to ask critical questions, to clarify one's own values, to envisage more positive and sustainable futures, to think systematically, to respond via applied learning and to study the dialectics between tradition and innovation (p. 8). Later, UNESCO (2017) stated that it is necessary for education to be holistic, inclusive and transformative, taking into account different objectives for teachers with the aim of promoting ESD: a) the contents and results of learning (the integration of sustainability issues into study plans); b) pedagogy and learning contexts (student-centred teaching and learning oriented towards action based on interaction and exploratory learning); c) the product of the learning (promotion of skills such as critical and systemic thinking, joint decision-making, the assumption of responsibility by current and future generations); and d) social transformation (empowering learners of any age and any educational context to transform themselves and the society in which they live).

Clearly, this is a challenge which requires an evolution from teaching to learning in order to educate current and future generations regarding sustainability. This requires "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" (UNESCO, 2017, p. 7). Therefore, it is hoped that via ESD current and future generations can achieve specific cognitive, socio-emotional and behavioural learning and, above all, develop key sustainability competencies, which are necessary for contributing to the comprehension and achievement of each of the particular challenges of the Sustainable Development Goals (SDGs).

In this context, the integration of TEfS is a growing field which aims to prepare future educators for their role as agents of social change by developing specific sustainability competencies (Brandt et al., 2020; Ferreira et al., 2014; Timm & Barth, 2020).

As an essential part of teacher training, the training of mathematics teachers cannot be excluded from this goal. The use of mathematics is currently one of the cross-cutting competencies which constitute the core of the curriculum as it enables the development of the ability to appropriately apply mathematical knowledge, comprehension and skills in different contexts and in different ways to communicate, manage information, think critically, resolve problems and take decisions (Council for the Curriculum, Examinations & Assessment [CCEA], 2020).

From this perspective, and with the aim of providing pre-service mathematics teachers with knowledge and strategies to enable them to contribute to the construction of a more inclusive, sustainable and resilient future for people and the planet, Alsina & Calabuig (2019) carried out an exploratory study in order to define the actions required for the promotion of sustainable development. From the data obtained, these authors highlight 20 elements of a profile of a mathematics teacher in connection with sustainable development, including the need to understand and appreciate mathematics in its disciplinary essence and its role as an agent of change, both social and cultural, in order to transmit it to students, and to work on EDM in a globalised and interdisciplinary way, amongst other actions.

Aiming to provide pre-service teachers and lecturers with the necessary tools to make progress in this direction, Alsina & Mulà (2019) developed the Transformational Professional Competence Model through Reflective Learning and Sustainability. This model describes some essential strategies for promoting the transformation of the everyday knowledge of pre-service mathematics teachers (knowledge, experiences and prior beliefs) into professional knowledge via the framework of ESD and using the model of realistic and reflexive training (Korthagen, 2001).

Based on these preliminary studies, Alsina (2022) integrates sustainability into the Model of Mathematical Literacy in Childhood (Alsina, 2017), with the aim of provoking authentic feedback and enrichment between mathematical education and sustainable development. Thus, the aim is not to offer guidelines for mathematics teachers to plan teaching practices in sustainability contexts or to integrate knowledge on sustainability when planning mathematical activities. Rather, what is sought is for mathematics teachers to plan and carry out teaching practices with the aim of reorienting the learning experiences of students so that they understand their professional responsibilities, capabilities and personal motivations (Mulà et al., 2017).

Other recent studies which integrate sustainability into mathematics teacher training focus on innovation and, consequently, the transformation of training plans. For example, Helliwell & Ng (2022), suggest that generative methods which support teachers in speculating on paths to potential futures as teachers of mathematics, can provide access to how prospective teachers negotiate issues in relation to the climate crisis and ways in which they conceive of related changes in their practices. According to these authors, by identifying the aspects of mathematics teaching that are viewed by the prospective teachers as contingent, and through offering tasks that support an expansion of this view, teacher educators are better placed to support the development of teaching practices needed for sustainable futures.

Studies have also been carried out with in-service mathematics teachers looking into the role of interaction, negotiation and dialogue as tools for the co-construction of knowledge around sustainability. Zhang et al. (2021), for example, reveal how mathematics teachers initiate informal interactions based on shared objectives, how they fulfil the expectations of the double role of teaching and educational research and how they perceive the effects of informal interactions in their teaching to advance towards sustainable professional development.

These studies show that mathematics teacher education for sustainability is an emerging research agenda which addresses such issues as professional teacher development and the teacher's interaction, context and practice. Until recently, these issues were addressed exclusively from the point of view of mathematics education research. However, nowadays they are beginning to be studied from an integrated perspective with education for sustainability.

3. Method

The STEAM training program focused on sustainability was named Pro-STEAM and was previously validated by experts in both the STEAM approach and ESD. The main focus of the program is to promote MTEfS through STEAM education. It consists of twelve 90-minute sessions, organised into three modules: a) Education for the 21st century; b) STEAM education; c) STEAM implementation. Table 1 shows the topics of each module that are developed in each session. All sessions have been designed from a gender equality and sustainability skills development perspective (Silva-Hormazábal & Alsina, 2022).

Table 1. Pro-STEAM training program

Module	Objective	Sessions	
Education for the 21st century	To update knowledge on the educational needs of 21st-century citizens, promoting education based on competencies for sustainable development.	1. Competencies for 21st-century citizens. 2. The nature of science. 3. Competencies for an education in sustainability.	**Development of 4 C skills**
STEAM education	To identify opportunities for disciplinary integration present in the curriculum via methodologies such as project-based learning, problem-based learning, situated learning and reverse engineering in significant contexts.	4. STEAM education from an integrated approach: Origin and foundations. 5. Curricular guidelines and interdisciplinarity. 6. Methodologies for the implementation of the integrated STEAM approach.	
STEAM implementation	To design STEAM experiences implemented via methodologies which promote the integration of at least two disciplines in a context which is challenging for students and which is jointly evaluated by teaching teams.	7. Co-teaching. 8 & 9. Practical design session. 10. Evaluation via the integrated STEAM approach. 11. Practical session – evaluation of learning. 12. Co-evaluation of the designs.	
Gender perspective: The role of gender in classroom interactions; the implementation of teaching practices with gender perspective.			

3.1. Sample

The selection of the sample was both non-probabilistic and by convenience (Otzen & Manterola, 2017).

A total of 23 in-service Chilean primary teachers participated as part of the Pro-STEAM on-going training program over the course of one school semester. All of these teachers participated voluntarily in the study and signed a consent form for the use of their work. However, in the interests of anonymity, they were all assigned a number from 1 to 23 (in this paper, teacher 1 will be referred to as T1, etc.).

Primary teachers made up 65% of the total participants, with the rest being teachers from other stages of education. As far as the participants' professional experience is concerned, 65% had more than 10 years of experience. The sample can, therefore, be considered to be experienced. As for the type of school in which the participants worked, 61% were from rural schools, with the remaining 39% working in urban schools. Furthermore, of those working in rural schools, 30% taught students from different levels in the same class. It should be highlighted that all of the schools which participated in this study belong to an island area in the south of Chile.

3.2. Data collection

The data for this study were collected from an open-ended questionnaire, the design and implementation of statistical tasks and interviews.

The questionnaire, previously validated by experts with experience in both the STEAM approach and ESD, was administered before and after the Pro-STEAM program and consisted of two domains: STEAM and Sustainable Development. The STEAM domain contained five sub-domains and the Sustainable Development domain (the focus of this study) contained two sub-domains: *Gender Equality and Climate Action,* relating to SDGs 5 and 13, respectively. The questionnaire consisted of seven items with open-ended questions (one for each sub-domain). This type of question was selected as it permits those surveyed to provide answers in their own words (Fink, 2003). For the purposes of this research, only items 6 and 7 have been considered (Table 2).

Table 2. Items considered from the questionnaire

SDG	N° item	Question
Gender equality	6	Dasgupta & Stout (2014) have reported that girls move away from STEM studies from childhood and adolescence. What do you or would you do as a teacher to close this gap?
Climate action	7	Considering the growing climate crisis in the world as a whole and in Chile in particular, what action would you propose from the teaching of your subject to mitigate or resolve the effects of climate change in your region?

This selection of these two SDGs responds to the characteristics of Pro-STEAM program which, as already mentioned, is focused on gender equality. Regarding climate action, it is included because the training is developed in an area where the location and its geographical and climatic characteristics allow for the contextualization of learning.

Within the practical phase of the Pro-STEAM program, all participating teachers collaboratively design integrated STEAM activities with a focus on sustainability. These activities consider data from preliminary studies linking sustainability and statistics (Vásquez & Alsina, 2021; Vásquez & García-Alonso; 2020; Vásquez et al., 2022), as noted in the introduction. As an example, a task has been selected for 5th and 6th grade students (11-12 years old), which has been designed and implemented by a team of four teachers.

After the implementation of the statistical tasks, interviews were conducted with the teams of teachers. The questions were open-ended, about what they had done and how, i.e. they were asked to describe the experience they had done. All of the interviews were recorded as audio tracks and were later transcribed.

3.3. Data analysis

Questionnaire data were analysed using a mixed approach. For the qualitative analysis, content analysis techniques were used (Rico & Fernández-Cano, 2013). Once the questionnaire was applied, the data was loaded into MAXQDA Analytics Pro 2022 software before being coded and analysed.

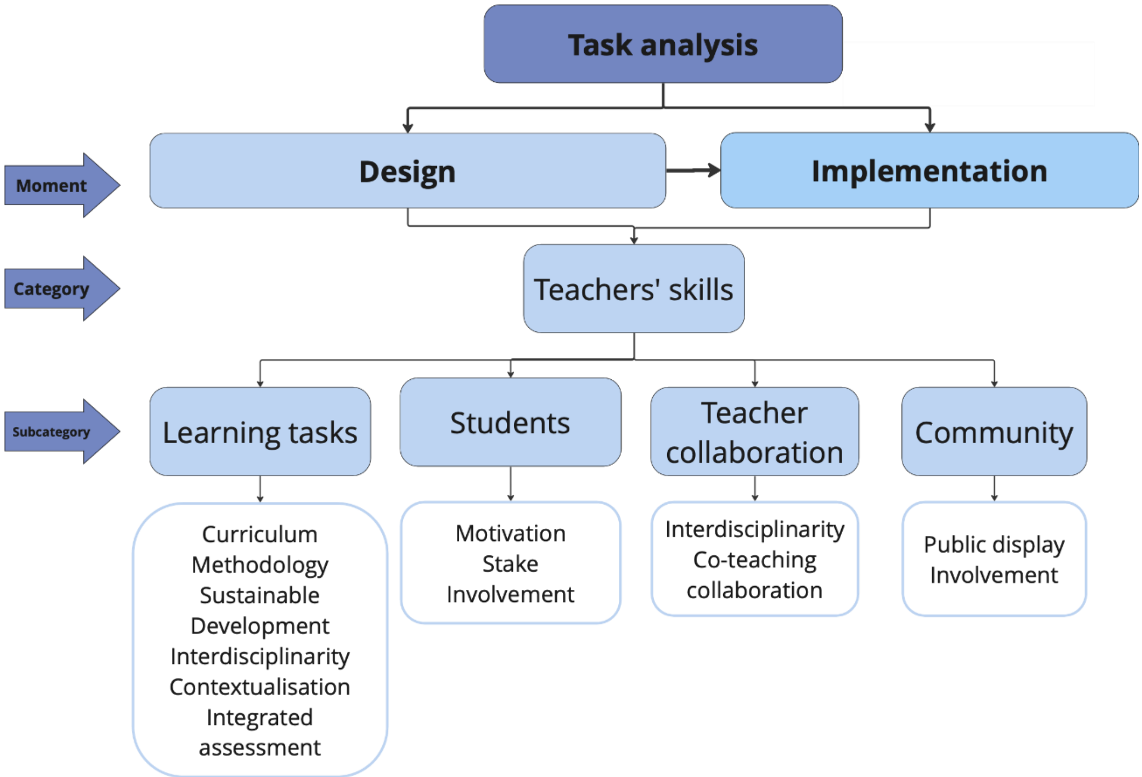
For the quantitative analysis, a rubric was built based on the learning objectives for teachers for the promotion of EDS described in the theoretical framework (UNESCO, 2017). Thus, it was possible to characterise and categorise the types of response obtained into four levels of action (Table 3).

Table 3. Response categories to the questionnaire

Level of action	Description	Example
Advanced	Demonstrates mastery of the SDGs, describing specific, explicit and contextualised actions which he/she does or would do, in which he/she is clearly involved as a teacher and/or citizen. Carries out specific actions which are related with his/her professional responsibilities (planning, approaches, methodologies, etc.) and which can involve different members of the school community.	I believe that the best place to generate change is at school, integrating in a transversal and interdisciplinary way, activities that help students to value and practice ways to improve the climate crisis; to graduate from school with attitudes of respect towards the environment; and to project those learnings in their context. (T12)
Intermediate	Proposes specific actions, describing certain aspects of how or why, along with his/her professional responsibilities in this regard.	Integrate female students from the beginning in all activities. Give them specific tasks, make them monitors, and also encourage them through examples of other women who have made history in these fields (T20).
Basic	Proposes generic actions but without describing them or demonstrating professional responsibilities, such as planning or the design of artifacts.	Providing equal opportunities for girls and boys in the classroom (19).
Unsatisfactory	Does not describe actions or claims to have no knowledge of the topic.	No answers were obtained at this level

To analyse the design and implementation of the statistical task (Figure 1), content analysis techniques (Rico & Fernández-Cano, 2013) are used.

Figure 1. Flow chart if the analytical process



In order to obtain categories and subcategories, we used as theoretical references the guidelines provided during the Pro-STEAM training, which include: a) cognitive, socioemotional and behavioural domains that should be included in the design of a task for sustainable development (UNESCO, 2015; 2017); b) contextualization of learning (OECD, 2018; Márquez and Roca, 2006); and c) statistical research cycle (Bargagliotti et al., 2020). Additionally, the framework of the Development of Teaching Skills (Perrenoud, 2004) is also considered (Table 4).

4. Results

In accordance with the aims of the study, first of all, the data of the two items of the questionnaire corresponding to the sustainable development dimension were analysed. Subsequently, the design and application of the statistical task relating to sustainability was analysed, and finally, these results were complemented by the interviews.

Table 4. Development of Teaching Skills

	Description
Learning tasks	Curriculum: Shows that he/she knows the curriculum, fostering interdisciplinarity in an organic way, focused on the context and the resolution of real-world problems. Methodologies and strategies: Show knowledge of strategies and methodologies which are appropriate for STEAM. Sustainable Development Goals: the task clearly and specifically integrates a gender equality perspective, as well as a link with another of the SDGs. Coherence: Presents objectives, products and assessments which are coherent among themselves and attainable within the established timelines. Evaluation: Proposes a series of evaluations (formative and summative) which make it possible to demonstrate progress during the process and a product which can be evaluated in an interdisciplinary way.
Students	Explain the relationship with the knowledge: The task begins with a problem which connects the students to the learning. Awaken the desire to learn: The students' motivation and participation is maintained throughout the course of the task, encouraged by its connection with their environment and interests. Meaning of schoolwork: The task encourages teamwork and student autonomy and creates space for self-evaluation.
Teacher collaboration	Interdisciplinary, collaborative and co-teaching work is demonstrated.
Community	The community is included both in the public exhibition and in taking part in the problem.

4.1. Analysis of the responses to the questionnaire

4.1.1. Gender equality (SDG 5)

With regard to the content and quality of the responses, in the pre-test, the answers were brief and simple concerning just one action. In general, these answers were focused on motivation and providing opportunities, albeit without specifying how they would be carried out or their level of involvement, so that, before the training, most of the participants were at a basic level. However, much more elaborate and complete answers are evident in the post-test, as they included theoretical elements and specific actions to be carried out in which the teacher is involved. These include reflecting on their responsibilities, proposing actions within the classroom and others on an institutional level or which involve the students' families, corresponding to an advanced level.

Therefore, in the pre-test, there was a concentration of the answers in the basic and intermediate levels. Indeed, 65.2% of the answers can be categorised in the basic level and 0% in the advanced level. On the other hand, in the post-test, 56.5% of the answers correspond to the advanced level, with only 4.3% of the responses being situated in the basic level (Figure 2).

Figure 2. Gender equality: Response levels pre- and post-test

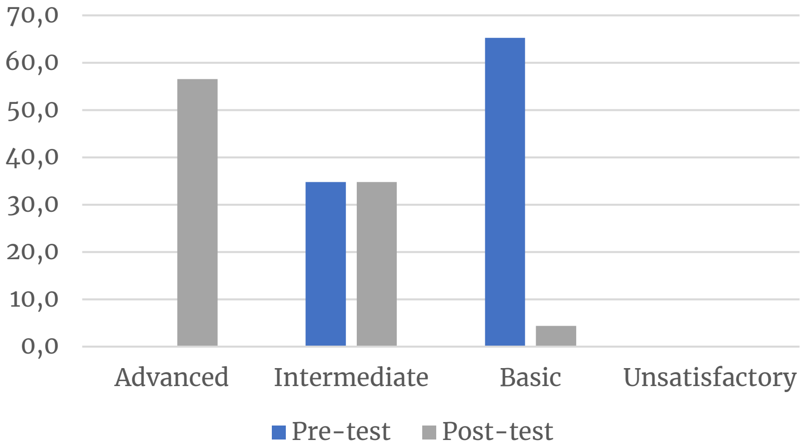


Table 5 exemplifies the participants' evolution through some quotes. T1 moved from a basic to an advanced level, showing the evolution from a lack of involvement to reflection on her own actions, her role in the process and how she can contribute to change from her position. T10 moved from an intermediate to an advanced level. In her response to the pre-test, she highlighted that she would carry out certain actions. However, the change is significant, not only in terms of the extension of her answer, but also in her way of reflecting and in her proposal for specific actions which include learning obtained from the teacher training process, such as searching for solutions to real-world problems via contextualised learning experiences.

Table 5. Gender equality: Direct quotes pre- and post-test

Pre-test	Post-test
A gender focus from pre-school level (T1)	The course made me reflect on everyday practices which lead one to reinforce this stereotype. The first step is to raise awareness and what I would do in my role as school principal is to firmly implement investment in teaching resources for learning in the sciences, the premises and staff training to give this the place that it deserves in the curriculum via a process of experiential learning in order to encourage an interest in these issues among our students from the first years of pre-school education (T1).
Continue to develop learning experiences avoiding gender bias (T10)	Women drop out of all levels of education due to having to shoulder the burden of caring for family members. Furthermore, in certain areas they are a minority, leading to a bias regarding their performance. I will continue to develop learning experiences which enable my students to learn by doing. This is directly connected to managing to encourage my boys and girls to discover their world from nature, from their own contexts and closest realities in order to then broaden our perspectives and knowledge. Generating solutions to problems of our everyday lives, which, without a doubt, will enable me to deliver significant learning as it is relevant, real and immediate to them (T10).

4.1.2. Climate action (SDG 13)

The analysis of the content and quality of the responses shows a greater mastery of the topic of climate change compared to that of gender equality. The participants produced more elaborate responses, stating a wide range of specific actions which, in some cases, included other members of the school community. Furthermore, some teachers identified methodological strategies to be implemented in their classes. However, a large number of responses focused on *caring for the environment* without stating any specific teaching actions.

As far as the post-test is concerned, more complete responses can be observed in which specific actions to be taken by the school community are identified. These include efficient systems for the re-use of water, greenhouses with systems for the collection of rainwater, trekking routes in rural and coastal areas to collect litter, the installation of composting bins for organic waste in the school kitchen, the separation of waste for making eco-bricks and campaigns to achieve energy efficiency at school.

The importance of making people aware of the fact that it is necessary to look after the environment was clear in the participants' responses. However, unlike in the pre-test, they proposed actions in the context of their local area, involving the school community and the students' families as important actors. It is also possible to observe a strong trend towards the proposal of actions relating to water preservation and the handling of waste.

In Figure 3 shows that teachers' responses were distributed across all of the different levels. However, there was a greater concentration of answers in the basic and intermediate levels, which comprised 73.9% of the total answers. In the post-test, the majority of responses (65.2%) were situated in the advanced level with 0% in the unsatisfactory level.

Figure 3. Climate action: Response levels pre- and post-test

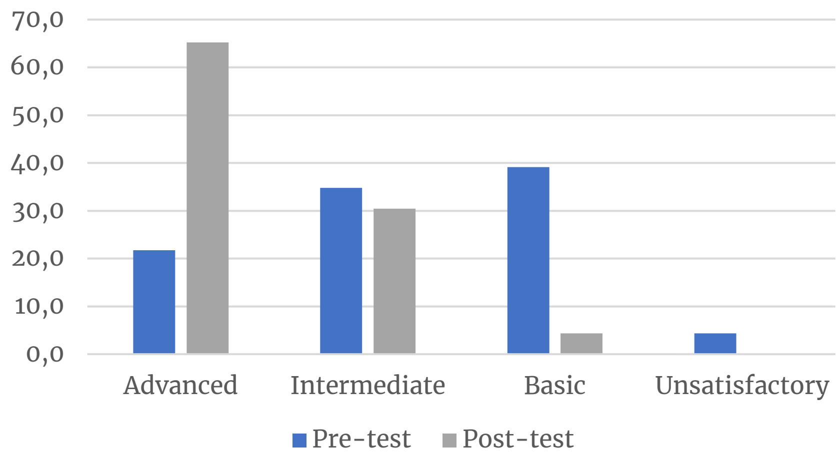


Table 6 exemplifies with some direct quotes the changes between pre- and post-test. T10 evolved from a basic to an intermediate level. Initially, her response was restricted to a generic proposal with no teacher involvement. However, in the post-test, she proposed specific actions, although she did not specify her responsibilities or a connection with the community. T23 went from intermediate to advanced and it is possible to observe how he reflected on his own role in the process as a citizen and a teacher. He identified local opportunities which can be linked to the SDGs and shows what he learned in courses relating to strategies, contextualisation and connecting with the community. Furthermore, a transformation oriented towards action can clearly be observed.

Table 6. Climate action: Direct quotes from pre- and post-test

Pre-test	Post-test
Working on environmental issues with the whole school community (T10).	Education for the school community and the local community. Carrying out specific actions in school which mitigate the damage of pollution: efficient use of water and energy; treatment of organic and inorganic waste; cleaning up; planting trees, etc. (T10).
Fostering a critical spirit for students to be aware of, appreciate and respect their environment; for them to become responsible citizens from an early age, agents for transformation who are innovative, creative and restorative (T23).	The first thing is to reflect on my own habits and activities at school ... activities which lead to the reproduction of habits and attitudes. Then, engage in thoughtful dialogue in collaboration with teachers and teaching assistants with the aim of raising awareness of the issue, seeking solutions and putting forward environmentally-friendly proposals. Based on both the adults' and the students' experiences, educational experiences can be carried out both inside and outside of the classroom and the school premises to raise awareness and enter into open discussion with the community. In this way, proposals can be put forward and projects generated which are effective in reducing our impact on the environment and which lead to an improvement in the environmental conditions causing the climate crisis in the short, medium and long terms. In a more everyday way, this problem can be approached in an interdisciplinary way, encouraging reflection and, above all, reasoned arguments, awakening an interest in the issue and the present and future consequences of this crisis (T23).

4.2. Design and analysis of the implementation of a statistical task related to sustainability

4.2.1. Design of the statistical task

The design of the statistical task has been based on the context and the integration of STEAM disciplines, in accordance with the training program. As far as the context is concerned, the local, global (OECD, 2018) and socio-scientific contexts were taken as points of reference (Márquez & Roca, 2006). The task was set in the context of the estuary of the Mapa river in Chiloé (Chile) (local context) and focused on SDG 13 on Climate Action (global context).

The design process has been sequential, with the opportunity to design the task step by step. For this, the identification of a problem, contextualization and its link with the curriculum was key. In order to successfully achieve this phase, they were given scaffolding, with examples and previous practice, as well as a design guidance template (Silva-Hormazábal & Iturbe-Sarunic, 2022). In addition, the dimensions proposed by UNESCO 2015) have been considered (Figure 4).

Figure 4. Conceptual framework for the creation of the task (based on UNESCO, 2015)

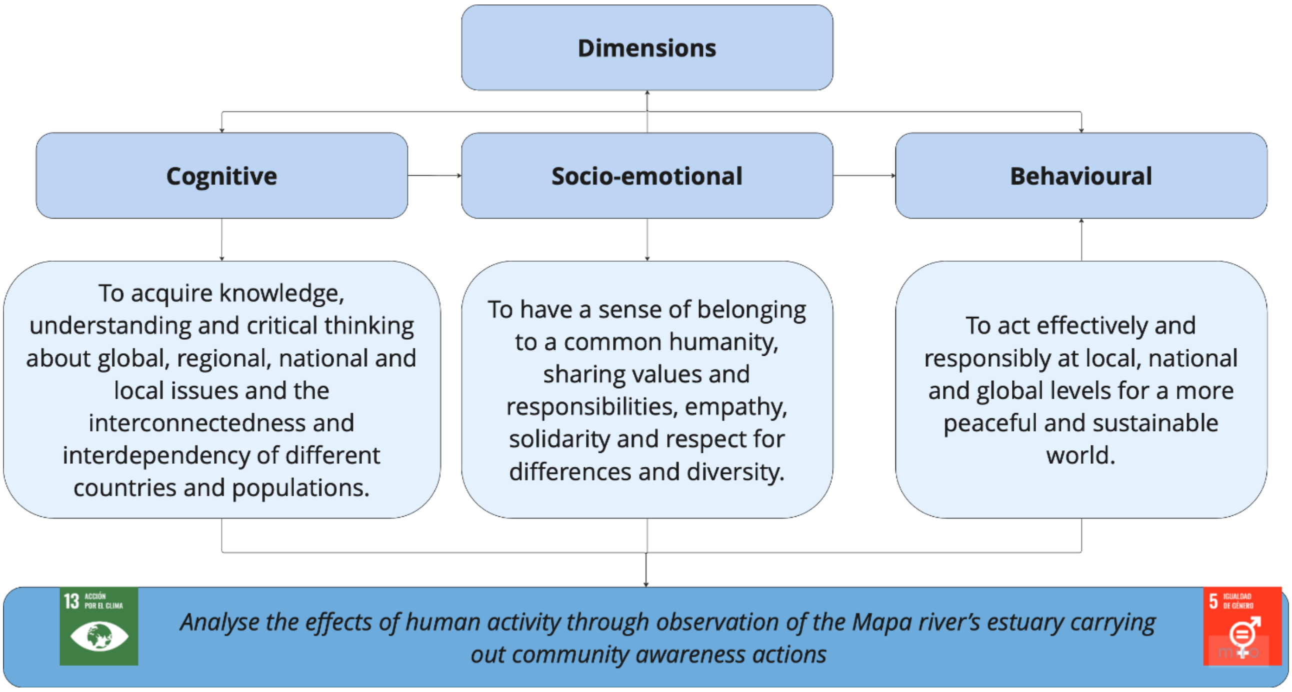
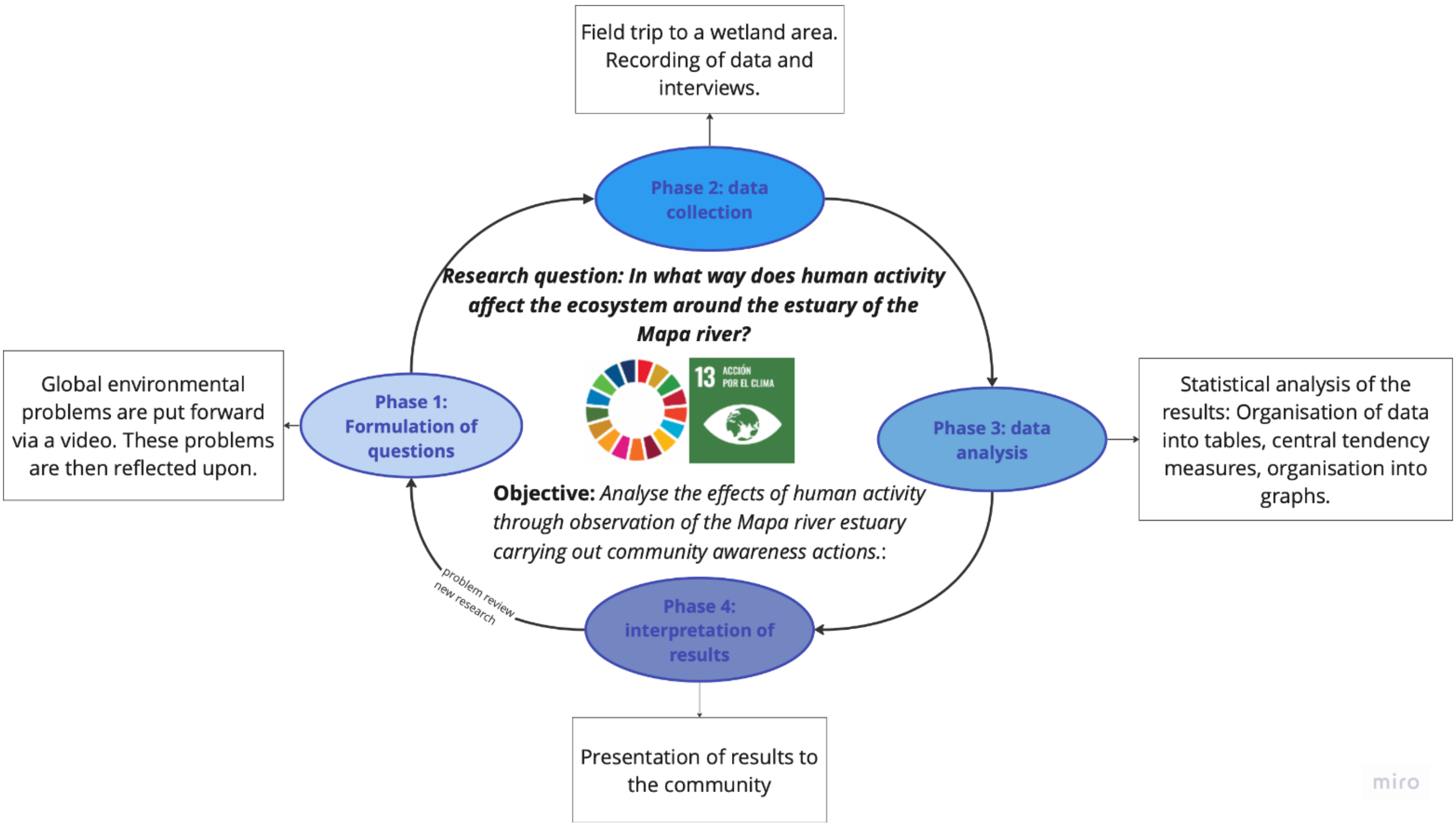


Figure 5 details the task's phases, which, as previously mentioned, follow the statistical research cycle of Bargagliotti et al. (2020).

Figure 5. Phases of the statistical task



Formulation of questions: The students think about the question *What type of waste is most present in the estuary?* The aim of this is to identify possible sources of greater pollution. It is of interest to note that, initially, the students believe the fishing companies are mainly responsible for the pollution.

Data collection: Research is carried out in the field in order to determine what type of waste (household or industrial) is most present. This information is recorded in charts. At the same time, residents and employees of the fishing companies are interviewed in order to discover if they are aware of the pollution and who is responsible for it.

Data analysis: Graphs are created and central tendency measures are applied.

Interpretation of results: The students conclude that the majority of waste originates from households, inferring that it is they and their community who are responsible for most of the pollution, although industrial fishing waste is also present.

This conclusion is of vital importance as it motivates the students to visualise the process of statistical research and encourages them to take action for change on a community level. To this end, they organise a six-step public display: 1) A photographic display, accompanied by a shocking motto to make the viewer reflect on the situation; 2) A visual artistic display which shows the contrast between the existing reality and the dream of achieving a clean and safe environment; 3) A statistical display: Via the presentation of graphs and tables, the students present the problem and the findings of the research to the community; 4) Commitments: The community is invited to put real and feasible commitments into writing in order to improve the current problem of pollution; 5) A display of the reuse of waste materials which expresses creativity and opportunities to reduce the amount of waste which reaches land-fill sites, lending them a new lease of life; 6) Members of the community who contribute to the change (old women who recycle and craftspeople, a local primary recycler, a representative of the community's environmental office).

4.2.2. Analysis of the statistical task

As previously mentioned, the task has been analysed considering the design and the implementation.

According to this, it can be observed how the theoretical elements learned during the training come to life. What is seen is a group of empowered teachers who bring about significant learning among their students but, above all, who promote actions which favour care for the local environment both among their students and the wider community. The in-service teachers were successfully able to link a real-world problem from their local environment with elements of STEAM disciplines. Specifically, in mathematics, they employed the statistical cycle to encourage comprehension of the problem, both among the students and the community.

With regard to the implementation, the process proved what was reflected in the planning phase, an integrated teaching unit in which students play a leading role and even issue a wake-up call to the community. One of the teachers stated that for her this teaching unit implied "a change of paradigm in the education we are offering here. Although we try to get the children more involved, maybe we didn't have the necessary tools to achieve this" (T23). Furthermore, the same teacher stated that "[the students] also realised that it was not enough for them to take action. It was also necessary for them to issue an invitation to other members of the community so that they could, hopefully, follow their example" (T23).

For the design and implementation, the development of teaching skills was analysed on the basis of four subcategories: Learning tasks, Students, Teacher collaboration, and Community (Table 7).

Taking into consideration the categorisation employed in the questionnaire, it can be observed that the actions originating from this task lie within the *Advanced* level. This is due to the fact that specific action is proposed which includes both *climate action* and *gender equality* as essential parts of the design. On the one hand, a contextualised problem is investigated concerning the quality of the local environment and, on the other hand, the design and pedagogical decisions for its implementation clearly include a gender approach.

In addition, the use of a planning format that favoured the integration of subjects, not only in the development of learning, but also in integrated assessment, for which teamwork was of vital importance, was appreciated. This was corroborated by one of the teachers, who stated the following: "for example, for us as colleagues, working as a team, carrying out collaborative work was extremely enriching and of great importance in achieving the aims" (T20).

Last of all, as far as the teachers' impressions at the end of the implementation, they stated that:

> It was wonderful because the island has a lack of opportunities for ongoing training and this training process was like a prize for us, an award for our effort, or something like that ... we were empowered and a world of possibilities was opened up to us for generating significant new learning experiences as a result of this project ... and now I believe being a part of the STEAM network opens us up to the world. (T21)

Table 7. Teachers' skills

	Observations	Direct quotes teachers
Learning tasks	Curriculum: The teachers managed to integrate the curriculum with a real and contextual problem, using statistical analysis and interdisciplinarity to find a solution to the problem identified. Methodologies and strategies: they managed to design and implement a statistical research cycle, using project-based learning methodology. Sustainable Development Goals: both in the design of the task and in the implementation, the intentional and planned linking of the SDGs was observed. In addition, they were able to include a gender perspective throughout the whole experience. Coherence: The goal, product and evaluation they planned and developed had a clear connection, which provided coherence. Evaluation: they thought and implemented an evaluation process that manages to evaluate both the discipline, as well as across disciplines through the presentation of the final product.	We managed to connect several subjects of the curriculum with a common objective in which the students were able to demonstrate, explain and argue the process and its results (T21). Instances of significant learning can be generated as they originate from the students' own context. We were already aware of the fact that we are educating citizens, but now we are aware that we are forming human beings for sustainability and that this is essential for the times we are living in. Pedagogical reflection has begun to be handled differently, in a more interdisciplinary way (T21).
Students	Explain the relationship with the knowledge: Through mediation, they ensured that the identification of the problem is carried out in the field and by the students. Awake the desire to learn: the integration of students in the identification of the problem kept them motivated during implementation and even involved their families. Meaning of schoolwork: The task encouraged teamwork and student autonomy, as well as self-evaluation.	They have realised that there are many human activities which affect this environment and have committed themselves to carrying out many actions to care for it and protect it. [Students] have also shown more interest in science. I think there is more interest in all areas, at least in those who participated in the project (T23).
Teacher collaboration	Teachers developed an interdisciplinary planning work that even includes the special educator. They managed to work on statistics education in an interdisciplinary way and visualized collaboration as an effective way of working.	This process led us to work in a more collaborative way. In effect, all the paradigms of working based on individual subjects were broken down: language for language, mathematics on its own ... we had never worked on all subjects in search of a common objective and this meant that all the skills of the teachers and students could be pooled together and complement each other (T21).
Community	Teachers motivated the students to involve their families and the community, so that they attended the public display and committed themselves to improving the issue.	(...) it has also had an effect on them [the families] because they have realised that their children are much more able to achieve things than they had imagined (T20). Neighbours, parents and guardians, all the community, were able to participate and they could see that this project is extremely good. We all learned and came out winning with this project (T22).

5. Final considerations

This study has analysed the impact of an ongoing STEAM training program focused on sustainability, named Pro-STEAM (Silva-Hormazábal & Alsina, 2022). First of all, based on the responses to a previously designed and validated questionnaire, it has been shown that more than 60% of the participants achieved an advanced level in the SDGs relating to *gender equality* and *climate action*. Furthermore, they developed teaching skills (Perrenoud, 2004) which enable them to establish relationships among teaching staff in order to organise interdisciplinary and contextualised learning tasks on problems relating to the sustainable development of the local environment, involving and motivating both their students and the wider community. On the other hand, the design and implementation of a statistical task as the final phase of the Pro-STEAM program showed that the professional development of teachers is aligned with the learning objectives for the promotion of ESD (UNESCO, 2017), according to data from preliminary studies linking statistics and sustainability (Vásquez & Alsina, 2021; Vásquez & García-Alonso, 2020; Vásquez et al., 2021). For these authors, statistics education through research cycles that start from real challenges is a very appropriate pedagogical strategy to achieve this purpose.

More generally, the participants showed that not only are they aware of issues concerning sustainable development, but they are also capable of extrapolating them to their own context in an inclusive way, taking into consideration social, environmental and economic aspects in an interdisciplinary manner and also identifying learning opportunities linked to problems of sustainable development (Geli et al., 2019). One possible interpretation of this conclusion could be attributed to the practical and theoretical nature of the Pro-STEAM training program, aimed at contextualising teachers' classes in issues of their local environment, making it possible to reflect on how these are linked to local and global challenges of sustainable development (OECD, 2018) and with the mathematics curriculum.

Although the results of this study are preliminary and cannot be generalised, it has been shown that it is possible to transform teaching practices in mathematics from the perspective of ESD. However, it is essential to continue working on these issues as, in general terms, it is a field in which mathematics teachers confess that they have few tools and little knowledge at their disposal. This may be related with the fact that ESD is generally linked with issues relating to caring for the environment, disregarding or ignoring the social and economic dimensions which make up the agenda (Geli et al., 2019). In the future, therefore, it will be necessary to continue to provide data that contribute to improving the pedagogical knowledge of mathematics teachers so that they can carry out teaching practices that are integrated with sustainability and all that this implies.

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Promoviendo la formación del profesorado de matemáticas para la sostenibilidad desde un enfoque STEAM

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Las políticas públicas y empresariales de desarrollo sostenible han centrado la atención en la lucha contra el calentamiento global, los conflictos sociales y las crisis económicas. En este marco, cada vez son más los gobiernos que proponen que la sostenibilidad se aborde de manera transversal a lo largo de toda la escolarización, incluida la educación superior, y se integre en las distintas áreas de conocimiento.

Desde esta perspectiva, nos centramos en la integración de las matemáticas y la sostenibilidad en la formación del profesorado, con el objetivo de dotar a los docentes de los conocimientos, la comprensión y las habilidades necesarias para poder avanzar en esta dirección. Por tanto, se pretende participar activamente, desde la educación matemática, en la adquisición de los Objetivos de Desarrollo Sostenible (ODS) y las Competencias para la Sostenibilidad, con el fin de contribuir a un futuro más inclusivo, sostenible y resiliente para las personas y el planeta.

Con el fin de proporcionar datos para comprender estas conexiones en la formación del profesorado y así consolidar progresivamente la agenda de investigación Formación del Profesorado de Matemáticas para la Sostenibilidad (FPMpS), se describe un estudio con 23 maestros en activo que pretende analizar el impacto de un programa de formación STEAM centrado en la sostenibilidad. En concreto, el estudio tiene dos objetivos 1) investigar el tipo de enseñanza que los maestros llevan a cabo, o deberían llevar a cabo, en relación con los ODS (en concreto, el ODS 5 sobre Igualdad de Género y el 13 sobre Acción por el Clima) a través de la administración de un cuestionario antes y después del programa de formación; y 2) una vez finalizado el programa, analizar el diseño y la implementación de una tarea estadística relacionada con la sostenibilidad destacando los dos ODS mencionados.

El programa de formación STEAM centrado en la sostenibilidad se denomina Pro-STEAM y ha sido validado previamente por expertos tanto en el enfoque STEAM como en la Educación para el Desarrollo Sostenible (EDS). El objetivo principal del programa es promover la FPMpS a través de la educación STEAM. Consta de doce sesiones de 90 minutos, organizadas en tres módulos: a) Educación para el siglo XXI; b) Educación STEAM; c) Implementación STEAM.

Para la recogida de datos, se administra un cuestionario antes y después del programa Pro-STEAM; y se analiza el diseño y la aplicación de una tarea estadística relacionada con la sostenibilidad, dentro de la fase práctica del programa. Los resultados muestran que 1) tras el programa formativo Pro-STEAM, más del 60% de los participantes alcanzan un nivel avanzado en los ODS implicados; 2) mediante el diseño e implementación de la tarea estadística, desarrollan competencias vinculadas a los objetivos de aprendizaje del profesorado para promover la EDS. Aunque los resultados son preliminares y no pueden generalizarse, se ha evidenciado que es posible transformar las prácticas de enseñanza de las matemáticas desde la perspectiva de la EDS. En términos más generales, se concluye que la FPMpS es una agenda de investigación emergente para crear soluciones sociales positivas.