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Supporting the Development of Pre-Service Primary Teachers PCK and CK through a STEM Program

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Abstract: STEM (Science-Technology-Engineering-Mathematics) education has received great attention in recent years not only for promoting interest and learning in these areas but also for encouraging children and young people to pursue careers in them. This research explored the effects of a STEM program in developing the primary pre-service teachers' Content Knowledge (CK) and Pedagogical Content Knowledge (PCK) about sound. A qualitative and interpretative study analyzed the impact of a STEM program on the CK and PCK of 18 pre-service primary teachers that were attending a master's degree program in a Portuguese higher education institution. The data was collected from their lesson plans, field notes, a focus group interview, and participants assignments throughout the STEM activities carried out. Findings revealed several scientific misconceptions and weaknesses in the participants' PCK. Nevertheless, there was a clear positive impact on pre-service teachers' CK and PCK, specifically regarding the principles underlying STEM integration that was proposed in the conceptual framework.

Keywords: Content Knowledge (CK); Pedagogical Content Knowledge (PCK); pre-service teachers; primary education; STEM education

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1. Introduction

STEM (Science-Technology-Engineering-Mathematics) Education is related to the need to attract students for STEM areas. The development of STEM literacy has become an educational priority [1] to improve the numbers reported by the Organization for Economic Co-operation and Development [2], according to which, in more than half of the OECD countries, the percentage of students who obtain a degree in STEM areas is lower (24% on average) than in other areas.

Even though the advantages of STEM education are well known, there have been numerous obstacles to the dissemination of these practices in the classroom, including a poor understanding about STEM education [3] and scientific concepts [4,5]. Teachers also have shown difficulties in adopting non-traditional teaching strategies [4,5] and integrating content from different STEM areas [6,7]. In fact, the way in which STEM disciplines should be integrated is still the subject of debate in the literature [8,9]. The situation is more problematic in primary education, where most teachers have limited knowledge in STEM areas, particularly regarding Inquiry-Based Learning (IBL) [10]. Research has shown that consistent exposure to IBL is fundamental for preparing future generations of primary teachers to teach using IBL, as well as STEM education [10]. In addition to the already highlighted obstacles to STEM Education, there are others specifically pointed out in the first levels of education, such as the problematic integration of engineering practices [11], the lack of attention to science [12] and technology [13]; the overemphasis on mathematics content and the absence of engineering in the curricula of primary education [14].

Therefore, "consistent exposure to the inquiry may be fundamental for preparing future generations of teachers to teach using inquiry as well as future STEM professionals" [10] (p. 159). Teachers play a decisive role in the successful implementation of STEM Education [1], so they must be supported in the development of their Content Knowledge (CK) and Pedagogical Content Knowledge (PCK) [15] in teacher education. Thus, this study aims to examine the effects of a STEM program on pre-service primary teachers' CK and PCK.

1.1. Theoretical Framework

The discourse in the field of science education in recent years has consistently referred to the importance "of cross-curricular 21st century skills such as collaboration, critical thinking, problem solving, design and engineering skills, creativity, and ICT literacy" in early years [16] (p. 89). The combination of an integrated STEM approach with IBL creates an excellent opportunity for the development of these skills, to which communication is added [17]. However, despite the potential of STEM integration for motivating students to pursue scientific careers, studies point to some concerns about how STEM integration is carried out and about the possibility of science content and process learning be lost in a hasty STEM teaching [18].

Nonetheless, research demonstrates that the success of STEM Education depends on the teachers' self-confidence, their perceptions, the importance they attribute to it, their attitudes, etc. [19–22]. Several studies focus on this subject. For example, one study [22] with 25 prospective teachers and 21 science teachers, sought to understand the participants' perceptions about the use of a project methodology based on a STEM approach that combined Project-Based Learning (PjBL) for science teaching. Pre-service teachers and teachers attended an eight-hour continuing education workshop on STEM-PjBL, during which they built toys to address physics topics with students: forces, sound, thermodynamics, electricity, etc. The results revealed that the students' involvement in this type of activity promoted their motivation for science classes. However, despite recognizing these benefits, the lack of time, resources, and training in STEM Education was pointed out as impediments to its implementation in the classroom. Kim and Bolger [19] described research in which 119 pre-service teachers (PSTs) developed a lesson plan that included an interdisciplinary STEM approach as part of a course they were attending. The results showed significant gains for PSTs in relation to the perception of their ability to create materials for STEM education, the confidence and commitment to develop such classes in their future practice, and the awareness of the potential of content integration to help students learn in a more interesting and meaningful way.

Thibaut et al. [1], based on an extensive literature review on STEM integration (iSTEM) and social constructivist view on learning, propose a framework containing five key principles (integration of STEM content, problem-centered learning, IBL, design-based learning, and cooperative learning) that describe the practices underlying STEM integration. According to this model, STEM content integration must be explicit to help students develop their knowledge and skills in the different STEM disciplines. In an integrated curriculum, content from more than one discipline is explicitly addressed, and the same emphasis is given to two or more disciplines [6,7]. In this respect, Roehrig et al. [23] propose a distinction between content integration and context integration. The first perspective focuses on merging disciplines into a single activity or unit, while the second focuses on the contents of a discipline and uses the others as a context to make the content more relevant.

Regardless of the STEM approach adopted, it is fundamental for its operationalization that teachers have support in the development of their CK and PCK [15] during initial education. Shulman [15] identified CK (or often also called subject matter knowledge or SMK) as the knowledge about the subject matter to be learned or taught and PCK as the knowledge about pedagogy that applies to teaching specific content. The first dimension of teachers' professional knowledge (CK) comprises the body of knowledge and processes that are a prerequisite for the development of the latter (PCK) [15]. Despite its undeniable importance, in research on teacher education, little attention has been paid to how teachers need to understand the content they teach [24]. Teaching a subject requires more than Content Knowledge alone. It requires a process of transformation of content into Content Knowledge, and, for that, it is necessary to develop PCK [25]. Shulman defines PCK as a "special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding" [15] (p. 8). Many studies focus dominantly on teachers' PCK, which has resulted in a variety of different models [25]. For instance, for Magnusson et al. [26], PCK is the result of a transformation of other domains of knowledge, which implies being more than the sum of the parts, and is conceptualized as being built through the process of planning, reflecting, and teaching a specific content. For these authors, PCK is determined by the content to be taught, the context in which that content will be taught, and how the teacher uses his/her experience. Although multiple views about the PCK coexist in the literature about these knowledge type, this study aims to shed light on the development processes when PSTs are engaged in a STEM program.

Knowing that Content Knowledge influences teacher confidence and practices [27] and that lack of CK is particularly common in primary teachers [28], initial teacher education programs for early-level teachers should focus on science topics in which PSTs have difficulties and IBL, to produce considerable progress in their PCK [29]. Indeed, research has shown that primary school teachers are not well prepared to engage their students in inquiry and problem-based learning approaches, which makes it essential to support teachers in developing their PCK [29,30]. Literature on STEM practices and the development of CK and PCK in initial education is scarce, highlighting the lack of investment in this field. This research intends to contribute to this gap, studying the effects of STEM activities, according to the IBL methodology, in the CK and PCK of primary PSTs about sound concepts. The sound topic was chosen because it is present in the curriculum guidelines from the first levels of schooling [31], involving fundamental concepts for the learning of complex physics concepts [32], and numerous studies reveal the persistence of alternative conceptions in students [33–38] and future teachers [32,39,40].

1.2. Research Aim and Questions

In this sense, this study aims to examine the effects of carrying out and planning STEM activities on the theme of sound in the CK and PCK of primary PSTs. To accomplish it, two research questions were formulated:

1. How do PST's CK and PCK evolve after participating in a STEM program?
2. What features of the STEM program influenced the development of the CK and PCK?

2. Methods

A qualitative study with an interpretative orientation [41] was developed to explore the effects of a STEM program on sound on primary PSTs' CK and PCK.

2.1. Participants

In this case, 18 pre-service primary teachers were enrolled in the last year of the teacher education program in a Portuguese higher education institution. The study sample was composed only of females, and none had previous experience with teaching science before their enrolment in the teacher education program. The justification for the sample being only composed of future female teachers is due solely to the fact that there were no male students attending this course when the study was carried out. In all classes, the PSTs worked in self-selected groups of three (G1—Group 1), four (G2—Group 2; G4—Group 4), five (G3—Group 3) and two (G5—Group 5) (Table 1).

Table 1. Identifier of participants and respective groups.

Groups	PSTs
G1	E1 E2 E3
G2	E4 E5 E6 E7
G3	E8 E9 E10 E11 E12
G4	E13 E14 E15 E16
G5	E17
	E18

2.2. STEM Program

In the first part of the program, the PSTs attended a course that included one physics content module for over 10 h, in which they could deepen their knowledge of sound concepts by performing STEM activities. Five activities were developed following the guidelines proposed by Thibaut et al. [1], as described in Table 2.

Table 2. STEM activities.

Activities	Description
Production of sound	After reading a small text and watching a video about the importance of acoustics in our lives, the PSTs plan a hands-on experiment to discover how sound is produced. After that, the whole class discusses and shares the results obtained by each group. In the last task, the PSTs explore a tuning fork and reflect on the definition of frequency.
Propagation of sound	A challenge is presented to the PSTs as to whether it would be possible to hear a concert on the moon. Next, they are asked to read a text about the measurements of the velocity of sound and solve some exercises using the mathematical equation. The last challenge focuses on the speed of sound in different mediums (solids and air), taking the example of tracking a train approaching from far away.
Attributes of sound	An adaptation of the 5E lesson proposed by Adams et al. [42] is presented to the PSTs, comprising the construction of a musical instrument to explore different attributes of sound (pitch, intensity, and timbre). The PSTs also simulate a wind instrument to study if the variation in sound pitch is related to the size of the column of air. After that, the PSTs explore the oscilloscope function by installing the app Physics Toolbox Sensor Suite® [43] on their smartphones. This app uses the device sensors to collect and display data and allows the PSTs to study wave shape and plot the signal against the time-lapse. Furthermore, they explore the simulation "Longitudinal periodic wave ∣ spring" [44].
Sound waves	Two PHET simulations "Wave on a String" [45] and "Sound" [46] are explored to study different waves and characterize sound waves. After that, there is a moment to share and discuss the main conclusions of the groups, and the PSTs answer some questions about the attributes of sound. In the end, PSTs analyze whether the speed of sound depends on wave frequency and amplitude, using the "Simple Wave Simulator Interactive" [47].
Behavior of sound waves	Starting from a text and a problem about sound reflection, PSTs are challenged to solve it by planning an experiment. After this experiment, the PSTs develop a new investigation to study other behavior of sound waves (refraction or absorption). This activity also comprises exploring the concepts of reverberation and echolocation through the analysis of practical examples. Finally, after viewing some videos exemplifying the Doppler effect, the PSTs explain the phenomenon, explore a computer simulation [48], and discuss possible scenarios for that to occur.

Afterwards, the PSTs enrolled in a science methods course in which, over a total of 17 h, they were introduced to the topics listed in Table 3.

Table 3. Topics covered in the science methods course.

Number of Hours	Topics
2	Science curriculum in primary education The benefits of science education in primary education Social constructivism in science education
2	Development of 21st-century skills Collaborative learning Problem and project-based learning
4	Hands-on activities Inquiry-based learning 5E-instructional model [49]
2	Authentic assessment tasks (Scoring Rubrics)
2	Integration of technology
5	Interdisciplinary approach STEM education

2.3. Data Collection and Analysis

This research study was approved by the Institutional Review Board (ethics board). All participants signed informed consent forms and were given the opportunity to withdraw at any time.

Data collection strategies included PSTs' assignments, lesson plans, observation, and a focus group interview. During the classes in the Physics course, we collected the PSTs' worksheets and took observation field notes, including a detailed description of the PSTs' actions and classroom situations. After the observations, the researcher reflected on the lessons based on the field notes taken while in class. At the end of the semester, the PSTs completed an assessment test, the analysis of which contributes to an in-depth understanding of their CK development.

The second part of the STEM program focused on the development of the PSTs' PCK, and for that, they planned collaboratively one STEM activity. In addition to the lesson plans, the PSTs were encouraged to write down their reflections during the science methods course. These reflections about the lesson plan the PSTs developed aimed to understand their perspectives about the benefits and challenges of STEM integration. In some cases, the PSTs had the opportunity to carry out the STEM activity in teaching practice, which contributed to a better understanding of the PSTs' views.

Lastly, a focus group interview was conducted with nine PSTs who volunteered. The interview targeted the PSTs' perspectives about the STEM program and discussed what they experienced during teaching practice.

For data analysis, we resorted to content analysis, using a mixed deductive-inductive method. In the first phase, the analysis relies on the PSTs' answers on different assignments (STEM activity worksheets and assessment tests) that were confronted with the explanations/conceptions identified by numerous authors in the literature.

During the PSTs' attendance in the science methods course, they planned one STEM activity covering basic sound phenomena and concepts. Accordingly, the analysis employed the predetermined categories, adapted from Thibaut et al. [1] and complemented by Roehrig et al.'s [23] distinction between content and context integration, as summarized in Table 4.

The analysis of the PSTs reflections and the transcription of the focus-group interview and inductive coding method was used [50]. The categories that emerged from the data represent the features of the STEM program that enacted the development of the CK and PCK.

Results generated through the different data collecting methods were compared and discussed among the two researchers.

Table 4. Categories based on the theoretical framework for instructional practices in integrated STEM.

Categories	Instructional Practices
Integration of STEM content	Content integration Context integration
Problem-centered learning	Focus on authentic, open-ended, and real-world problems
Inquiry-based learning	Hands-on activities Posing questions Planning and carrying out investigations Collecting, analyzing, and interpreting data/information
Design-based learning	Learning through design Developing and using models Designing solutions Opportunities to learn from failure and to redesign based on that learning
Cooperative learning	Collaborative and cooperative learning

3. Results

3.1. CK of Primary PSTs

Table 5 synthesizes the main conceptions revealed by the primary PSTs concerning the issues of sound (CK) that were explored on STEM activities carried out during the physics course.

Table 5. PSTs' answers relate to sound subjects.

Activities/Subjects	Explanations	Groups
Production of sound	vibration of the sound source resulting from an action	G3
	sound as an entity	G1–G4
Propagation of sound	sound propagation requires a medium	G1–5
	sound is fast in solid, as it is denser	G2, G5
Attributes of sound	in wind instruments, a higher pitch is related to a small column of air	G3
	sound intensity and sound pitch are the same	G1, G2, G4
Sound waves	confuse frequency with amplitude	G2
	speed of the sound is dependent on frequency and amplitude	G1, G2, G4, G5
Behavior of sound waves	Doppler effect is directly connected to distance between source and observer	G3, G5

In the first STEM activity, the PSTs proposed an explanation for the production of sound caused by the vibration of the sound source. In the assignment of a group (G3), it was possible to identify the idea that the vibration of the sound source is a result of an action. Overall, the PSTs' answers point to an interpretation of sound as an entity.

Regarding the second STEM activity, the PSTs described sound propagation at a microscopic level, revealing that they were aware of the need for a material medium for sound to propagate. Two groups (G2 and G5) presented a wrong explanation for the fact that sound propagates faster in solids, associating the speed of sound with the density of the material.

As for the sound attributes (third STEM activity), some participants (G3) found it difficult to conclude that in wind instruments a higher pitch is related to a small column of air. In the hands-task of exploring a tuning fork, three groups (G1, G2 and G4) could not distinguish the concepts of pitch and sound intensity.

The analysis of the fourth STEM activity worksheets confirmed the persistence in G2 of the misunderstandings about two sound waves characteristics—amplitude and frequency. Most groups considered that the speed of sound depends on those parameters and did not realize that the frequency depends on the source, not the medium. However, the analysis of the test answers showed that these scientific inconsistencies were overcome, as all PSTs were able to distinguish between amplitude and frequency, determine the relationship between the intensity and amplitude of the sound and between the frequency and the pitch of the sound, and to characterize these sound attributes in graphical representations.

The PSTs' answers were thoroughly correct about reflection, refraction, absorption, and other sound phenomena explored in the last STEM activity (behavior of sound waves). Nonetheless, about the Doppler effect, two groups (G3 and G5) incorrectly justified that it is directly related to the distance from the source to the observer.

3.2. PCK of the Primary PSTs

The results obtained regarding the analysis of lesson plans were summarized (Table 6), according to the predetermined categories.

Table 6. Instructional practices are evidenced in lesson plans.

Category	**Instructional Practices**							
	Content Integration				**Context Integration**			
Integration of STEM Content	**S**	**T**	**E**	**M**	**S**	**T**	**E**	**M**
	G1; G2; G3; G4; G5			**G2; G3**		**G1; G2; G3; G4; G5**	**G1; G5**	**G4; G5**
Problem-centred learning	G1; G2; G3; G4; G5							
Inquiry-based learning	G1; G2; G3; G4; G5							
Design-based learning	G1; G5							
Cooperative learning	G1; G2; G3; G4; G5							

The STEM lesson planned by G1 focused on the subject of sound propagation. First, students should touch with an arch of a violin on Chladni plates covered with sand and watch the patterns caused by the metal vibration. Then, students are challenged to design a cymatics device to create "pictures of sound" (i.e., wave patterns). In the end, they play a team game in which they must recognize different sounds produced by the other groups and animal and other familiar sounds played on YouTube®. There are some connections to mathematics content, but it was not mentioned in the lesson plan. The same happened with engineering content, although the lesson allowed students to engage in a hands-on design challenge that was not sufficiently highlighted.

G2 presented a lesson about sound production and the factors that affect it. Students must pose questions, predict, plan, and investigate. Additionally, students should create a graph based on the data collected throughout the experiment and discuss it. A second activity consists of exploring the most appropriate materials to absorb sound. All the proposed activities involve students in open-ended and real-world problems and working in small groups. Math learning goals were explicit, although not so relevant as science learning goals. Students visualize a video to become familiar with the theme, so technology was present, but merely as a resource.

G3 proposed a simplified version of Carrier, Scott, and Hall's [51] lesson, in which students explore the sound concepts of frequency and amplitude as they learn about various species' calls and their uses for survival. In this activity, students listen to recordings of animal calls and match them to the corresponding visual representations of sound (spectrograms). These can be found in the audio files of the software Raven Lite® [52]. G3 explicitly emphasized mathematics learning goals, content, and practices. However, they did not apply equal attention to both disciplines (mathematics and science). This lesson focused on open-ended, real-world, authentic problems that engage students in a hands-on group activity.

G4 provided a learning environment that engage students in a hands-on activity to develop new understandings regarding the reflection of sound. Students worked in groups. There was a concern to identify students' misconceptions and confront their previous ideas through discussion and some assessment exercises (assessment sheet) at the end. G4 did not establish mathematics learning goals and contents, although the planned STEM activity included knowledge of angles. Furthermore, this lesson plan integrates technology by including a video to engage the students with the theme and explain some underlying concepts. The problem is relevant (Is the repeated sound heard in the same way as the incident?) and open-ended, but the way it is presented does not sustain a real-world context.

G5 planned a STEM lesson that was adapted from a 5E lesson developed by Merricks and Henderson [53]. This activity explores sound propagation and acoustic communication using an inquiry-based and problem-based approach. The first part of the activity (Engage) starts with a dialogue with students to understand their previous conceptions, and then they must develop a model of waves. In the Explore phase, students investigate how waves travel; for that, they must build "cup phones". Later, students explore the free software Audacity® (Explain) to examine human's ability to detect sound and to develop knowledge about sound features. The final part of the activity (Elaborate) immerses students in the study of the role of acoustic communication for other living organisms. Through the analysis of oscillograms produced by different species of frogs, students can distinguish the species and locate them in their habitats in a scenario provided by the teacher. In all activities, the students work in groups, are involved in authentic, open-ended, and real-world problems, and in design challenges. Although the lesson planned included the content of all STEM disciplines, besides science, G5 did not mention it in the learning goals. For instance, the lesson comprehends graphs analysis (mathematics), artefacts development (engineering), and the use of computer software (technology).

In short, only one group (G5) integrated the areas of mathematics and engineering (albeit in terms of context). G1 and G4 also integrated one of these two dimensions in the same way. Finally, G2 and G3 integrated mathematics content, although not as much attention is given to this area as to science.

3.3. Features of the STEM Programme That Influenced the Development of the CK and PCK

The analysis of the PSTs' reflections and the transcription of the focus group interview emerged several features of the STEM program that influenced the development of CK and PCK, as synthesized in Table 7.

Table 7. Results regarding the features of the STEM program that influenced the development of the CK and PCK.

Categories	Subcategories	Frequency
Integration of STEM content	Content integration	18
	Technology integration	14
Inquiry-based learning	Inquiry (in general)	10
	5E model	9
	Planning and carrying out investigations	11
Collaborative learning		16
Meaningful/motivating/engaging context		11
Student-centered pedagogies		11
Design-based learning		8
21st century skills		6

3.3.1. Integration of STEM Content

The integration of STEM content was the most prominent feature of the STEM approach. All PSTs seem to value the "curricular flexibility that it allows for the teacher" (E13, reflection), but they also pointed out numerous difficulties in content integration. For instance, they mentioned that they struggled to articulate different STEM disciplines is a "very demanding challenge for a PST, both in planning and in its implementation in the classroom", and they "found it difficult to have time to implement the activity during the classroom practice" (E9, reflection). The integration of different STEM disciplines requires from the teacher, according to one of the participants, a "great capacity for reflection, creativity and time" (E15, reflection). During the focus group interview, the PSTs also mentioned these concerns, and they all agreed that the most challenging discipline to integrate into their lesson plans was engineering. When they were asked about the reasons for that to happen, they explained:

> E17: I think it's the most difficult because we don't have that much knowledge and, therefore, we're not so comfortable with this discipline.
>
> E15: I think it also depends a lot on the content you work on. Not all science topics are suitable to articulate with engineering. (Focus group interview)

Despite being such a demanding and time-consuming process, some PSTs demonstrated that this experience helped them to overcome the problems they had encountered when planning and/or implementing STEM lessons:

> After carrying out this planning and subsequent implementation in the classroom, I believe that there was a change in my thinking regarding this type of activity, since I considered that they were more complex. (E6, reflection) STEM activities are a type of activity that can be a little complex to plan, as they have a certain number of characteristics that are not always possible to have. However, in my opinion, they are activities that enable students to understand the integration of various content areas. That, in turn, facilitates the teachers. (E17, reflection). Despite the work that requires planning a STEM activity, the gains in students' learning overcome the teacher's difficulties. This means that no matter how demanding the teacher's work in planning is, namely, interconnecting STEM areas (. . .), building a plan that meets the content that is intended to be addressed, predicting possible students' difficulties, adapting the assessment instruments to the various phases of the activity, and managing the groups throughout the activity (. . .). Creativity, meaningful learning, interdisciplinarity, motivation, involvement, and active participation are positive aspects that the STEM activity develops in students. (E15, reflection)

For one PST, "the greatest difficulty for students was the acquisition of scientific terms to designate the events arising from the experiments" (E6, reflection).

During the interview, one PST goes further and talks about the potential of these activities to integrate content from subjects other than STEM, which is very convenient in primary education.

> I think that STEM activities in the classroom, in addition to mathematics, engineering and technology can integrate other subjects, in other words, the fact that I work on subjects of mathematics does not mean that I cannot work the subject of language. I think that starting from a STEM activity, the teacher can proceed to different curriculum disciplines. (E15, Focus group interview)

The results indicate that the integration of technology caught the attention of most PSTs, as illustrated by the following statements.

> With so many technological resources at our disposal, if we ignored the potential of these resources, we would be contributing to a school out of step with current reality. For children, sooner or later, contact with technologies is inevitable.

> Teachers must take a responsible and informed attitude using the technological resources to enhance learning in the most diverse areas. (E11, reflection)

> Nowadays, children grow up and are exposed, at an early age, to the digital world. It is known today that technologies increasingly have both positive and negative impacts on society. Both the school and us, as future teachers, must be attentive and organized to obtain pedagogical advantages from this situation, that is, use technologies as a strategy to improve the teaching and learning process in our classes, as it is something very stimulating to arouse interest of children in the desire to learn. (E13, reflection).

However, when we confront the PSTs' perspectives about technology integration that arose from the analysis of these documents with their lesson plans, what prevails is the use of the technology as a mere resource, as demonstrated by the following extract:

> The role that technology played in this activity was solely and exclusively through the interactive manual. We provided several explanatory videos, which we played as we explained, that is, the students did not have the opportunity to manipulate technological resources. (E10, reflection)

This last statement reflects the experience of teaching practice, in which most PSTs were forced to change their initial lesson plan deeply. This need for change, among other factors, is "due to the lack of resources in schools, this task becomes an even greater challenge, as it is not possible to secure sufficient resources" (E7, reflection). The transcription of the focus group interview also revealed that these reasons forced the PSTs to practically suppress the use of technology by students:

> E15: It would provide them more time to use ICT. In my case, I used ICT at the end of the activity and then the time was short, and they did everything in a hurry.

> E17: Many times, ICT is involved, but we are the ones who use them. We don't have time, so let's be us to be faster. (. . .) and schools don't have the resources. (Focus group interview)

3.3.2. Inquiry-Based Learning

In the second category, the PSTs mentioned numerous aspects related to inquiry-based learning, particularly planning and experiments. One PST highlighted that:

> The students were able to achieve these goals and acquire the knowledge because they had experimented, because they were the ones planning what they had to do and if they found that it didn't work for them to do it again until it did. The fact that it is the students who reach the desired result, without being given all the information, allows this increase in learning. (E17, reflection)

Nevertheless, some stages of the scientific inquiry could be problematic for students, according to some experiences in teaching practice. For instance, besides the great enthusiasm in the discovery and hands-on moments, students did not appreciate analyzing and interpreting data and drawing conclusions, as described in the following statement.

> When they [students] made the discovery, the degree of excitement was very high, and the level of satisfaction and well-being was also seen, which remained until we asked them to stop and draw conclusions from what had happened. (E10, reflection)

Some PSTs' experience during teaching practice also revealed some problems with another moment of the inquiry, which is predicting results, as the following examples indicate.

> Another of the students' difficulties were related to the concern with having all their predictions correct, and the fact that after each experiment they verified a difference between the predictions and the conclusions, they were frustrated

> because they were wrong. In this way, I intervened to make them understand that predictions are not used as an object of evaluation but as a way of verifying what the students considered before reaching conclusions. (E6, reflection)

> For them [students] it did not make much sense to be predicting results without having carried out the experiment, so this was a complex process, for them to understand that in this part of the activity, they were not manipulating, but only observing. This difficulty arose since these students are not used to carrying out an investigation, and never being asked about their previous ideas, that is, they never confronted the results with their previous ideas. (E1, reflection)

These issues observed during the implementation of STEM activities, according to several PSTs, are related to the lack of experience of students in planning and carrying out investigations, besides the small amount of time to perform it, as exhibited in the following statements.

> I felt that the group had a lot of difficulties in following the steps to reach the result. On the other hand, these difficulties may have occurred due to the lack of experiences that the class had. Another difficulty was the time for the activity, which, in my view, passed very quickly, and I was so involved that I ended up not having time to assess all the children. (E10, reflection)

> The main challenges I faced with this activity were quite a few, as it is an activity that, despite being extremely enriching for teachers and students, is also incredibly demanding for both parties. (. . .) One of the problems that exists in the primary education is the time given to implement hands-on experiments, which is very short, so trying to fit these activities into the schedule is unfortunately not always possible. (E1, reflection)

Therefore, some PSTs mentioned the need to provide more guidance to students from the beginning until they become more acquainted with all the processes involved in an inquiry activity (posing questions; planning and investigating; collecting, analyzing, and interpreting data/information): "if students are used to carrying out investigations, and became more autonomous, they can develop all the steps with little guidance" (E6, reflection). This discussion also came up during the interview:

> It's a little difficult at first, until they get used to it. They were always "how can I do this?" or "How do I do this?". They wanted us to provide all the steps. We noticed that they are not used to it. The first few times, the probability of going wrong is great, but then, it starts to get better. (E10, focus group interview)

The PSTs were introduced to the 5E-instructional model (Bybee et al. 2006) and used it to plan their STEM activities, which was very challenging. But despite some difficulties in using this instructional model, as the following extract demonstrates, the PSTs recognize its usefulness for the teacher in the process of planning a STEM activity.

> Through the activities developed, it is possible to face challenges and learning. In the first case, it is related to all the stages for the construction of the lesson plan, considering the 5E model, that is, all the five, six phases included in the STEM plan. Building a plan that contains all or part of these phases turns out to be a constraint as well as the integration of the STEM disciplines because, although possible, it is complicated to carry out tasks of this magnitude that take a long time and several classes, to work on the same content and still find different strategies for all these phases. However, after developing this STEM plan, I ended up also having a new perspective about the constraints presented above. Because the 5E model ended up being a kind of "guide" for the teacher to know what each of the phases should contain and the benefits for the child's development through it. (E13, reflection)

An aspect present in focus group interview transcription and in the reflections was that "communicating during inquiry or design tasks is very difficult for students" (E15, focus group interview), especially when they describe their results or conclusions to the entire class. Communicating information also related to other features of STEM activities, such as collaborative learning and design-based learning.

Another aspect discussed during the interview was that for students interpreting the results based on the experiment is a hard task: "in explaining. They try and see what worked and then have a hard time explaining why it happened in such a way. You may have understood but explaining and arguing I think is where they have the most difficulties". (E18, focus group interview)

3.3.3. Collaborative Learning

This was the third most common feature of the STEM program in the PSTs reflections. More than half of the participants mentioned it as a strength and/or a challenge. For instance, one PST stated that "It not only benefits students' learning as well as the relationship between teacher-student and student-student, and values such as cooperation, teamwork, and respect for the opinion of others" (E13, reflection). For E11, collaborative learning is as challenging as technology integration, as she pointed out that:

> The teacher must be aware that he must teach his students working as a team. This is a skill that can be learned like any other and not should be taken for granted. (...) In my view, the main difficulties of students are related to collaborative work and the ability to work with a computer. I believe that a flexible classroom in terms of furniture placement would facilitate working in groups or in pairs. As for computers, the solution will involve investing more in visits to the library to use computers to search for information, carrying out and disseminating group work. (E11, reflection)

PST's reflections about their teaching practice experience indicate that students were not used to collaborating, so PSTs had to be very active in monitoring the groups and resolving frequent conflicts, as described in the following assertions.

> Another of the difficulties felt was group work, but this difficulty occurs due to the specificity of the class, as it is a group of very complicated boys, very striking and special personal experiences, and sometimes it is reflected in conflicts between elements of the class. Working in groups in this class is always a delicate and time-consuming process, which takes a while to get into the work rhythm. (E1, reflection)

> Makes group management difficult. Because most of the time, the students are talking to their colleagues, and this made the interventions I had to do or my colleague difficult. Students could not understand what we were saying as they were talking. I believe this was a learning experience because we had to use a strategy to demonstrate to students the importance of speaking down. (E17, reflection)

3.3.4. Meaningful/Motivating/Engaging Context

One of the most emphasized features of STEM activities was the focus on meaningful, real, and open-ended problems. This real-life context allows more meaningful learning to students, makes it easier for teachers to "contextualize the various areas and highlight their practical use in everyday life" (E11, reflection), and will "arouse students' interest and attention" (E4, reflection). About this, E13 gives an interesting example in the following description.

> Let's imagine that the teacher is facing a problem within the classroom, which is student noise, through everyday life the teacher can perfectly alert students to the situation and make them think about what kind of sound it is. That is,

> whether the reflected sound is heard in the same way as the incident sound. (E13, reflection)

During the focus group interview PSTs reflected on the STEM activities they performed in the first part of the STEM program and come to the consensus that, "It could have been easier to perform more structured activities, but we weren't as involved" (E17) "would not be that meaningful" (E5). These ideas demonstrate their agreement that this engaging context helped them build their own knowledge (CK).

3.3.5. Student-Centered Pedagogies

There were several references to the use of student-centered pedagogies. According to some PSTs, in a STEM activity, students "take the lead of their own learning" (E11, reflection); "is the center of their own learning, active, critical, explorer, and autonomous" (E15, reflection). The next statement exemplifies the non-traditional roles assumed by teachers and students in this type of activity.

> These types of approaches require from the teacher a very different attitude from what we are used to, placing the student as the protagonist of their learning. In this case, the teacher assumes the role of moderator and facilitator, making available to the students the necessary means so that they can build their own learning while respecting the interests, needs and rhythms of each one. (E11, reflection)

3.3.6. Design-Based Learning

This category refers to the use of engineering design. In their reflections, eight PSTs mentioned this feature as either strength and/or challenge of a STEM unit. For example, E7 stated that engineering tasks "allows the student to focus on solving the problem, articulating the mathematical and scientific knowledge previously worked on" and that "this was what they liked the most". (E17, reflection)

Two G5 students had the opportunity to implement a STEM activity in teaching practice and emphasized, above all, the integration of engineering and the involvement of students in a prototype design task, as demonstrated in the following citations.

> Children design something and have to change it, improve it, and it is in this analysis of what they have done that they are also able to acquire more knowledge (. . .) and apply it in other situations. (E17, focus group interview)

> I emphasize the involvement of students in the entire process, from the construction of materials, to verify and discuss the results, that is, the students' involvement is much greater than in any other type of activity. And this is quite advantageous. (E18, focus group interview)

Despite this, during the focus group interview, all respondents expressed that the most difficult area to include in STEM activities is engineering, due either to their limited experience at this level or to the students' lack of familiarity with this type of tasks.

3.3.7. 21st Century Skills

Some PSTs emphasized that STEM activities promote the development of 21st-century skills, as the following excerpts exemplify.

> This is a methodology that aims for the student to become the protagonist of their own knowledge, thus developing in the student extremely important skills for their future life, such as leadership, resilience, conflict resolution, collaboration, these are fundamental skills in your future life. (E1, reflection)

> I believe that STEM activities are corrupting traditional formfs of teaching that are increasingly out of step with the realities present in schools. The implementation of this type of activity can stimulate the development of knowledge in science, technology, engineering, and mathematics areas, but also other transversal skills

(linguistic knowledge, critical thinking, teamwork, decision-making, and creativity) in a more interactive, practical, and autonomous way. (E14, reflection)

The focus group interview encouraged the participants' reflection about the positive effect of the STEM program in learning, highlighting the practical nature of STEM activities, the students' active role, and the content integration of different STEM disciplines. The PSTs recognize not only the importance of carrying out STEM activities for learning the different disciplines, but also consider that they have contributed to learning how to plan and carry out investigations.

The following statement evidence the importance PSTs attribute to this experience of articulation between STEM areas for student learning.

> On the one hand, it is beneficial because students learn in action, they learn to handle, and it allows them to develop skills that even older people do not yet have, for example, programming. I can't, I mean I can but it's not immediate, I have to think. I think that working on this with children from an early age is important for them to learn, however, I think that schools are not prepared yet. (E7, focus group interview)

They also added that students are not used to carrying out practical activities of the investigative type or to working collaboratively. The biggest obstacle to the integration of technology, in their opinion, are the few resources available in schools.

4. Discussion and Conclusions

As in the study developed by Küçüközer [32], it was possible to identify aspects of sound production as a phenomenon based on the action or physical properties of the source, although PSTs did not mention it in the conclusions. Most groups exhibited the misconception that sound is an entity distinct from the medium through which it propagates, such as a "material or substance" [34] (p. 247) and/or an "entity carried and transmitted by the molecules of the medium" [32] (p. 1891).

All groups evidenced the correct idea that for sound to propagate, it requires a material medium, which contrasts with the study carried out by Küçüközer [32], in which most PSTs gave an incorrect explanation. Another wrong idea presented by the PSTs was that the velocity of sound is associated with the density of the material [40].

On the topic of sound attributes, the participants presented difficulties similar to those identified in other studies [33,37,38], namely in distinguishing pitch from the sound intensity. In the following STEM activity (sound waves), one group still demonstrated the persistence of misunderstandings about these two sound-wave parameters (amplitude and frequency), which is one of the most common misconceptions in the topic of sound [33]. Another problem was identified in the subject of sound waves, which was the fact that they consider that the velocity of sound depends on the frequency and the amplitude, a wrong idea that, according to Barniol and Zavala [33], is related to inadequate use of the equation $v = f\lambda$. The PSTs did not realize that frequency depends on the source and not on the medium (such as velocity) because they attributed it to the objects and not wave properties [38].

Regarding the behavior of sound waves, the students demonstrated a good understanding of reflection, refraction, and absorption, including correctly identifying the most appropriate materials for acoustic insulation, contrary to the results obtained by Bolat and Sözen [40]. Nonetheless, about the Doppler Effect, the PSTs' answers revealed incorrect links that were made between some of the concepts, such as in the study developed by Mosabala [36].

Results for participants' PCK (Table 3) revealed that problem/inquiry-based learning and collaborative work are present in all lesson plans, while design-based learning received little attention. Although design engineering process through integrated lessons is well recognized as a key to increasing student motivation and knowledge in science and/or mathematics, probably due to little preparation of teachers' candidates in primary level [11], only two groups included this STEM subject.

The results revealed that all the STEM lessons developed by the PSTs did not meet the efforts to integrate technological literacy in primary curriculum [13] because technology is used merely as a resource. In most of the lesson plans (except G2 and G3), the other STEM disciplines were just used to make the content of sound more relevant or as a resource [23]. For instance, engineering, as in the lesson planned by G1, is a vehicle to provide a real-world context for learning science and mathematics [7,23].

Only two STEM activities (G2 and G3) presented explicit assimilation of concepts from more than one discipline, according to Satchwell and Loepp [6] view about integrated curricula. That integration between science and mathematics is particularly important in primary education [12]. More evident was the concern of the PSTs in establishing connections to real-life situations [6,7].

The attributes of Thibaut et al.'s [1] model common to all STEM lessons were problem-centered learning, inquiry-based learning, and cooperative learning. Other aspects mentioned in Thibaut et al.'s [1] review, such as assessment, is not very detailed by most groups. Only two groups (G1 and G3) stand out for proposing a scoring rubric, as claimed by Satchwell and Loepp [6].

The results point to the overcoming of scientific inconsistencies about sound, including the indistinction between the concepts of amplitude and frequency, which supports the idea that an integrative approach to STEM, based on active methodologies, contributes positively to the development of CK of the PSTs of the first levels of schooling [39]. Another conclusion of this study is that due to the inaccurate scientific mental models that have been identified, it is crucial to continue addressing the topic of sound in pre- and in-service continuing education initiatives.

The STEM integration program also positively affected the development of the PCK of the primary PSTs, as demonstrated by the lesson plans developed and the perspectives highlighted by the participants interviewed. Yet, the aspects less achieved in the lesson plans that the PSTs' developed reinforce the need to continue to implement and improve STEM activities, with emphasis on the integration of different STEM disciplines [6,7], particularly, to overcome deficits in primary technology [13] and engineering practices [11]. Furthermore, according to Gresnigt et al. [12], the better way to solve the problem of lack of attention on science and technology in primary education is to integrate those disciplines with mathematics. It is important to make connections between disciplines to motivate students to learn, as it is to connect learning activities to real-life situations [6,7].

With these results, the authors conclude that teacher education play a critical role for the appropriation of the main attributes of STEM education. Indeed, it seems evident that engaging PSTs in carrying out and planning STEM lessons favors an effective development of PSTs' knowledge (CK and PCK). Hence, it is recommended that teacher education in addition to focus on STEM integration frameworks in method courses, include opportunities for PSTs to strengthen their knowledge about complex physics topics. This investment in teacher training is even more pressing in primary education, given the low level of confidence of teachers to develop and implement STEM lessons [20]. Additionally, future work, should focus on PSTs' PCK and CK enactment in classroom practice. The findings of the current research are valid for the studied group. Studies focusing on PSTs' professional knowledge development through a STEM program using a larger group are to be pursued in future investigations.

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