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Development of a Mathematical Experience from a STEM and Sustainable Development Approach for Primary Education Pre-Service Teachers

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Abstract: Advances in education are increasingly important, and it is necessary to look for methodological strategies that enhance the value of mathematics in society and promote integrated training that helps students reason critically and rigorously. In this sense, math trails with a focus on STEM and sustainable development are a good resource to connect mathematics with the environment in a transversal way with other disciplines. A total of 35 postgraduate students in secondary education and 30 undergraduate students in primary education participated in this research and received a training course from experts in mathematics teaching. During the experience, the graduate students designed trails that were tested by the undergraduate students after a prior review by three in-service primary teachers. Likert scale questionnaires and open questions were asked of the students to evaluate the training received and the execution of the experience. Likewise, it was also decided to hold a debate with the participants and a guided interview with in-service teachers to assess the possible application of the resource in primary education courses. The results show a very positive assessment of the experience and allow us to support this approach to promote a change in the teaching–learning of mathematics in the last years of primary education.

Keywords: mathematics education; mathematics learning; STEM education; STEM approach; primary education; pre-service teachers training; outdoor education; math trails

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1. Introduction

Mathematics is undoubtedly an essential part of the development of students' preparation throughout primary education because it is a discipline that helps them develop logical and calculation skills to understand and solve problems present in their day-to-day lives. Therefore, effective teaching–learning of mathematics is required that introduces students to meaningful learning through activities that promote critical and creative thinking. For many years, mathematics education has been characterized by a tendency to memorize concepts, formulas, and properties that students are not able to understand [1,2]. However, this is changing thanks to the advances and curricular reforms that have been carried out in recent years in the field of mathematics teaching, in which, with increasing frequency, the use of computer packages or the implementation of different active methodologies guarantees more effective and quality teaching–learning.

One of the challenges in the teaching–learning of mathematics is to create an expectation and curiosity in students to learn mathematics from a useful point of view, in a practical and meaningful sense based on reasoning. Obviously, for this, it is convenient for the teacher to design and implement innovative strategies that allow students to reason logically and acquire flexibility and the necessary mathematical rigor. For this reason, it is important to ensure that pre-service teachers have quality training regarding the use of resources, active methodologies, new technologies, and educational innovation. Likewise, for students to be mathematically competent, it is necessary for teachers to master strategic and attitudinal skills that allow them to formulate problems that connect mathematics with the environment [3].

To achieve an effective mathematics teaching–learning process, it is necessary to create contextualized spaces for discussion and reflection that allow students to understand the application of the different mathematical notions and procedures that are studied [4]. Making contact with the real world is essential for students, from the initial educational stages, to obtain a good mathematical education and to be able to progress successfully in their studies. Therefore, it is important that, to the greatest possible extent, students develop experiential activities that help them develop their mathematical skills from a practical point of view. The degree of abstraction inherent in mathematics means that experimenting with the mathematical objects that we have around us makes them closer and more understandable. That is why interacting with the environment will make students capable of creating real contexts and providing solutions to everyday life problems.

To develop this concept, the concept of "math trails" emerged in the 1980s, which consists of walking through the environment to solve mathematical problems by analyzing objects or structures [5,6]. However, with advances in technology and communication, the "MathCityMap project" emerged in 2012 with the aim of creating a worldwide platform with which to create and design math trails that any person or group can carry out through a mobile application and a GPS navigator. This idea has progressed over the years to become a collaborative learning environment that is being used in many countries as an educational resource for the teaching–learning of mathematics [7].

After a search in different databases, we have been aware of the little use that is being given to this resource in primary education, in which it is essential that students develop good mathematical ability integrated with the environment and the community. In this sense, as part of this integrative training, we see it as necessary that the profile of the math trails that are designed involve other disciplines transversally with mathematics, such as science, technology, and engineering (STEM education), as well as including other important aspects in education, such as digital education, sustainability, social responsibility, and the environment. For this reason, we believe it is advisable to analyze the possibility of integrating STEM education and sustainable development (SD) into math trails and evaluate whether their application in primary education is possible [8,9].

On the other hand, it has also been possible to observe the little training that in-service and pre-service teachers receive in this area. These aspects are part of the university training that future mathematics education teachers should receive to achieve success in the performance of their duties. For that reason, a new vision of mathematical knowledge must be promoted in teaching practice because it is teachers who "have the power to release the creative, innovative and critical potential of young students" [10] (p. 16). In this sense, we believe that it is important to provide integrated training in STEM education, sustainability, new technologies, and educational innovation to future teachers of different educational stages.

To bridge these gaps, in this research project, we develop an experience that combines the theoretical mathematical knowledge that a future teacher must have with the knowledge of educational innovation and new technologies. Specifically, it seeks to link outdoor education with STEM and sustainable practice through the creation of math trails and the use of computer tools. The evaluation of this experience will allow us to assess the possibility of implementing this type of activity in primary education courses.

2. STEM-SD Education and Outdoor Mathematics Education

2.1. Integrated STEM-SD Education

As students advance in their studies, they demand a justified and reasoned explanation of the mathematical concepts they study in the classroom and their use in everyday life. In this sense, it is important to make them see that mathematics is used as an essential tool in many fields of study, among which are natural, social, and experimental sciences, engineering, and technology (STEM education). For this reason, it is necessary to look for methodologies focused on solving problems in which mathematics is applied in a transversal and interdisciplinary way [11].

The STEM methodology, an acronym in English for science, technology, engineering, and mathematics, is a current topic that is being used more and more frequently in the curricular processes of many countries. This way of approaching teaching–learning allows us to create a common link between the environment and the educational community, promoting solid and integrated training that eliminates learning barriers [12] and, in turn, gives students the ability to solve problems in a society that is continually evolving [13]. Likewise, one of the main objectives of education is to meet social demands by promoting social, scientific, and technological development [14]. In this sense, STEM education is a priority for the educational system and a resource that responds to the great technological advances and educational innovation of the 21st century [15].

In a recent study carried out by Herce-Palomares et al. in [15], it is observed that 62.04% of research on STEM education focuses on compulsory secondary education and only 17.59% focuses on primary education. This suggests a deeper investigation of STEM education in primary school courses because it is in this period when the competencies and attitudes that derive from STEM disciplines begin to develop. In this regard, it is essential that teachers offer students early STEM experiences [16] in which the skills of each of the specific domains are promoted so that they are able to act efficiently [17], as well as to help them reason logically, deductively, and creatively [18].

STEM education involves comprehensive competency development training for students' actions in society that, in most cases, is connected to sustainability [9]. It is important to guide students toward a sustainable culture and provide them with the knowledge, skills, and values necessary to face certain human and social challenges, such as climate change, the loss of biodiversity, or the use of unsustainable resources, among others. Education on sustainability is a learning process throughout the educational stages that all teachers should take into account to achieve integrated training, as it will allow students to make autonomous and informed decisions with the purpose of changing society and acting responsibly in favor of environmental integrity and economic viability [19–21].

To guarantee a quality education, it is necessary that primary education teachers have interdisciplinary training because they are ultimately responsible for the teaching process, and therefore, their training should be a priority in all countries [22,23]. There are many studies that show significant differences between the training that future teachers receive in their university education and what is actually implemented in the classroom. The external internships that university students receive are of great importance in their training because they represent the beginnings of their careers as teachers and constitute a representative stage in their professional growth [24,25], but their durations are insufficient.

For this reason, it is important to provide future teachers with all possible training and give them greater learning opportunities that will serve them in the implementation of their future teaching practices [26,27]. In fact, today's society demands that teaching that integrates STEM disciplines from an early age be promoted through educational centers, as Cannady et al. pointed out in [16]. Therefore, it is essential that different institutions reinforce the STEM-SD training (STEM training aimed at sustainable development) of primary education pre-service teachers, providing them with the necessary tools that allow them to implement this methodology.

Regarding practicing teachers, primary education teachers generally do not have adequate training to work on the teaching–learning of mathematics from a STEM perspective in an integrated and interdisciplinary way [28]. A large part of the training activities offered for teachers of this educational stage are taught independently, without establishing connections between disciplines or addressing the design of strategies in which transversal training predominates [29]. In the study of mathematics and science, in which the capacity for abstraction is important, this represents a clear obstacle for students to successfully face the basic contents of the educational stage regarding STEM-SD training. Therefore, it is advisable to promote the STEM approach among teachers to create, in this sense, new learning situations that connect mathematics with the rest of the disciplines and promote a change in educational practice that increases the motivation and scientific vocation of students [15].

2.2. Outdoor Mathematics Education

One way to introduce the STEM-SD methodology in the teaching–learning of mathematics in primary education is by carrying out activities within what is known as "outdoor education". For students to adequately experience the mathematization process, it is necessary that they know how to transform a real problem into a mathematical problem in which they must use the basic concepts of mathematics to solve it in an organized and meaningful way [30,31]. One way to achieve this is by taking mathematics outside the classroom so that, in this way, students can discover for themselves the connection that mathematics has with the environment [7,32,33], are more aware of the great usefulness of the mathematical content that the teacher explains theoretically in the classroom and, above all, know how to value the cognitive, historical and socio-cultural dimension of mathematics that they have [34].

This pedagogical practice began to develop in France, with the article titled "L'enseignement par l'aspect à l'école primaire", written by Paul Berton and published by the journal *Revue Pédagogique* in 1879. In this article, "field trips" are introduced as resources that enhance outdoor education to use everything that catches the eyes of children to achieve meaningful and practical learning of sciences and the arts [35]. In this sense, we can say that outdoor education is a pedagogical method or strategy understood as contextualized learning that takes place outside the classroom and takes advantage of the potential of the environment to promote a shared educational experience [36,37] "whose goal is didactic effectiveness and efficiency through the recontextualization of educational processes" [38] (p. 10).

Outdoor education encompasses three clearly differentiated aspects, including the pedagogical approach, the methodological techniques or strategies that bring theory closer to practice, and the set of resources or places that materialize the concepts learned in the classroom outside of it [38] (see Figure 1).

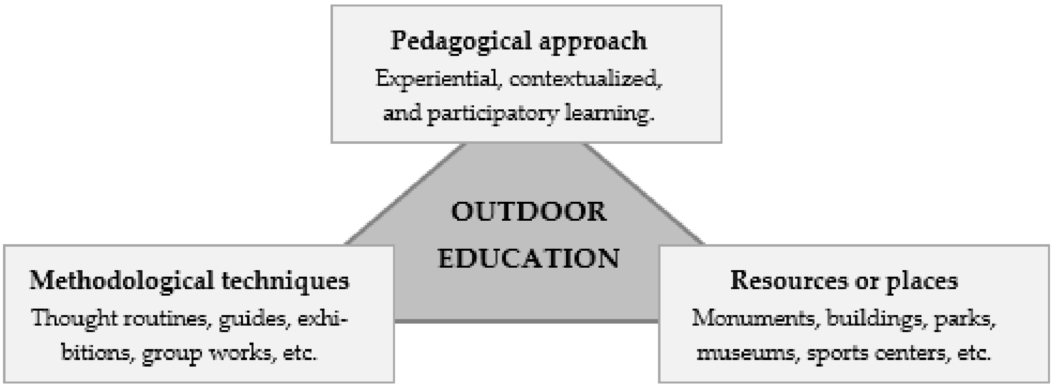

Figure 1. Aspects of outdoor education. Source: Adapted from [38] by the authors.

Outdoor mathematics in primary schools is now mandatory or at least encouraged in several countries [39]. The responsibility for implementing this type of outdoor methodology in the primary mathematics curriculum falls on the teacher, who needs to experience and understand this approach to apply it in their teaching practice [32].

A recent advance in the way of approaching outdoor mathematics education is through what is known as "math trail". A math trail consists of a sequence of stops along a predesignated trail in which students learn mathematics in the surrounding environment [10]. It is, therefore, a learning environment in which mathematical tasks are solved [40] that allow students to develop their mathematical skills outside the classroom while analyzing different objects or structures found in the streets or parks in their city [41].

The origin of math trails dates back to 1980 when David Lumb [5] developed two three-stop trails in the center of Newcastle, one for 8- and 9-year-old children and another for 12- and 13-year-old children, with the purpose of involving mathematics in their environment. These trails were presented to the children in the form of a booklet with a cheerful, original, interesting, and well-written presentation. Nine years later, Dudley Blane reintroduced the term at a conference on the popularization of mathematics at the University of Leeds in the United Kingdom [42].

With this type of activity, a mathematical modeling process is carried out that transforms the environment into a problem that can be addressed mathematically as students interact with the rest of their classmates. Likewise, a math trail can be considered an "informal meeting space" whose objective is to teach mathematics through problem-solving and encourage communication and teamwork [43]. Therefore, it is advisable for students to work in groups, collaboratively, to address the tasks set within the trail [7]. Furthermore, because a math trail is carried out outside the classroom, this makes it a motivating and interesting activity for students, who will not only discover, in situ, the mathematical properties of the environment and the real problems that it can offer us but will also make use of mathematical flexibility and creative thinking to pose and solve them.

2.3. Pedagogical Framework of Outdoor STEM-SD Education

At this point, we can ask ourselves the following question: Why not connect STEM-SD education with outdoor education to study mathematics? Each of these concepts works very well separately, but together they could give excellent results if applied properly, especially in primary education, in which students begin to develop their mathematical skills. It is important to provide students with integrated training that involves skills and content processes that are part of a pedagogical framework that serves as a guide in the professional development of pre-service teachers [44]. In this sense, it is valid to think that designing math trails that include mathematical problem-solving tasks with a STEM-SD application can be a good resource to connect mathematics with the real world and enhance the mathematical and scientific–technological skills of students.

In line with the research article by [44] on the study of the implementation of outdoor STEM education in primary education, this type of methodology connects three main skill processes, namely, (a) problem-solving, (b) reasoning ability, and (c) proof or statement (see Figure 2).

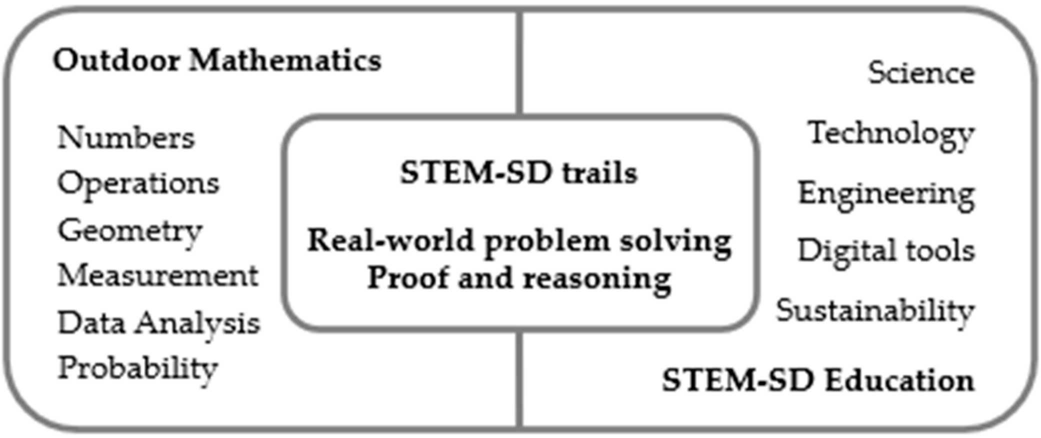

Figure 2. Pedagogical framework of outdoor STEM-SD education. Source: Prepared by the authors.

That is, teachers must design trails with tasks whose solution methods are not known in advance and with which mathematical skills and knowledge are transferred to find a possible solution to the problem. This will be performed collaboratively by arguing and discussing the possible solutions to the problem and analyzing and justifying each step of the resolution process. Regarding the content of the trail, it should include tasks in which concepts about number theory and operations, geometry, measurement, representation, data analysis, and probability must be used to solve STEM problems with a sustainable background [44].

3. Materials and Methods

3.1. Context

The didactic proposal that we present is developed within the framework of two active educational projects, including the "MathCityMap Project" and the "MiniOpenLabs Project", both of which are dedicated to the improvement of mathematics and science education.

3.1.1. The MathCityMap Project

"MathCityMap" is a project of the working group on mathematics teaching in secondary education (MATIS I), which was created in 2012 by Goethe University in Frankfurt with the purpose of developing a worldwide platform through which to design and carry out math trails [45], as well as promoting its use as an innovative teaching tool that enhances the teaching–learning of mathematics in an educational and technological context.

MathCityMap is the main tool of the "Mobile Math Trails in Europe" (MoMaTrE) and "Math Trails in School, Curriculum and Educational Environments of Europe" (MaSCE^3) projects, started in 2017 and 2019, respectively, and coordinated by Goethe University (see Figure 3). Such projects are part of the "Erasmus+ programme" of the European Union and provide the most appropriate theoretical and empirical considerations and methodological strategies for the creation of trails in the educational environment and adapted to the European curricula of mathematics education. In addition, it supports teachers in the implementation of courses to introduce pre-service teachers to this type of activity [45–47].

Figure 3. Logos of MaSCE3 and MoMaTrE projects. Source: [46,47].

The "MathCityMap platform" is divided into two work tools, including a "centralized website" [48] to design math trails and a "mobile app" to carry them out. The MathCityMap website is the main tool for teachers that will help them create and design math trails anywhere in the world. It is also useful for any other hobbyist who wants to share their trails with other members or educational centers.

To create a math trail, we must register and follow the design guidelines as follows: title, brief description of the trail, number of tasks, level of education, distance of the itinerary, approximate duration, etc. The website will ask us to select, through GPS, the exact location of the places of the tasks that make up the trail, as well as add photographs of the study objects, in a task and response format to choose from among the nine currently available. The platform offers a series of clues that help students solve the tasks and a possible solution to the problem that serves as feedback. It is worth mentioning that for the math trail to be published, it must contain a maximum of four tasks with the option of including a subtask within each of them.

Each of the designed math trails, before being published on the website, is exhaustively reviewed by expert evaluators to guarantee their quality [49]. In this review, experts evaluate the following aspects:

1. *Time and level*: The tasks are adjusted to the indicated level and the estimated completion time of the trail is adequate.
2. *Format and statement*: The formulation of the tasks and the response format chosen for each of them is appropriate according to the context. The tasks admit more than one possible solution (mathematical flexibility), can be posed from various points of view

(creative thinking), and can be solved only in the designated place, or at least data had to be collected in situ to be able to carry them out.
3. *Solution*: The approach and procedure used in the solution proposed by the creators of the trail uses mathematical concepts appropriate for the level indicated.
4. *Application*: The tasks have a real practical application and serve to clarify concepts for participants and make them see that mathematics is present in the surrounding environment.
5. *Material*: The material needed to solve the tasks is within reach of all participants.

On the other hand, the MathCityMap mobile app is the main navigation tool that participants need to complete the trails. It is a free downloadable app that does not require an internet connection to be used. It allows you to see the location of the trail using GPS and indicates the stops at which participants must stop to complete the tasks. At this point, when selecting the task, the app shows images of the objects under study along with the statement of the task and the clues necessary to solve them. Participants must enter their solution where and how it is specified, and the app will immediately inform them whether their solution is correct or close to the true value, depending on the response format chosen by the math trail designer.

3.1.2. The MiniOpenLab Project

The "MiniOpenLab (MOL)—Open community and Hands-on approach to Sustainable Development and STEM education project" (MOL project), co-funded by the European Union through the Erasmus+ programme mentioned above, arises with the aim to establish an open community focused on promoting sustainable development and STEM education among children aged 6 to 12.

On the one hand, this project proposes testing and educational methodology different from the traditional one in which meaningful and experiential learning prevails through participation in projects based on STEM and SD education guided and supervised by the educational community and, on the other hand, carries out training workshops to involve and train teachers and the scientific and technological community in activities with this approach [50]. The methodology that prevails in the MOL project is STEM-SD problem/project-based learning. However, many STEM-SD activities can be performed outdoors [51], and therefore, the MOL project also includes outdoor activities in contact with nature.

With the appearance of the European MiniOpenLab project, the need arises to propose activities related to STEM education and sustainable development as an educational resource for primary education that, a priori, had to be developed in an educational center or laboratory open to the community. However, we want to take this research a step further and extend these activities outdoors by carrying out math trails with a STEM-SD focus. In this way, the ideas of both projects are grouped into the same concept, creating what we have called here STEM-SD trails.

As we mentioned before, both undergraduate and master's students complete, at the end of their training stage, internship periods in educational centers that generally represent the beginning of their career as teachers and, above all, constitute a significant stage in their growth, both personal and professional [24,25]. However, these external practices are generally insufficient due to their duration and their concentration in short periods of time. For this reason, it is important to give students the possibility of participating in experiential situations prior to teaching through active methodologies and educational innovation.

The educational model of teacher training at universities, in which academic knowledge is considered the foundation for teaching, should change to another, in which the interaction between academic, professional, and community experience is promoted [52]. In this regard, postgraduate students in secondary education designed different math trails and had the opportunity to put them into practice with primary education pre-service teachers, making the transfer of knowledge between different educational levels possible.

3.2. Intervention Study

The experience was carried out at the end of the 2021–2022 academic year and involved both students pursuing master's degrees in teacher training at secondary and preuniversity levels and students in the last year of the degree in primary education at the Rey Juan Carlos University (URJC) in Madrid (Spain). As this is a proposal in which the STEM-SD practice was applied, we believed it was convenient that those master's students who were training in the specialties of mathematics, physics, chemistry, and technology could participate.

To collect the sample, a registration form was opened aimed at those URJC students who were very interested in improving and expanding their training in terms of the design and implementation of innovative didactic proposals. Among the minimum requirements to participate in the experience were (a) being a URJC student in the last year of a degree in primary education or a master's student in one of the specialties indicated above and (b) having passed the following corresponding didactics subjects to their studies: "Mathematics and its didactics I, II and III" in the case of undergraduate students and "Didactics of mathematics, physics and chemistry or technology" in the case of master's students.

The maximum number of participants was limited to 80, information was provided on the minimum specifications required to participate in the experience, time and place, description and schedule, professors and collaborating experts, and information about the anonymous evaluation questionnaires that were going to be carried out during this study. Interested students had to indicate their name, university student email address, and degree or master's degree in which they were enrolled. Likewise, undergraduate students had to indicate their current course and whether they had passed the three subjects corresponding to the "Mathematics and its didactics" module, and postgraduate students had to indicate if they had passed the "Didactics" subject corresponding to their study field.

A total of 71 registrations were received, including 27 master's students in the field of mathematics, 7 in the field of physics and chemistry, 5 in the field of technology, and 32 undergraduate students. No participants had to be excluded because all of them met the minimum requirements. Finally, a sample of 32 undergraduate students and 39 master's students resulted, of which 30 undergraduate students and 35 master's students attended the entire experience.

To carry out this research, work teachers and experts participated in providing the training and collaborating in the development of the experience, as follows:

- Three teachers specialized in mathematics teaching from the URJC;
- Three primary education teachers from an educational center located in Madrid;
- A MathCityMap expert, member, and collaborator of the MoMaTrE project;
- An expert in the use of digital tools for teaching mathematics.

The development of the experience took place in three stages, including *diagnosis* (or training), *execution*, and *discussion* (see Figure 4).

In the *training* or *diagnosis stage*, the students and primary school teachers who participated in the experience received a training course from university professors and experts in mathematics teaching, in which the following aspects were explained:

1. What do we mean by innovating in education? Why is it so important? STEM-SD education as a methodological strategy in the field of mathematics.
2. How can we integrate STEM-SD activities into the teaching–learning of mathematics? Which active methodology is the most appropriate for this?
3. The MathCityMap project. How can we create, design, and carry out math trails?
4. Use of digital tools in mathematics education. Introduction to *GeoGebra*.

Figure 4. Stages of research. Source: Prepared by the authors.

The first two points of the course were taught by URJC teaching and research staff, whose lines of research focus on STEM education and the optimization of resources in the teaching–learning of mathematics. Pre-service teachers usually tend to think that by simply introducing new technologies in education, they are already innovating; however, the reality is different because educational innovation must be considered in a broader sense. It is necessary to make students see that to innovate in education, it is not only necessary to introduce technological tools but also other fundamental elements, such as knowledge, people, and methodology. To conclude this part, the participants are made aware of the MiniOpenLab project and the objectives it pursues.

The third point of the course was taught by a member of the MathCityMap project, a reviewer, and an evaluator of math trails who collaborates in the MoMaTrE project. The participating students received a training session, in which they received in-depth learning about the objectives of the project and the operation of both the MathCityMap website and the mobile app for the design and implementation of math trails. They were taught how to create math trails on the platform, the main characteristics that the tasks included in the trails had to have, the different possible response formats, how to publish them, etc. At the end of the session, students downloaded the mobile app, searched for a public trail, and browsed it.

To finish, a basic workshop on GeoGebra was taught by an expert in the use of this digital tool in education. GeoGebra Classic (online version) is free and flexible mathematical software widely used in mathematics education, as it can be used to solve problems in arithmetic, geometry, algebra, statistics, etc. Because the math trails that are going to be designed in this experience must be focused on STEM-SD education, we believed that it would be convenient to analyze the possibility that at least one of the tasks to be solved in the trail could be solved with GeoGebra. Specifically, the workshop took place in two sessions, as follows:

- *Session 1*: In the first session, lasting two hours, explained the basic notions of the tool and the possibilities it offers, both in primary and secondary education. In addition, the modules of graphs of functions and geometric elements in two dimensions (lines, circles, angles, parallelisms, perpendicularity, construction of polygons, and area calculation) were also explained;
- *Session 2*: The second session, also lasting two hours, taught the modules on proportionality and three-dimensional drawing (solid figures and volume calculation).

In both sessions, different activities similar to those that the trail executors were going to have to face were carried out, such as, for example, drawing a tessellation and calculating its area or sketching a prism and finding its area and volume. After the training course, the participants were taught what the experience was going to consist of and the role they were going to play in it. Specifically, it was explained to them how the execution and discussion stages were going to be developed, which we will explain below.

In the *execution stage*, the experience is applied in four phases, as follows:

1. *Design phase*: The URJC master's students will be in charge of creating and designing math trails with a STEM-SD approach through the MathCityMap platform. Work groups are formed, and they are told that the tasks on the trail must be at a sixth-grade level (basic knowledge of the first year of secondary education). It is very important in this phase to make students aware that what is fundamental in the design of the trails are the tasks they contain and not so much the environment in which they are developed because outdoor math trails can be carried out anywhere; the truly complicated thing is knowing how to adapt the environment to didactic knowledge. In Figure 5, we can see an example of how the tasks are displayed in the MathCityMap application. In this case, the screenshot on the left is an example of how the tasks in the trail appear to participants, indicating the number and title of each task. The screenshot on the right is an example of a specific task in which they are asked to calculate the area of the shaded area to obtain the meters of plastic lone necessary to cover the garden area.

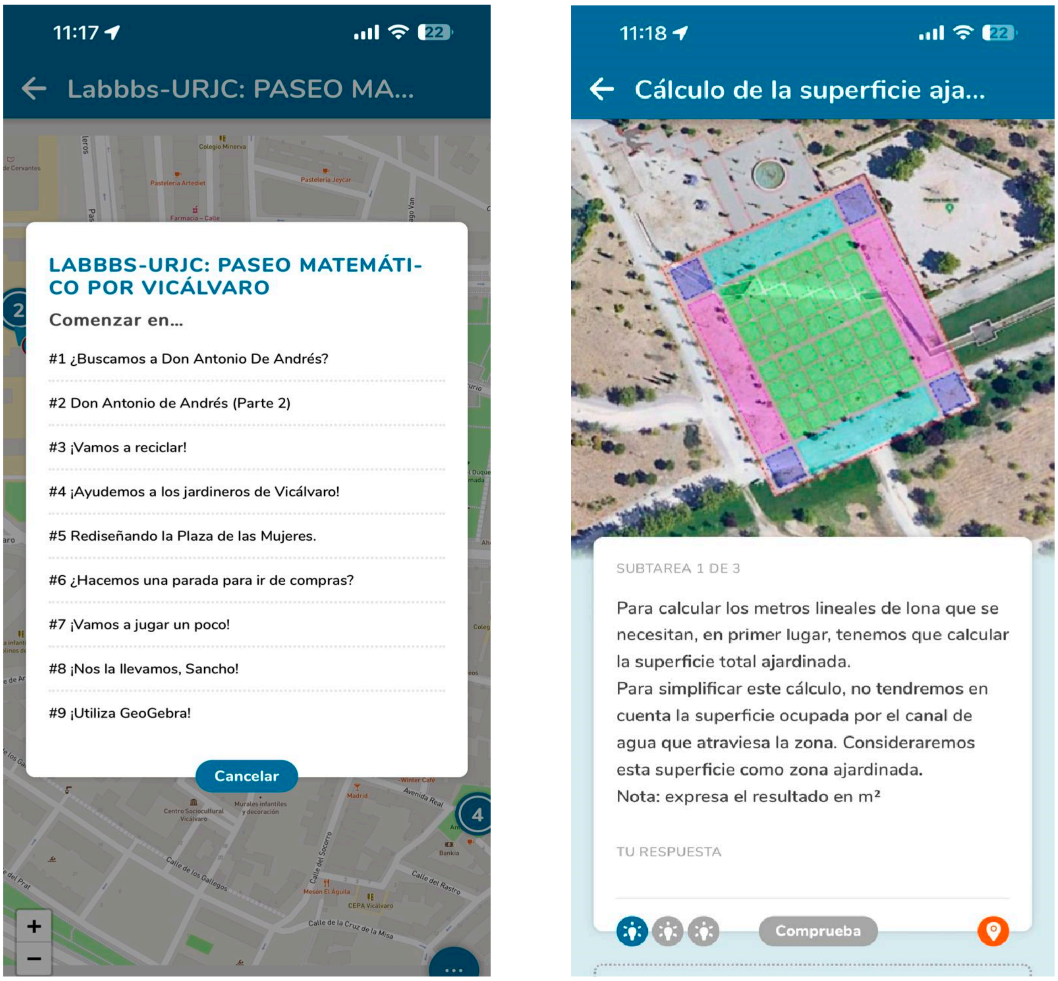

Figure 5. Task example from the MathCityMap mobile app. Source: Images captured in the MathCityMap mobile app of the math trail designed by the authors.

The trails that were designed took place in the urban environment of the Madrid district of Vicálvaro, an area in which one of the URJC campuses is located. This area contains many parks and leisure areas in which students designed their trails. Specifically, we find the Valdebernardo East Park, located a few meters from the university, which is a forestry-oriented park that helps make contact with nature easier for citizens of urban centers, ideal for taking a trail focused on STEM practice and sustainable development. The trails included aspects such as sustainability, architecture, and artistic expressions related to social awareness, and they were approximately 6 km long, on average, and were scheduled to be completed in a time of 75 min.

2. *Selection phase*: Once the math trails have passed the review process and have been made public on the platform, they are shared with three primary education teachers who are currently working as teachers in an educational center in Madrid, who, by consensus, choose the three trails that according to their criteria, are best adapted to the established level.
3. *Application and control phase*: The 30 students from the URJC primary education degree are organized into 5 work groups to carry out the chosen math trails through the MathCityMap mobile application. They will be accompanied and guided in the process by a representative from each of the groups that designed the trails and the three primary school teachers who participated in its selection, who will cooperate with them when necessary (Figure 6 shows a group of students collecting

measurements to carry out the task). At the end of the trail, the participants returned to a computer classroom set up to solve the specific tasks that were carried out with the dynamic mathematics software GeoGebra (Figure 7).

Figure 6. Participants carrying out a math trail task. Source: Prepared by the authors.

Figure 7. Participants performing the task with GeoGebra. Source: Prepared by the authors.

4. *Experimental phase*: In this phase, students from the primary education degree collaboratively create and design a STEM-SD trail in an urban environment in Madrid for hypothetical 5th-grade students. The trail had to be focused on the areas of geometry and measurement, and each of the tasks had to use mathematics as a transversal discipline, along with other STEM disciplines.

Finally, the experience concludes with the *discussion stage*. In it, the participants who carried out the math trail share their results and make a global assessment of the activity that will serve as feedback for the group of master's students who designed the implemented trail. On the other hand, in both the degree and master's courses, the advantages and disadvantages of implementing this type of activity in primary and secondary education, respectively, were also discussed, as well as the possibility of including STEM-SD trails as a methodological strategy at an early age. This phase was also useful for us to assess whether the students had benefited from the experience to improve their learning and grow professionally.

Table 1 summarizes the stages and phases of the experience, including the partici-pants and collaborators in each of them.

Table 1. Summary of the stages and participants of the experience.

Stage	Phase	Participants	Collaborators
Diagnosis	Training	Master's students	URJC [1] teachers MCM [2] expert GG [3] expert
		Primary education teachers	
		Primary education students	
Execution	Design	Master's students	URJC [1] teachers MCM [2] reviewers
	Selection	Primary education teachers	---
	Application	Primary education students	URJC [1] teachers Primary teachers
	Experimental	Primary education students	URJC [1] teachers
Discussion	Debate/Analysis	Master's students	URJC [1] teachers
		Primary education students	

[1] Rey Juan Carlos University; [2] MathCityMap platform; [3] GeoGebra mathematical software.

3.3. Research Objectives

The main objective that is intended to be achieved with this intervention proposal is to connect STEM-SD education with education abroad to promote a change in the teaching–learning of mathematics, especially in primary education, in which the mathematical training of the student is essential for the good progress of their training. In this regard, the training provided will serve, on the one hand, as an essential resource for future secondary and pre-university teachers to put into practice in their careers as mathematics teachers and, on the other hand, as an experiential and immersive process for undergraduate students in primary education, allowing them to perform the same tasks that their future students would have to perform and design their own math trails for hypothetical primary school students.

It also seeks to make this methodology known to primary education teachers who are currently working as teachers in an educational center, who are given the opportunity to test the designed STEM trails and to determine and assess the applicability of this type of activity within the MiniOpenLab project and in the primary school, which, as mentioned above, is the ultimate goal of our research project.

To respond to these objectives, the following research questions were posed:

1. Is the training provided adequate and sufficient to raise awareness among mathematics teachers in training about the importance of applying innovative resources in the classroom?
2. Has the experience developed served the participants as a practical application for their professional futures? Could its application be considered in primary education courses?

3.4. Evaluation Instruments and Data Collection Procedures

The experience was evaluated through the use of three questionnaires, as follows: an initial questionnaire, prior to the development of the experience, based on open questions;

another questionnaire using a Likert scale and open questions to evaluate the methodological and teaching quality of the training received in the diagnosis stage; and the last questionnaire, also using a Likert scale and open questions, with the purpose of obtaining feedback from participants in each of the phases of the execution stage. Apart from these three questionnaires, interviews were also carried out with each of the primary teachers who participated in the selection phase to determine the criteria followed to choose the most appropriate trail and their opinions about the implementation of this type of activity in primary education.

To design the Likert scale questionnaires, we relied on previous similar studies [53,54], from which, based on valid and reliable questionnaires, we obtained evaluation instruments with sufficient internal consistency to determine the pedagogical dimension and the cognitive (conceptions and beliefs toward the activity) and behavioral (behaviors and action intentions) perceptions of the students participating in the experience. Specifically, different aspects were taken into account, as follows:

- *Selection arguments*: The questionnaires were anonymous to avoid socially desirable answers, that is, answers that the respondents believe would cause them to receive better treatment from the evaluator;
- *Construction of items*: Items (that may be satisfactory in terms of validity due to their relationship with the characteristic that is intended to be measured) were proposed to easily control the response effects;
- *Analysis of items*: An objective verification was carried out to determine if the items were differentiators, that is, they were not answered in the same way by the entire group;
- *Number of alternatives*: To improve the reliability of the test, it was decided to increase the response options from 2 (agree and disagree) to 5 (totally agree, agree, neither agree nor disagree, disagree, and totally disagree);
- *Degree of alternatives*: All items were formulated so that there is no contradiction between them and to avoid bias in the results. That is, an affirmative item is expected to obtain a favorable response (4 or 5), and an unfavorable response is expected for a negative item (1 or 2). In this case, we decided that all the items were affirmative to avoid any conflict of this type;
- *Intermediate alternative*: It was decided to include an option of indecision or ambivalence among the response alternatives with a moderate effect on the validity of the test so as not to force the respondent to position themselves between the options of satisfaction or dissatisfaction with the item. It is preferable not to force this decision to avoid causing errors in the data;
- *Readability of items*: Items were formulated in simple and clear language to prevent respondents from answering the intermediate alternative due to a lack of understanding.

On the other hand, open questions, which were also anonymous, had a qualitative nature and were designed as an extension of the Likert scale questionnaires to determine the opinions and perceptions of students on certain aspects in a broader way. Depending on the nature of the question and the interest of the respondent, the answers varied greatly in terms of length and depth, so the results were enriched. In addition, they were useful in explaining and understanding the answers to some of the closed questions in the questionnaire.

3.4.1. Initial Questionnaire

Before beginning the training stage, students who participated in the experience completed an initial questionnaire, in which they were asked questions about educational innovation, STEM-SD education, and digital resources, among other aspects, to evaluate their knowledge about these concepts. This questionnaire was carried out online and anonymously a few days before beginning the experience so that we could get an idea of the participants' prior knowledge of the contents that were going to be studied during the experience. The questions posed were the following:

1. What do you understand by educational innovation? What is its main objective?

2. Do you know or have you heard about the STEM or STEAM methodology in education? If the answer is yes, explain in what context.
3. Do you think it is important to use digital tools and/or computer packages in the teaching–learning of mathematics and other sciences? Why? What mathematical software for educational use do you know? Have you used it on any occasion?
4. What do you think is the best methodological strategy to teach mathematics?
5. Do you know or have you heard about mathematics outdoor education? If the answer is yes, explain in what context.
6. Do you know or have you heard about the term “math trail”? If the answer is yes, comment on where you have heard of it and if you find its application interesting in the teaching–learning of mathematics.

Apart from determining the initial level of the participants, these questions were also designed to measure the level of demand and depth with which to deliver the training workshop dedicated to STEM-SD education that was going to be carried out prior to the execution stage of the experience. It is assumed that both master’s degree students in teaching and students in the primary education degree have already acquired extensive theoretical knowledge about educational innovation because it is a mandatory subject in both degrees; however, there are still students who find it difficult to relate it to practice, and giving them guidelines and examples of application is important in their educational development.

3.4.2. Training Course Evaluation and Activity Assessment

Once the experience was completed, an evaluation questionnaire was carried out to find out how satisfied students were with the training received and the process of designing and carrying out STEM-SD trails. The questionnaires were composed of 5-level Likert scale questions (1 being “totally disagree” and 5 being “totally agree”) and a series of open questions to measure the degree of satisfaction of the participants, evaluate the quality of learning, and determine the students’ point of view on the application of this type of methodology in mathematics education.

Regarding the training stage, each of the training modules received was evaluated separately, including STEM-SD, the MathCityMap platform, and the GeoGebra workshop. On the one hand, a total of 27 items (with a Likert scale) were evaluated, including course objectives, content, materials, methodology, theoretical and practical training, duration, and speaker evaluation (see Table 2). The following open questions were asked:

- Do you consider it necessary and useful to include STEM-SD training in primary education? Why?
- Do you consider it a good resource to implement math trails with a STEM-SD approach in primary education? Why?
- Do you think that the GeoGebra tool could be useful in the teaching–learning of mathematics in primary education? Why?

On the other hand, the 13 evaluation items for the design and experimental phases of the execution stage were based on practical training, the MathCityMap platform, the trail testing process, and teacher collaboration (see Table 3). In this case, the open questions were as follows:

- What has been the most complex part for you in the process of designing the trail?
- What do you consider most important in the creation and design process?

The items in this questionnaire were carefully created to obtain feedback regarding the sufficiency of the theoretical–practical training received, the use of the MathCityMap platform (ease of navigation, ease of creating trails and tasks, and assessment of the review process), and the interaction of collaborators during the creation and design process. The variable “trail testing” was also included to assess how important it is for the participants to test the trails before putting them into practice. With the open questions, we wanted more in-depth insight into what they considered most important in the creation and design process and where they had had the most difficulties.

Table 2. Items of training stage.

Variable	Items
Objectives	The objectives of the workshop were clear and specific. The learning outcomes were as expected.
Content	The work program was adequate to achieve the course objectives. The course content was relevant. The topics covered give me new knowledge.
Material	The material provided was appropriate and useful. The material provided was sufficient. The presentations used by the speakers were easy to follow
Methodology	The methodology used was appropriate. The methodology used facilitated learning. The development of the course allows me adequate monitoring. The development of the course allows me adequate learning.
Theoretical training	The theoretical training was appropriate and useful. The theoretical training was sufficient. All the theoretical concepts that fell within the content of the course were explained.
Practical training (MCM [1] and GG [2])	The practical training was appropriate and useful. Sufficient practical exercises were carried out. Sufficient practical training has been received to be applied in my professional future as a teacher.
Duration	The course duration was sufficient. The duration of the course was balanced between sessions.
Speakers' evaluation	The speaker has planned and well-structured the presentation. The speaker is orderly in the presentation of the workshop. The speaker dominates all the topics covered in the course. The speaker explains clearly. The speaker adequately clarifies doubts. The speaker encourages participation. The speaker encourages the exchange of ideas and experiences. The interaction of the speaker within the group is good.

[1] Math trails workshop: The MathCityMap project—Creation, design, and implementation; [2] GeoGebra workshop: Digital resource to teach mathematics.

Regarding the application phase of the execution stage, a total of 17 items were evaluated, which involved aspects such as practical training in using the MathCityMap application and GeoGebra, the adequacy of the level and estimated time of the trail, and teacher collaboration, especially in the use of GeoGebra (see Table 4). The only open question posed here was as follows:

- What has been the most complex for you in the process of executing the STEM-SD trail (difficulty of the tasks, use of the mobile application, response formats, sufficient clues, use of GeoGebra, etc.)?

In this case, the items in this questionnaire were created to obtain feedback regarding the sufficiency of the theoretical–practical training received on the application of MathCityMap and the use of GeoGebra, the adequacy of the trails to the indicated level, the adequacy of the trails of the estimated duration, and the interaction of collaborators during the trail application process. With the open question asked, we wanted to give the participants the opportunity to express what had been most difficult for them in the process. At the end of the experience, the responses were shared with the creators of the trails so that they knew the opinions of the executors to improve future applications.

Table 3. Items of design and experimental phases (execution stage).

Variable	Items
Practical training (Aligned with MCM [1] training course)	The practical training received in the previous training course was sufficient to create and design the STEM-SD trails. I have been able to transfer the theoretical training given in the previous training course to my trail. I have been able to apply the STEM-SD concept to my trail. It has been easy to create tasks in which to use GeoGebra.
MCM [1] platform (Web facility, task design and review)	The website is clear and easy to use. The website offers enough alternatives to create math trail tasks. MathCityMap reviewers offer suggestions and guidelines necessary to create a quality math trail.
Trail testing	The trail testing process is important for the good performance of the activity (suitability of the trail, materials, duration, etc.). The tasks have been created while keeping in mind the objectives you want to achieve (STEM areas you want to work on). Different options have been evaluated before creating a task, and the most appropriate one has been chosen.
Collaboration	URJC [2] teachers collaborate in the process of creating and designing the trail offering help and suggestions.
	URJC [2] teachers adequately clarify doubts during the process of creating and designing the trails. The interaction of the URJC [2] teachers within the group is good.

[1] MathCityMap; [2] Rey Juan Carlos University.

Table 4. Items of application phase (execution stage).

Variable	Items
Execution process (MCM [1] application)	The practical training received in the previous training course about the MCM [1] application was sufficient to carry out the trail. The MCM [1] application is clear and easy to use. It has been easy to follow the trail. The material for data collection is available to all participants. The tasks have a real practical application. The tasks allow more than one possible solution. The response format chosen is appropriate.
Practical training (Use of GeoGebra)	The practical training received in the previous workshop on the use of GeoGebra was sufficient to carry out the indicated task. It has been easy to carry out the GeoGebra task.
Trail suitability (level and duration)	The trail adjusts to the indicated level. The solution proposed by the creators of the trail uses math concepts appropriate for the level indicated. The GeoGebra task adjusts to the indicated level. The estimated time to complete the trail is adequate for the level and distance indicated.
Collaboration	Primary and URJC [2] teachers collaborate in the execution of the trail, offering help and suggestions when requested. Primary and URJC [2] teachers adequately clarify doubts during the trail execution process. The interaction of the primary and URJC [2] teachers within the group during the trail execution process is good. URJC [2] teachers adequately clarify doubts during the completion of the task with GeoGebra.

[1] MathCityMap; [2] Rey Juan Carlos University.

Finally, the selection phase of the execution stage was evaluated through group and structured interviews with the three primary education teachers participating in the experience. This allowed us to exchange ideas and obtain much broader, deeper, and more substantial information. The following questions were asked:

- What did you base your selection of STEM-SD trails on?
- What do you think a STEM-SD trail should have to be successful?
- Do you think this type of activity is suitable to be applied in primary education? If so, how would you apply it?
- Do you think it is necessary for primary education teachers to receive training in this type of activity?
- Did you find it an interesting experience to implement in your classes? If so, would you make any modifications?

3.4.3. Data Analysis Process

On the one hand, to evaluate the Likert scale questionnaires, it was decided to regroup the items into variables (as shown in Tables 2–4) and average the results obtained in each of them. A very favorable result is obtained if a score between four and five is obtained; a favorable result is achieved if between three and four points are obtained; an unfavorable result (to improve) is achieved if a score between two and three points is obtained; and an unfavorable result is achieved if the score is less than two.

On the other hand, to analyze the results of the open questions, both those formulated in the initial questionnaire and those posed after the development of the experience, a process of coding and categorizing the responses was carried out based on the identification of the most common patterns or trends, as follows:

1. *Reading:* All responses were read carefully. This gave us an idea of the variety of responses and helped us identify common themes;
2. *Identification of themes:* A second reading was carried out, and the patterns (phrases or key ideas) that emerged as the reading progressed were identified;
3. *Creation of codes:* Brief and descriptive codes were created that identified and captured the essentials of each of the patterns;
4. *Assignment of codes to responses:* Each response was reviewed, and codes were assigned based on the patterns that represented it;
5. *Analysis of the coded data:* Once all the responses were coded, the data analysis was carried out by identifying the most common trends.

Finally, the analysis of the data from the group interview was performed by sharing the comments and suggestions provided by the interviewees, highlighting the key ideas.

4. Results

After carrying out the data analysis process described above, very positive results were obtained that allowed us to assess the applicability of the proposed proposal in the last years of primary education. Next, we go on to break down these results in detail, taking into account the aspects included in the methodology, differentiating each of the stages, and including the main evaluation variables in each of them.

4.1. Initial Questionnaire

The process of coding and categorizing the responses received from the initial questionnaire allowed us to identify four patterns to study, with two categories each, namely, educational innovation (definition and implementation), STEM education (knowledge and implementation), GeoGebra (knowledge and use), and outdoor education (definition and implementation).

The questionnaire was completed by a total of 65 students (35 master's students and 30 undergraduate students), of which 38.46% associated educational innovation only with the use of information and communication technologies (ICT), identifying other aspects as much more important, such as the use of active methodologies and learning strategies or the incorporation of transformative practices. However, everyone agrees that its introduction in the classroom is very important to improve the quality of the teaching and learning process. The strategy for teaching mathematics that is most repeated among those surveyed is problem-based learning applied to everyday life. The use of audiovisual resources and gamification to capture students' attention and improve motivation in the classroom are also mentioned.

On the other hand, only 12.31% of the participants have heard of the STEM concept in education, and of those who know it, they believe that the best option to apply it in the classroom is through robotics and experimental learning in laboratories. In this sense, it can be seen that there is a clear tendency to associate STEM with pure science and technology, leaving aside other very important aspects in this practice, such as social sciences or involvement in environmental and sustainable development. These results allowed us to assess the level of extension of the training workshop on STEM-SD and educational innovation carried out in the diagnosis stage, where apart from highlighting the importance of working on STEM competence from early educational stages, we also wanted to emphasize other very important aspects, such as the inclusion in these stages of comprehensive training in skills linked to citizen participation and sustainability.

Regarding the use of resources, everyone agrees that using mathematical software will help to better understand the mathematical concepts that are studied in the classroom. In this regard, 92.31% of the participants claim to know the GeoGebra tool, and 63.33% of them have used it on more than one occasion. Given these results, we thought it advisable to extend the GeoGebra training workshop to two sessions, as indicated in the previous section, instead of dedicating only one session to it, as originally planned. However, we will see later, when we analyze the results of the execution stage, that for some students, it is still not enough.

Finally, 52.31% say they have heard about mathematics outdoor education, but they associate it with school trips on mathematical dissemination, thus ruling out the possibility of seeing it as a learning strategy. Furthermore, none of them know what math trails are and the benefits that their application can have in mathematics education. This is actually a good thing because one of the things we seek with the development of this experience is to provide students with innovative educational tools, a priori unknown to them, that can be useful for their professional lives as teachers.

4.2. Training Course Evaluation (Diagnosis Stage)

The objective of the first stage was to train students in educational innovation and STEM education, provide them with the necessary skills to create, design, and carry out a STEM-SD trail, and also introduce them to the digital tool GeoGebra as a possible resource to promote the technological part of the STEM methodology.

As indicated in the previous section, a total of 27 items were evaluated corresponding to each of the training workshops implemented and referring to the objectives, the adequacy and relevance of the content, the material provided, the methodology followed, the sufficiency and development of the theoretical and practical training received, the duration of the courses, and the evaluation of the speakers. Each of these variables was valued with a score greater than three, which indicates that the workshops were of great relevance and usefulness to them.

Nevertheless, it should be noted that among these very favorable scores, what received the lowest score, with an average score of 3.17, was the duration of the GeoGebra course. Despite providing two two-hour sessions, the participants did not find it completely sufficient, especially among the participants in the primary education degree program, who had already, in the initial questionnaire, acknowledged having used the tool on very few occasions or stated that they had never used it.

On the contrary, the most highly valued variables, with scores of four and five, were theoretical training and teaching evaluation. All participants think that the theoretical training provided was very useful, appropriate, and sufficient and that the speakers taught their courses in a structured manner, with clear explanations and fluid interaction, encouraging participation and the exchange of ideas. However, although the practical training had good ratings in general, it is true that there were participants who considered it insufficient, receiving some scores below three. This allowed us to evaluate the inclusion of more practical activities during the training workshops in future applications of this experience.

In general, this first phase was valued very positively by the 65 participants who attended the training course, with an average on the Likert scale of 4.27 points out of 5. A summary of the results is shown in Table 5 and Figures 8–10.

Table 5. Post-test results (Diagnosis Stage).

Training Stage Variables	STEM-SD [1]	MathCityMap [2]	GeoGebra [3]
Objectives	3.85	4.52	4.58
Content	3.97	4.54	4.65
Material	3.85	4.38	4.54
Methodology	4.15	4.51	4.42
Theoretical training	4.31	4.85	4.51
Practical training	3.74	3.88	3.77
Duration	3.94	3.94	3.17
Speakers' evaluation	4.71	4.89	4.88
Average rating	4.06	4.44	4.31

[1] Training in educational innovation, STEM education and sustainable development (SD). [2] Math trails workshop: The MathCityMap project—Creation, design, and implementation. [3] GeoGebra workshop: Digital resource to teach mathematics.

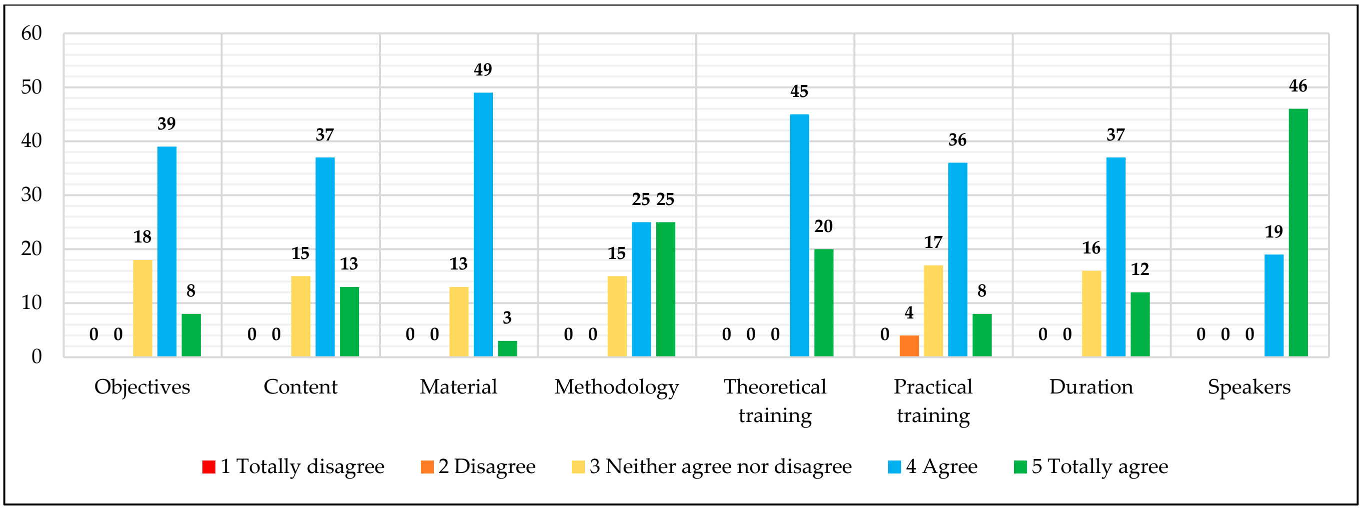

Figure 8. Scores on the Likert scale of the STEM-SD training course and educational innovation. Source: Prepared by the authors.

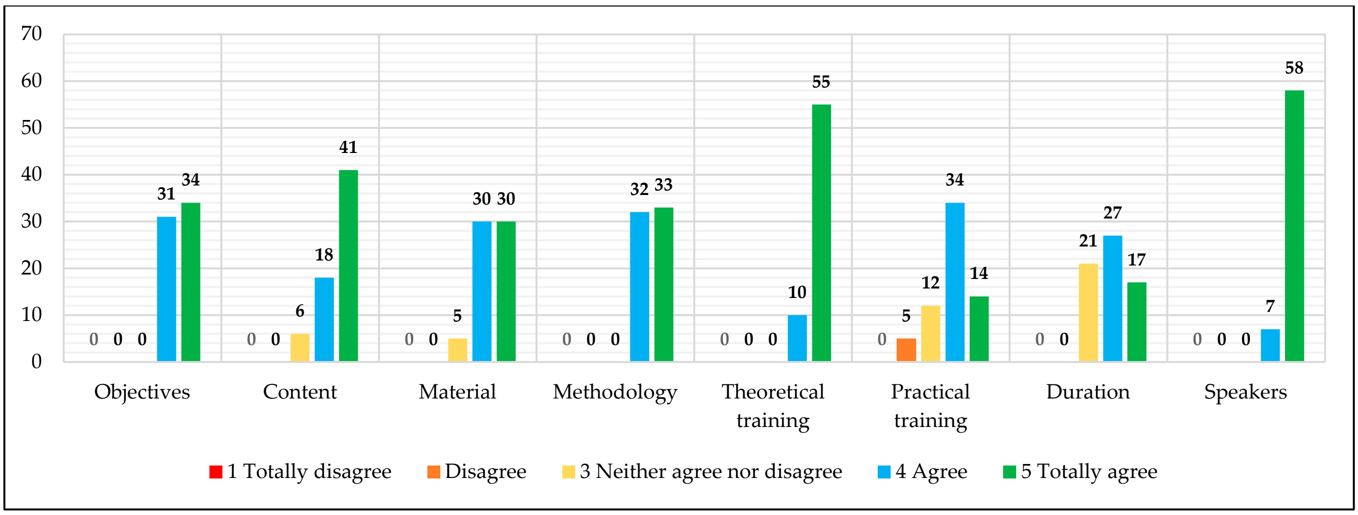

Figure 9. Scores on the Likert scale of the MathCityMap training course. Source: Prepared by the authors.

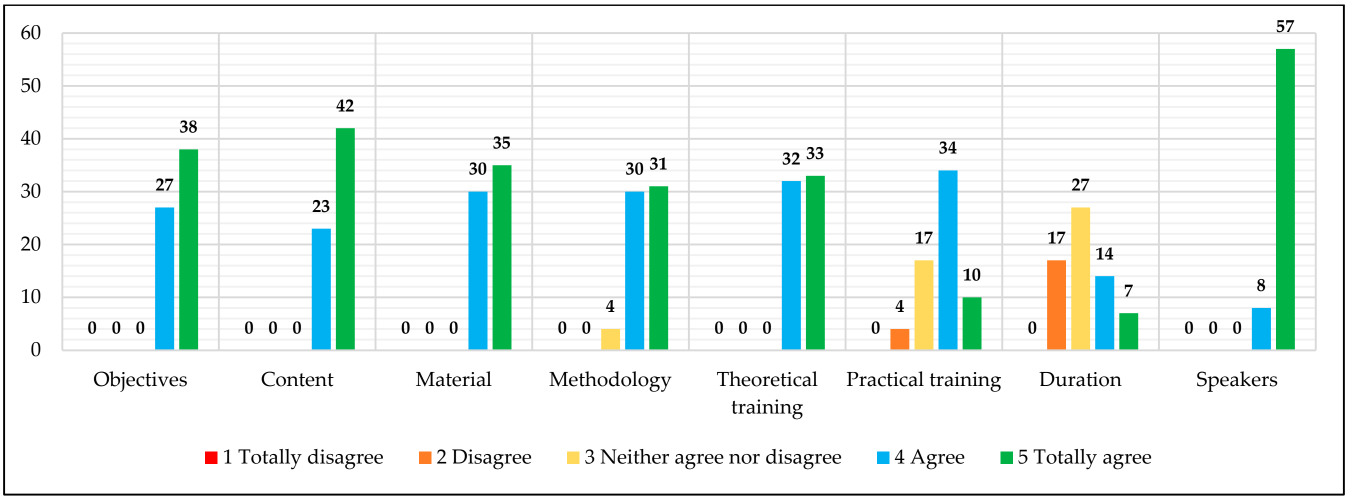

Figure 10. Scores on the Likert scale of the GeoGebra training course. Source: Prepared by the authors.

Regarding the open questions that were asked, the patterns that were most repeated in the responses to the question referring to whether they considered it necessary to include STEM-SD training in primary education courses were as follows: *innovation*, *useful*, *technological resource*, *scientific vocation*, and *environmental awareness*. Most attendees pointed out that STEM-SD training is an innovative alternative in teaching–learning that is very necessary in any educational stage that promotes the use of technology, the vocation of science, and environmental and sustainable education.

On the other hand, regarding the responses to the question referring to whether they considered it a good resource to apply STEM-SD trails in primary education, the patterns identified were as follows: *use of technology*, *motivation*, *innovation*, and *possible difficulty*. As could already be seen in the initial questionnaire, none of them were aware of the use of math trails in education and agreed that it is an innovative resource to improve mathematical skills, increase student motivation, and promote the development of scientific and technological thinking, as well as the use of technological tools, such as MathCityMap's mobile application. Some of them point out here the difficulty of including tasks with a STEM focus in some parts of the mathematics subject.

However, they were not very sure if including GeoGebra in the teaching–learning of mathematics in primary education could be a useful resource because they consider it a complex tool for early ages. In any case, they considered that it could be adapted to the last courses of this educational stage in the study of geometry as a way of representing lines, parabolas, and polygonal or polyhedral figures, as well as calculating areas and demonstrating the basic concepts of functions.

4.3. Activity Assessment (Execution Stage)

The execution stage was dedicated to the development of the experience. This includes the creation of math trails as group work by the master's student participants, the choice of three of these trails by three in-service primary teachers with teaching experience, the completion of these trails by students of a degree in primary education (the trail itself and the activity with GeoGebra), and the design of a STEM-SD trail for the fifth grade, also carried out by the latter.

The designed trails were about 6 km long and although they were scheduled to be completed in a time of 75 min, the participants managed to complete it in an average time of 90 min. At the end of each trail, the group went to one of the URJC computer rooms, where they carried out the corresponding activity with GeoGebra. At this point, we were aware that although the previous training in GeoGebra allowed the participants to learn the rudiments of the tool, it was not enough for them to develop the proposed task adequately because some of the participants needed the help of the teachers who managed the activity to complete it. It is also determined that it would have been positive to spend a little more time carrying out simulation exercises for the design of math trails in the training stage.

As indicated in the previous section, in the design and experimentation phases, in which the master's students and undergraduate students participated, respectively, a total of 13 items categorized into four variables were evaluated. These variables referred to the practical training aligned with the previous course on the MathCityMap platform, the MathCityMap platform itself, in terms of the ease of use of the website, the trail creation and review processes, their opinions about the importance of testing the trails before applying them, and of course, the collaboration during this phase of the teachers and collaborators involved in the experience.

These phases were also rated positively, with an average on the Likert scale of 3.92 points out of 5. In fact, in both phases, each of the variables was valued with a score higher than three, which indicates that the creation and design process of the trails was very rewarding for them. Participants pointed out that the MatyCityMap platform is easy to use and offers varied alternatives to formulate tasks and choose the most appropriate response format, and they also agree that in the review process, reviewers give the necessary guidelines to create quality trails. It can be noted here that the work of the teachers is not as good as that in the training courses. However, it is worth mentioning that in these phases, the teachers take a back seat, providing suggestions or resolving doubts, and it is the students themselves who have to deal with the design of the trails, developing their creative thinking and taking into account the training received. A summary of the results is shown in Table 6 and Figures 11 and 12.

Table 6. Post-test results: execution stage—design and experimental phase.

Execution Stage Variables	Design Phase [1]	Experimental Phase [2]
Previous training (MCM[3])	3.63	3.53
MCM [3] platform	4.29	4.03
MCM [3] (task design)	3.89	3.60
MCM [3] (review process)	4.31	3.83
Trail testing	4.23	3.93
Teacher's work	3.83	3.87
Average rating	4.03	3.80

MCM platform ← (MCM [3] platform, MCM [3] (task design), MCM [3] (review process))

[1] Evaluation of the design phase in the execution stage: 35 participants. [2] Evaluation of the experimental phase in the execution stage: 30 participants. [3] MathCityMap.

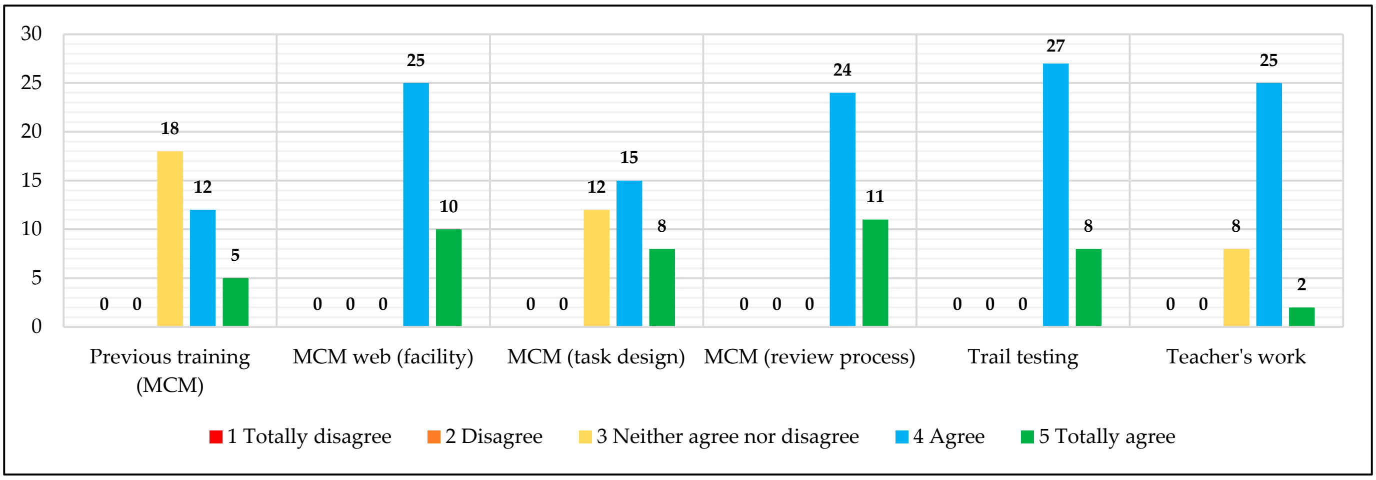

Figure 11. Scores on the Likert scale of the design phase (execution stage). Source: Prepared by the authors.

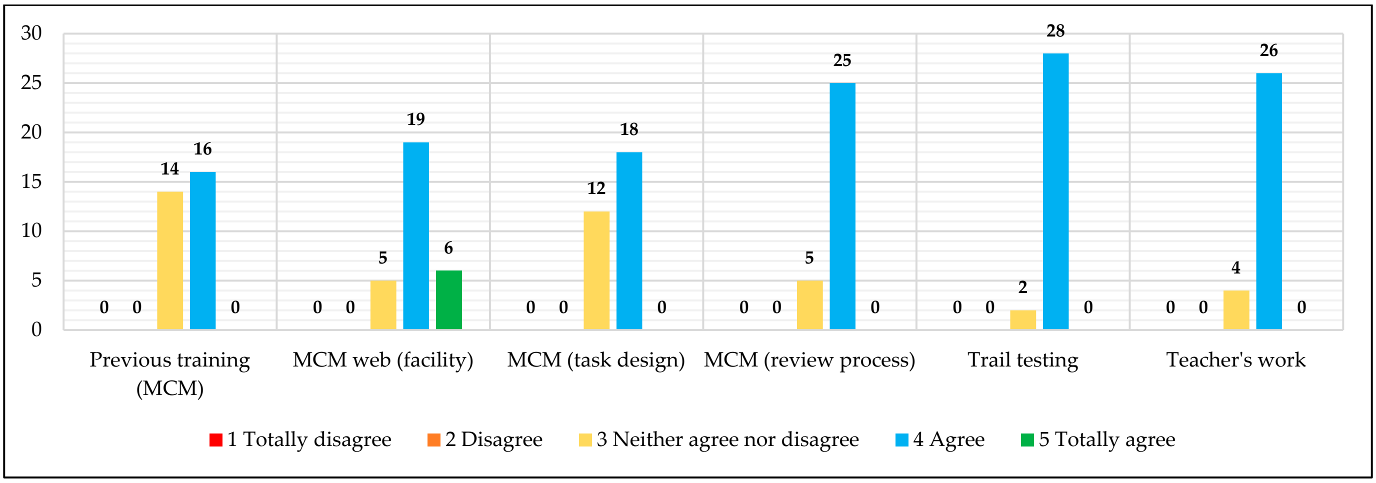

Figure 12. Scores on the Likert scale of the experimental phase (execution stage). Source: Prepared by the authors.

Regarding the open question that was formulated and referred to the complexity of the process of creating and designing a STEM-SD trail, they commented that the most complicated thing in the design process was searching for STEM-SD activities appropriate to the level that was sought, and as some already pointed out in the diagnosis stage, the difficulty was especially increased when having to think about tasks that involve certain mathematical concepts a priori, which were difficult to apply in the environment. Most commented that it is easy to think about geometry, as it is the most applicable in this type of activity, and this can lead to repetitive tasks. Regarding the question about what they consider most important when designing a trail with these characteristics, they affirmed that testing the trail is very important to be able to estimate an adequate time. They suggested that it is better to take a shorter trail with fewer tasks and a longer time than a long trail loaded with content that causes rejection; this is because, although it is an outdoor activity, which can motivate them more, it must be ensured that students do not become disengaged from the objective, which is none other than applying mathematics in natural and urban environments.

On the other hand, with regard to the experimental phase, after evaluating the trail that the undergraduate students designed for hypothetical fifth-grade students, we considered that it was appropriate for the targeted level. Although it was developed with the MathCityMap application, it was not made public because, after the review by the platform's evaluators, we considered that it was necessary to refine some of the proposed tasks.

Finally, in the application phase, in which only the undergraduate students participated, a total of 17 items were evaluated, again divided into four variables, in this case referring to the process of executing the trails and managing the MathCityMap mobile application, practical training aligned with the previous course on GeoGebra, the adaptation of the trails to the level and duration, and again, the collaboration of teachers and collaborators during the execution of the trail. A summary of the results is shown in Table 7 and Figure 13.

This phase was the one that received the least favorable scores because, according to the open question that was asked regarding the complexity of the trail execution process, the participants considered that some of the activities were quite complex or did not meet the indicated level. In this sense, they perceived that the mathematical knowledge that was presupposed to be able to carry out the tasks was greater than what they expected, which led them to the need to delve deeper into such content to be able to apply it properly and thus be able to guide their future students in a hypothetical STEM-SD trail. Furthermore, although very few indicate it in their responses, difficulties were observed when carrying out the activities with GeoGebra, which is something that is reflected in the results of the variable referring to the use of GeoGebra (aligned with the previous training), with a score very close to three. Even so, results above average are obtained, which allows us to evaluate this phase as positive.

Table 7. Post-test results: execution stage—application phase.

Execution Stage Variables	Application Phase [1]	
Execution process	3.43	
Previous training (GeoGebra)	3.07	
Proper trail level	2.73	→ Trail suitability
Proper trail duration	3.03	
Teacher's work	3.60	
Average rating	3.17	

[1] Evaluation of the application phase in the execution stage: 30 participants.

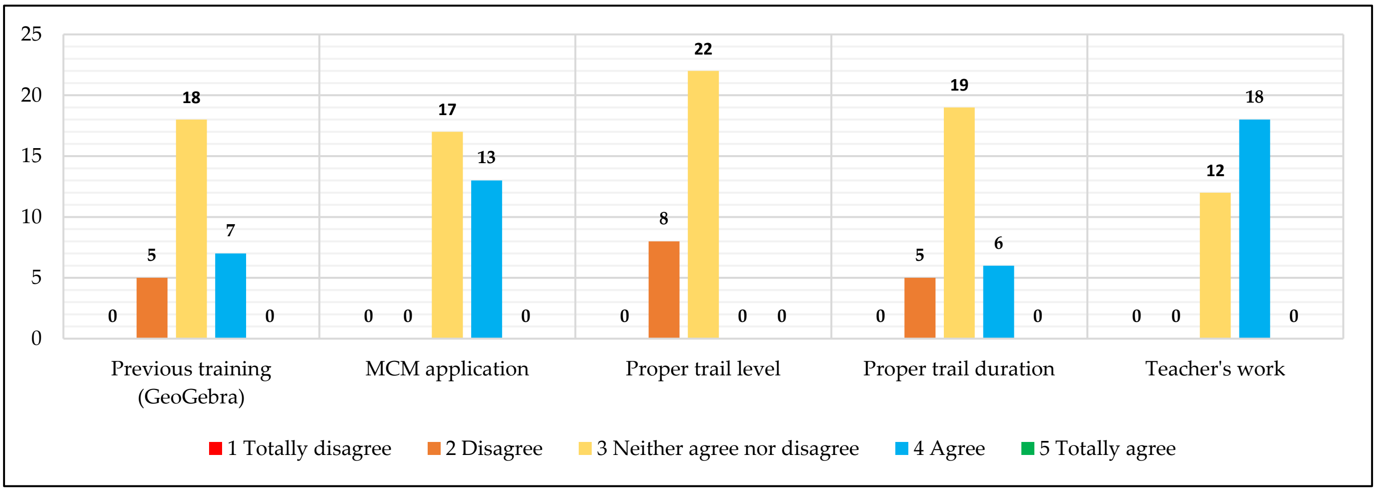

Figure 13. Scores on the Likert scale of the application phase (execution stage). Source: Prepared by the authors.

Regarding the active primary teachers who participated in the trail selection phase and who also collaborated as support teachers during the completion of these, they agree that it is an interesting and very useful activity in primary school education because it is essential that children understand that mathematics is present in many situations of daily life. However, they consider that it would have better results in more advanced primary courses, from fourth grade to sixth grade, although they value its applicability in the first grades, but without using GeoGebra and reducing the trail time and the number of tasks to two or three. In this case, they consider that it is best to conduct it in the schoolyard as much as possible.

Furthermore, they comment that, in this type of activity, the ideal would be to form work groups that are as equitable as possible based on the skills and competencies of their members. It would be useless to put those students with greater mathematical skills in the same group and those with less skill in another because the objective is also to encourage collaborative work and help each other. They also point out that it must be made clear from the beginning that it is a serious activity and that it is part of their learning because, when carried out outside the classroom, they may think that it is something extracurricular and informal and may not take it seriously.

On the other hand, they emphasize that the training received by teachers is essential to developing activities as innovative as this one. There are many centers still stuck in traditional mathematics classes, and this is a problem because we live in a constantly changing society in which advances in education are increasingly important. The educational system needs mathematics teachers who take risks in their classes with active methodologies and innovative activities that provoke students' curiosity about what they are learning and avoid the general fear of mathematics.

Regarding their participation in the experience, they comment that the STEM-SD trails proposed by the master's students were creative and generally adapted to the level requested. To select the trails that were going to be carried out in the experience, they took into account, apart from the adequacy of the level, that they were trails that included tasks that gave rise to more than one approach and, in this way, promoted the mathematical flexibility of the participants.

They appreciated that there was a variety of content because, for example, some of the trails only contained tasks on geometry, and there are many more topics that can be addressed transversally with technology, engineering, and sustainability. In fact, this is one of the main characteristics that, according to them, a STEM-SD trail should have. These characteristics include that it should be mathematically flexible and creative and involve a variety of tasks that each contribute something different.

4.4. Global Assessment (Discussion Stage)

The experience ended with the debate and analysis of the learning situations that occurred during the development of the activity. They agree with the teachers who participated in the selection of the trails that it is a very appropriate methodology to be implemented in primary and secondary education, and they all emphasized that implementing training courses for teachers is very necessary to achieve quality education.

They also agree that adapting this type of activity in primary education requires a little more effort and training than what is needed for pre-university or secondary levels, especially the digital part, but they consider that it is an activity that it could be adapted to any level if the appropriate methodological strategy is sought. At this point, they also propose another interesting way to introduce this concept, which is by sending them as homework assignments to locate a mathematical object on the street and invent a problem with it because, in this way, the creative capacity of the students is also enhanced.

5. Discussion

Once the different stages of the experience carried out in this intervention study were evaluated, some important findings were concluded, as follows:

It is observed that before the beginning of the experience, a lack of knowledge was perceived regarding educational innovation and STEM education in the students who participated in the experience. For this reason, a special emphasis was placed on these topics in the training stage. On the other hand, although approximately half of the participants believed they knew what outdoor education means, the truth is that the majority associated it with "school outings" [35], and very few linked it with its real meaning, which is a heuristic teaching of mathematics focused on the search for alternatives to solve certain problems [37–39,55].

Regarding the sessions dedicated to the transmission of knowledge about STEM education, math trails, and the use of GeoGebra, very positive data were obtained in general. At this point, the participants were shown different tools to contextualize the STEM-SD teachings, and they achieved the maximum benefit in terms of managing the MathCityMap platform. However, it is true that in this last point, it would have been positive to spend a little more time carrying out simulation exercises for the design of the trails. Regarding training in GeoGebra, it is observed that to be able to incorporate it into the tasks within the STEM-SD trails, more in-depth training in this field should be carried out. Furthermore, although it is not clear that its use can be adaptive in primary education, and of course, it may not be advisable, depending on which trail is designed; we believe that it is interesting to introduce it to enrich the STEM dimension of the activity and enhance its use in this educational stage [44].

In this sense, we believe that it is essential to adequately prepare future primary school teachers and connect them with learning experiences in which outdoor STEM education is used as a facilitating resource for the teaching–learning of mathematics [44,56]. It is essential that in their professional futures, they know how to look for possible alternatives to traditional teaching that help enhance students' mathematical skills and ability to solve problems [57]. For this reason, it is essential to be clear about the pedagogical approach that you want to implement and the patterns that future teachers must develop during their professional development [44].

On the other hand, in the execution phase, future teachers and current university students perceived that the mathematical knowledge that was presupposed to carry out the proposed trails was greater than what they expected, so we conclude that it is necessary to delve deeper into the approach of the trail and test it properly before putting it into practice. As has been demonstrated in other intervention studies on STEM trails in primary education, it is important to design the trails taking into account the mathematical content, resolution procedure, level of cognitive demand, degree of contextualization, and creativity of the tasks included in the trail [44,56].

In the trails that were designed for this experience, we were able to realize that there is a tendency to propose typical exercises with a low level of cognitive demand, as demonstrated in the article by [44], in which after carrying out an exhaustive analysis of tasks included in STEM trails, the lack of creativity and the tendency to focus on classic problems with closed tasks and short and poorly contextualized statements was confirmed. This is due, once again, to the clear lack of training that future teachers receive because, although they tend to show good performance in activating procedural knowledge of the problem, they do not have the sufficient capacity to design problem-solving strategies [58].

Despite this, we believe that math trails are a great step in addressing the mathematical needs that future teachers will face [30]. Continuing with the design of the trails, we observe in our study that in line with previous research, students confirm that MathCityMap is a project with great potential and that it could be of great help to increase the problem-solving capacity of students when facing mathematical problems [7,10,44,45,56,58]. However, what most worries participants is the inclusion of tasks with a sustainable and interdisciplinary approach because creating mathematical tasks in the environment is not complicated; the really complex thing is to adapt them until they become STEM-SD tasks. For this reason, we once again remember that it is essential to provide them with sufficient knowledge in this field so that in their future as teachers, they can use it correctly.

In line with the study by [44], the trails included in this experience had to include tasks that had to be solved using mathematical representation and calculation software. We chose GeoGebra as it is a free, dynamic mathematics software whose use in education is increasingly widespread. In this sense, although more than half of the participants in the execution of the trail claim to have used this tool at some time, it is true that this is not reflected during the activity because the majority of participants had difficulties in solving the task proposed with this software within the STEM-SD trail. In this regard, for future applications, we believe that it is necessary to increase practical training in the use of this tool as it is an excellent resource to improve the central activity of mathematics in solving problems, both analytical and geometric, at any educational stage [44,59,60], providing greater attention in the primary stage [61,62], which is when they begin to connect mathematics with aspects of real life.

We have also been very struck by the tendency of future primary school teachers, and even active teachers, who have participated in the experience to think that math trails would be better applied in the last years of primary education. However, this is something that tends to predominate in the studies that have been analyzed; for example, in the study by [56], 55% of the STEM trails that were analyzed corresponded to the sixth grade, and those carried out in [44] were designed for children between 10 and 12 years old. Here, again, we think that this is due to the insecurity that many teachers claim to have due to not having sufficient training in mathematical educational innovation [63].

Finally, the debate that was carried out with the participants in the last stage of the experience and the interviews carried out with the primary teachers who collaborated in this study allowed us to opt for including the STEM-SD trails in the MiniOpenLab project described above because it has been possible to verify that incorporating STEM education and sustainable development through math trails is a useful methodology to motivate students and give them an opportunity to connect and contextualize STEM disciplines.

6. Conclusions

The experience that has been carried out in this research combines the theoretical mathematical knowledge that a pre-service teacher must have with the knowledge of digital tools, STEM education, and sustainability education through the design and creation of math trails.

The developed experience involving pre-service teachers in a STEM-SD-integrated approach with outdoor trails was very satisfying in its outcomes. The activity was valued very positively, and all participants pointed out that the math trails applied to sustainability and STEM education is a good methodological strategy that can be applied as transversal training in the different educational stages. STEM-SD education has become a priority in the different curricular reforms of many countries, and implementing it together with math trails will allow the teaching–learning of mathematics to be linked with society and the world around us. This links directly to the STEM-SD approach, in which the contextualization of the situations and problems raised is essential.

The design of math trails requires a little training, as already mentioned. It is necessary to propose a mathematical objective that guides the trail and relates to the activities that adapt to the level of the users and the environment and respond to a real need. Remember that the purpose of the trails is to help contextualize mathematics and STEM teaching in general. On the other hand, incorporating the use of technology was significant in this experience and was also a valuable tool for learning STEM didactics. We think that for the proper use of the trails, more training time should be dedicated to GeoGebra, both for the teachers who design them and for the students who execute them.

It is known that teachers are ultimately responsible for the teaching process, and consequently, their training must be a priority. Of course, leading them toward real teaching practice is an essential element for their training as teachers. To improve the mathematics learning process from an early age, future teachers must also receive the best training, and we must ensure that to the greatest extent possible, this learning is experiential and they know how to develop problem-solving skills, improve critical thinking, and establish mathematical connections, both from theoretical and practical points of view.

The need to provide specific training in problems posed to future teachers in the initial stages, who are not specialists in STEM-SD areas, is fundamental for the emergence of a rich and varied awareness of what a good mathematical problem is [55,56]. This study has pointed out some deficiencies in terms of the content and nature of the problems proposed in the context of STEM-SD trails that must be considered so that future teachers and the students who will be trained by them can develop a deeper understanding of what it means to perform math.

Although this research seeks to provide an innovative approach to mathematics teaching and allow teacher candidates to acquire the practical experience necessary to face the educational challenges of the 21st century, it is also essential to give them sufficient tools to be capable of creating quality resources with which to apply mathematics in a real-world context and with the potential to strengthen the role of mathematics in society. This research allows us to opt for including STEM-SD trails as an educational resource within the study plans in the last years of primary education courses because tasks can be created with which to work on any area of mathematics based on the minimum required competencies at this educational stage.

With this type of experience, apart from developing mathematical and scientific skills with which to promote logical–deductive reasoning, digital skills are also acquired because technological tools are used, such as the MathCityMap mobile application itself, the GPS global positioning system, and mathematical calculation and representation software. In addition, linguistic communication skills are also developed, as collaborative work is encouraged, and dialogue between students is promoted to solve a problem; In addition, of course, social skills are developed because during the activity, students learn to positively value the sociocultural dimension of STEM disciplines and to control and manage their own learning, adapting to changes that may arise. In addition, attitude is improved, and planning capacity, a sense of responsibility, and decision-making are promoted.

Moreover, the experience was linked to two projects, including the MathCityMap project and the MiniOpenLab project, the first to design and carry out math trails and the second to focus on the development of STEM-SD activities for children between 6 and 12 years old. We have been able to verify that two projects that work separately can come together to connect mathematics with the environment and other disciplines to promote meaningful learning and creative thinking in students, as well as improve their mathematical attitudes and skills [32].

Finally, we consider that connecting math trails in an interdisciplinary way with the study of sustainability and STEM disciplines in the first stages of students' scientific training could be a good approach with which to promote a change in educational practice and develop learning based on STEM-SD competencies that allows the teaching–learning of mathematics to be enhanced and contextualized with other areas of knowledge. However, a pedagogical framework focused on this type of methodology and, of course, adapted to future research should be made available to teachers.

7. Limitations and Future Lines of Research

With this research study, we wanted to contribute to the field of mathematics education and its practical implications for the integration of STEM-SD practice in primary education through an innovative teaching methodology. However, throughout the experience, there were a series of limitations. For example, the participants may limit the generalization of the results, that is, the sample is limited to one university and specific degrees, so it is not representative of all university students, and therefore, generalizations must be made with caution.

On the other hand, the trail tasks that were designed were not limited to any specific area of mathematics, but participants were given the opportunity to create tasks in which they could use mathematical concepts from any didactic unit of the mathematics curriculum to which the trail was directed (sixth grade). However, to assess the applicability of the resource in a broader way, it would be advisable to create specific STEM-SD trails for each of the areas of mathematics teaching. If during the creation process, the participants had been required to take trails within a specific area, the results would probably have varied because, for example, it is much more complicated to give a STEM-SD approach to algebraic concepts than to geometric concepts. It is proposed as a possible future line of research to study the STEM-SD trails, individualizing them according to the field of knowledge.

Finally, this study presents the immediate results of the intervention because it was only intended to measure the perceptions of the participants toward the developed methodology and their opinions on a possible implementation in primary education courses or if they believed that this could help improve educational processes. In this sense, we can say that this research has been carried out from a prospective vision, keeping in mind the main educational challenges and opportunities that teachers will have to face in the coming years. In this line of research, a future application is proposed to collect long-term data to measure the change in attitude of the participants toward similar methodologies. This would substantially improve the impact of the results.

This experience opens other new lines of research to continue studying and improving this new and innovative methodological approach. One of the objectives is to incorporate this type of activity into studies focused on training future teachers. We also intend to adapt the realization of this type of experience to the first years of primary education and the last years of early childhood, as well as to continue promoting its use in the last years of primary education, secondary education, and pre-university courses, including different itineraries through natural and urban spaces, starting from the creation of a STEM-SD trail layout that could be used by the entire educational community.

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