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STEM EDUCATION DURING THE COVID-19: TEACHERS' PERSPECTIVES ABOUT STRATEGIES, CHALLENGES AND EFFECTS ON STUDENTS' LEARNING

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Abstract. *This research aims to examine: (a) how Physics teachers who participated in a STEM project, adopted and implemented a STEM activity in the context of a pandemic; (b) from the perspective of Physics teachers, what were the effects on students' learning of a STEM activity implemented in the context of the pandemic; (c) what challenges had Physics teachers faced in implementing the STEM activity during the pandemic. A qualitative and interpretive methodology was used. The participants are four Physics teachers who implemented a STEM activity on sound, during the pandemic. Data were collected through interviews and written reflections. The study has shown how, in a crisis context such as COVID-19, which affected schools all around the world, teachers were able to deal with it and kept developing a STEM activity, revealing the main challenges and effects on student learning, from the teachers' points of view. Moreover, it was clear that carrying out with success a STEM activity, in such an adverse scenario, was strongly related with teachers who found new strategies and keep students motivated, by guiding them proficiently, and that requires to merge scientific and technological knowledge.*

Keywords: *COVID-19, pandemic context, physics teachers, online teaching, STEM activity*

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Introduction

Crises are uncertain situations in their causes, effects, and ways of resolution (Wart & Kapucu, 2011) that result from a diversity of calamities of natural origin (e.g., earthquakes), manmade (e.g., terrorism) and even related to social health problems (e.g., COVID-19). Public emergencies require appropriate responses from government to protect civil society (Pepper et al., 2010), including in the education sector, by involving different stakeholders who support education decisions, as in the context of the current COVID-19 (OECD, 2020). Research on this topic is scarce in education. Some of the exceptions are Whitla's (2003) and Pepper et al. (2010) books containing case studies (e.g., teacher's suicide at school, shooting at school). Yet, only two of Pepper's cases are focused on unpredictable disasters such as coronaviruses (Hurricane Katrina and 11th September 2001). Still important is Gainey's research (2009) on crisis planning, exploring the topic in US public schools and Smith and Riley's (2012) work about attributes and skills needed for effective school crisis leaders. Other researchers examined school actors' reactions to two 1999 earthquakes in Turkey (Akbaba-Altun, 2005) and the preparedness of Turkish schools towards them (Ozmen, 2006). Lately, studies about disasters on Australia (the 2009 Victorian bushfires), Japan (the 2011 magnitude 9.0 earthquake) and New Zealand (the 2011 magnitude 6.3 earthquake) were undertaken, adopting a pastoral care approach (Bolton et al., 2014). Fletcher and Nicholas (2016) also studied the impact of a New Zealand earthquake on school community and the principal as a community leader. These are valuable studies associated with dramatic events.

Research Questions

In this COVID-19 crisis, Arroio (2020) reinforced the importance of Education, as well as the need to increase the number of studies related with COVID and Education. In fact, studies about the pandemic and education are still scarce, and few of them are focused on how teachers had adapted their practices, and which teaching and learning strategies have been used

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to manage it. The research aim was to make a strong contribution in this regard. More specifically, it has intended to answer the following research questions:

- How did Physics teachers, who participate in a STEM project, adapt, and implement a STEM activity in the context of a pandemic?
- How did Physics teachers perceive the effects on students' learning of STEM activities implemented in the context of the pandemic?
- What challenges did Physics teachers face in implementing the STEM activity during the pandemic context?

STEM Education

In the last decades, STEM Education (Science-Technology-Engineering-Mathematics) has been playing an increasing role on educational policies at an international level, given, on the one hand, our contemporary world need to enable youths to realize the importance of scientific and technological developments that are occurring at an ever-increasing pace; and, on the other hand, because the global competitiveness we are living in, requires that more students are attracted to pursue STEM careers (Chiu & Duit, 2011). According to the Organisation for Economic Co-operation and Development (OECD) report "Education at a Glance" (OECD, 2018), in more than half of the OECD member countries, the percentage of students who obtain higher education in STEM areas is lower (24% on average) than the percentage of those who complete higher education in other areas. In response to these results, a large investment has been made by government entities to attract students to STEM areas.

Considering this global scenario, initiatives have been developed to reformulate curricula and create learning environments that bring STEM Education to the fore. Then, what prospects for STEM Education are behind these initiatives? There is no consensus in the literature regarding the meaning of STEM Education and how the four disciplines can be integrated (Breiner et al., 2012). Some authors consider that STEM Education must focus on one of the four disciplines (i.e., Science, Technology, Engineering or Mathematics) (e.g., English, 2016; Vasquez, 2014). This is the case of Gazibeyoglu and Aydin (2019), who developed STEM activities for the 7th year, focused on two topics of Physics (Energy and Forces), and supported by technology (e.g., simulations) or engineering (construction of measuring instruments) to lead students to explore scientific concepts related to these topics. Other researchers consider that STEM Education is about merging disciplines at an interdisciplinary level ("closely linked concepts and skills are learned from two or more disciplines with the aim of deepening knowledge and skills") or transdisciplinary ("knowledge and skills learned from two or more disciplines are applied to real-world problems and project, thus helping to shape the learning experience") (e.g., English, 2016, p. 2).

Based on a literature review, Thibaut et al. (2018a) proposed a STEM integration framework that supports teachers to make decisions about practices related to STEM Education. The framework comprises five key ideas: (1) integration of the contents of the STEM disciplines, which can take place at the discipline level, or at the interdisciplinary or transdisciplinary levels. Whatever the option, it is important that the contents (i.e., concepts) are explicit to help students to develop their knowledge and skills; (2) problem-based learning. This is a key methodology to involve students in real problems, linked to an engaging and motivating context; (3) inquiry, i.e., a methodology known to promote student involvement in different processes (e.g. questioning, data collection and interpretation, experimentation, etc.), in order to solve an initial problem; (4) design-based learning, which allows students to be actively involved in challenges of an engineering project, during which students mobilize content and ideas from all STEM disciplines; (5) cooperative work to develop group work and communication skills, which is crucial, since they need to be encouraged to communicate scientific concepts and the explanation of phenomena, etc.

According to Thibaut et al. (2018b), the success of the implementation of an integrated STEM Education relies heavily on teachers, specifically, on their attitudes to this teaching approach. This is reinforced by Margot and Kettler (2019), who highlighted that the pedagogical component is strongly determined by the role of teachers. Hence, the success of STEM integration depends on the way teachers put it into action. Therefore, to benefit from all the profits of STEM Education, it should be implemented properly (Stohlmann et al., 2012). Two factors are described in the literature as determinant in the implementation: teachers' characteristics (e.g., their attitudes and values towards STEM Education) and the teaching context (e.g., time and resources) (e.g., Henderson et al., 2011; Lund & Stains, 2015; Stains & Vickrey, 2017).

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Research Methodology

General Background

A qualitative and interpretive methodology was used (Hennink et al., 2020) to examine (a) how Physics teachers who participated in a STEM project have adapted and implemented a STEM activity in the context of a pandemic; (b) how Physics teachers had perceived the effects on students' learning of STEM activities implemented in the context of the pandemic; (c) what challenges did Physics teachers face in implementing the STEM activity.

Participants

The participants in this study were four Physics teachers who collaborate in a STEM research project that aimed to understand the effects of STEM activities on students' learning and motivation, as well as their interest in pursuing scientific careers. The project started in 2019 and will end in 2022. The participants were selected because they kept on collaborating on the project during the context of the pandemic, showing availability to develop one of the STEM activities with their students in the confinement period. They were all acquainted with STEM and were motivated to develop STEM activities for facilitating science teaching. They had different years of teaching experience (Table 1).

Table 1
Teachers' Portrayal

Teacher	Age	Teaching experience	Formal education
1	41	8	Master's degree in teaching physics and Chemistry
2	46	21	Graduation in Teaching Physics and Chemistry
3	60	32	Graduation in Chemistry Engineering
4	37	10	Graduation in Teaching Physics and Chemistry

The participants were teaching the 8th grade in different lower-secondary schools within the Lisbon district. As part of the project, all of them have decided to implement, in their classes, a STEM activity to teach about sound, which is a topic included in the elementary Physics Portuguese curriculum for the 8th grade.

Ethical Considerations

The teachers all volunteered to be part of the research. The anonymity of the participants and the confidentiality of personal data were guaranteed. Prior to the research, ethical approval was obtained by the Ethics Committee of the Institute of Education of the University of Lisbon. Moreover, teachers have been informed about the goals and the nature of the research and have signed an informed consent agreement to participate in the study, being also informed about their right to leave the research at any time.

STEM Activity

The activity was built before the pandemic by the University team that coordinates the project, in collaboration with teachers. The activity was supported in the principles of the STEM integration framework proposed by Thibaut et al. (2018a), and was based on the following key-aspects: (1) integration of STEM content, i.e., before the pandemic, it was predicted that students would explore explanations and answers to a problem related to their city's excessive noise, by integrating science, technology, engineering and mathematics subjects; (2) problem-centred learning, by taking into account a problem related with their local context, which facilitates the construction of personal meanings. As already mentioned, the activity started with a text about the noise in the city where they live in, and it was proposed to them that, in group, they would answer to the following starting problem: - Are the noise levels you are exposed to in your city safe for your health?; (3) inquiry-based learning, i.e., in order to answer the initial problem, students had to: (a) discuss and decide which city areas were more representative to make sound

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level measurements; (b) make measurements using a sonometer; (c) organizing data; (d) build the city noise map; (e) organize a local community awareness campaign on the noise levels detected; (4) use design-based learning. Therefore, the STEM activity built before the pandemic period asked students to imagine they were engineers and that they had been hired by their school to carry out a project for the construction of a radio studio. To this end, they were asked to outline a project for the radio studio and build a model, taking into account acoustic comfort and best cost-benefit ratio; (5) cooperative learning, i.e., during the STEM activity, students were expected to work in groups. The STEM activity lasted eight 90-minute lessons and it involved work in the classroom and outside school.

Instrument and Procedures

Two data collection methods were used: individual interviews and teachers' individual written reflections. The interviews were conducted by the first and third authors of this study, at the end of the STEM activity. Each interview lasted 60 minutes and was conducted online, using the ZOOM platform and video recording. The interview script was designed specifically for this research, consisting in the following nine open-ended questions: How did you develop the work with your students during the confinement period of the pandemic? How did you adapt to distance learning? In which way was the activity adapted to the new circumstances? What are the biggest difficulties you have faced? How did you cope with that? How was the activity received by the students? What lessons did students accomplish during the implementation of the activity? What difficulties did the students experience? How did you deal with students with different characteristics (social class, ethnicity) during the activity? These are semi-structured interviews, to allow to ask additional questions whenever necessary (Patton, 1990), as it happened during the interviews.

Teachers have made individual written reflections that allowed to triangulate the data obtained from the interviews (Patton, 1990). Therefore, they have been asked to reflect on the work developed with students during the pandemic (i.e., distance working, the infrastructures used, the media used), the challenges they have faced and the adaptations they have made in the activity. Also, they were invited to think over the challenges they have faced and the learning that students have accomplished. These individual written reflections were sent via email two weeks after the implementation of the STEM activity.

Data Analysis

A descriptive and content analysis were performed for qualitative data (Patton, 1990). The interviews were transcribed, and the transcripts have been read by the first investigator. After that, the targeted text was segmented, representing an idea related with the research questions. Each segment was assigned a code and a category, according to its features. Next, the second author has analysed the transcripts of the interviews and, based on the descriptive categories, has created interpretive codes. The two researchers have compared their codes and discussed a consensus coding scheme, which has been 93%. Miles and Huberman's proposal (1994) was considered for the calculation of reliability.

Taking consensual codes into account, researchers, independently, have analysed interview transcriptions and recoded data. This procedure yielded the following categories of analysis: changes in the way of working; changes in the STEM activity; effects on students' learning; challenges faced by teachers. In addition to the transcripts of the interviews, the written reflections were also examined by the two researchers, who autonomously have analysed the content of the reflections, considering the categories already defined in the interviews, thus comparing their analysis. Disagreements and doubts have been discussed to reach a consensus. The consistency between the researchers was 87%.

Validity and Reliability

The validity and reliability of the research were ensured by the clear explanation of the researchers' position regarding the study and the definition of the participants in the study; by the researchers' presence from the beginning to the end of the research process (such as, visualizing the video record of the interviews several times, reading the written reflections several times, explaining in detail the data collection and its analysis, analysing independently the data and comparing and confronting researchers' analyses); by using a variety of data collection instruments; by relating the results to the literature (Merriam, 1998; Mills & Birks, 2014; Patton, 1990).

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Research Results

Changes in the Way of Working

In the context of a pandemic, the way of working with students was changed so that it could be possible to implement the STEM activity. All teachers decided to use digital platforms (e.g., ZOOM, Microsoft Office TEAMS, and Google Meet) to take synchronous classes, to complement students' autonomous work at home. During synchronous classes, there were times when students were able to carry out group work in different rooms. For example, one of the teachers in the interview said:

> *"In the school where I teach, the distance learning regime was organized based on weekly plans. All classes were aware of the activities to be carried out by discipline, and we had the possibility of having one synchronous session per week. The platform for communication between students and teachers was the Microsoft Office TEAMS. (…) So, I organized the five weeks of work of the STEM activity on sound, based on synchronous classes and asynchronous classes" (interview, teacher 2).*

Teacher 2 got on with the description on how the STEM activity was implemented:

> *"We started with a synchronous class, which was important to present the activity and the objectives of the activity, and then I had interspersed the autonomous work with the synchronous classes. During synchronous classes, students worked in groups, in different rooms" (interview, teacher 2)*

Also, during the interview, one of the teachers reiterated that, to implement the STEM activity, she did online teaching, using digital platforms:

> *"When we all went home [in March] we still didn't have a plan at school to deal with the pandemic. After Easter, we started using various means to communicate with students, with WhatsApp, email, etc. and we went clearing students' questions about the STEM activity. The platform adopted at school enabled the development of the activity and made possible to interpolate synchronous classes with autonomous work" (interview, teacher 4).*

Changes in the STEM Activity

Teachers also made changes in the activity, so that it could be developed in the context of a pandemic, and ensuring the key-aspects of the framework proposed by Thibaut et al. (2018a) were present. The first change was related to the context of the activity, as mentioned by a teacher:

> *"In view of the exceptional circumstances that we have been experiencing, related to COVID, we had to adapt the activity so that students could do it at a distance. The first change was the context of the activity. The context of the activity that had been planned before the COVID was based on noise maps of their city location for daytime, evening, and night-time. Because of the pandemic, it was necessary to change the context, and seeking to maintain the theoretical framework of STEM activities [Thibaut et al., 2018a]. So, what change was that? The students were confined at home, quarantined. (…) Each student was asked to locate their home, using Google Maps, and to collect an image of the area. This became the 'new' context, and the measurement took place but in relation to the sound levels of the divisions of their homes" (interview, teacher 1).*

Teacher 2's testimony also reinforces the relevance of having promptly introduced changes to the context of the activity that had been planned before the pandemic and which was now an inappropriate context:

> *"The first change was in the context. Nobody could leave their house, so it didn't make sense to continue an activity related to the measurement of sound levels of the city. The initial context and problem turned out to be cantered on students' new reality - their home, where they were quarantined" (interview, teacher 2).*

In addition, there were other changes that needed to be made. One of them was related to the sound level measurement instrument. They opted to use an application on the mobile phone that allowed students to measure, in a different way, the sound level. This aspect is stated by a teacher in her written reflection:

> *"They were asked to make sound level measurements in the area of their residence, by installing the sonometer on the phone, at the window, at different times of the day. Each student identified areas of their home, where noise was highest, and took measurements at different times. They did it for 3 days a week and recorded it for later treatment. They had organized the*

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collected data in a table, and made the averages of the values collected, as well as they constructed the noise map of the area where they live (…), using the same scale of the maps analysed initially" (reflection, teacher 3).

Another change was the development of flyers to distribute to the local population, and making them aware of health effects from noise. As it was not possible to do this due to the pandemic, it has been decided to arrange students in groups of three, and then, as one teacher wrote in his reflection:

"each group of students researched on sites such as the World Health Organization. After the research they selected the information collected in order to plan a campaign to raise awareness of noise levels. In this campaign, all groups opted to create a digital poster" (reflection, teacher 2).

These posters were then disseminated to the local community through social networks (e.g., Facebook) and the school's website. According to one of the teachers:

"This moment was important for the students and a way to get recognition for their work. If it weren't for the pandemic, we wouldn't think about social networks, it was a gain from COVID, i.e., using social networks to alert the population to the dangers of excessive noise. It was a real gain if we think that young people are the ones who use social networks a lot and they are the ones who are exposed to certain noises like the ones in discos. The strategy worked" (interview, teacher 3).

In addition to the posters, students also used videos made by themselves and other videos about the problems that excessive noise can cause, as declared by an interviewee:

"They were very creative from video research to making videos. The parents helped make the video and I think that was also an advantage of the pandemic. The parents' involvement in the activity was notorious and important" (interview, teacher 1).

Finally, there was also a need to make changes to the project so as to build a model of the school's radio. As one of the teachers said in her written reflection:

"In the task, a partial plan of the school was presented, which included the building of the school bar, the canteen, the stationery and the radio station. They were asked to identify the radio studio and measuring the size. In order to outline a project for the soundproofing of the school radio studio, it was proposed that they research on materials with sound insulation characteristics, justifying which materials guaranteed acoustic comfort and the best cost-benefit ratio. (…) What the students did was a project for the radio (reflection, teacher 2).

Effects on Students' Learning

Articulation of scientific and technological knowledge

According to the teachers, one of the positive effects of the activity, in a pandemic context, was the development of students' knowledge about digital technologies and the articulation with the scientific knowledge related to sound. For example, regarding the use of mobile phones by the students, during the activity, one of the teachers mentioned:

"The fact that students were in a different context of working, online teaching, have developed skills on digital literacy and its articulation with scientific concepts. With the activity students had to answer a question "How can you measure the sound level in your home?" which is part of their daily lives, that is, they had to mobilize knowledge from various areas of knowledge. The fact that they had to use the mobile phone made them growing awareness of the potential of the electronic device to work on curriculum. It also motivated them to use the application outside the context of the activity. Some students reported that they used the application to take measurements in other situations of their daily lives. The students learned how to install the application and how to use it" (reflection, teacher 1).

This teacher's insight was corroborated by teacher 4, in her written reflection:

"Students are very connected to this electronic device and rarely are allowed to use it in a formal context. The fact that they had to use the mobile phone to make the sound level measurements got them involved in the activity and motivated them to solve it, thus promoting their learning. They learned that this instrument can be used to learn science" (reflection, teacher 4).

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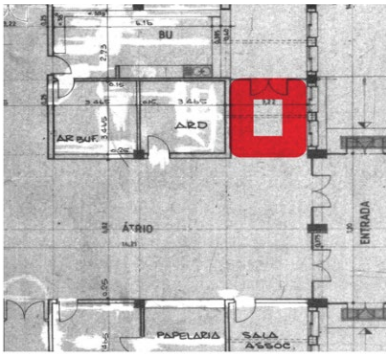
In addition to using a mobile phone application as a sound level measurement instrument, students also learned to use excel in building tables. This served to record sound level data in the various rooms of their homes and in making graphics. One of the teachers gave an example of a graphic and a table built by a student:

> *"Take, for example, the representation of this student. We, teachers, we think that as they use these technologies, since they were born, they completely know how to use the Excel or Word basic functions. The context of the pandemic proved that this is not the case. The students have difficulties in using the Excel and this was one of the lessons they did at a distance, during the development of the STEM activity. They learned how to use this tool to give a sense to the sound levels they collected in the various rooms of their homes, as well as how to organize the data in a table and to building graphs, and they learned how to carry out research and selecting information. Once again, there is a strong link between technology and science and math" (interview, teacher 1).*

According to the teachers' opinions, the integration of knowledge between technology and science has also been mobilized by students during the development of the school radio model plan. This was referred to in the interviews:

> *"They had to build a plan for the school's radio model. They started by using Paint to mark the place where they would build the radio, and then to develop the model [Figure 1]. Most students had never used this tool, and this context [of developing STEM activity during COVID-19] allowed them to learn how to use it and then start the development of the model plan and making relationships with good sound isolation" (interview, teacher 2).*

Figure 1
Radio Installation Location Marked on School Plan



Developing Students' Autonomy

All the teachers considered that the STEM activity, during the pandemic, led students to develop their own autonomy:

> *"A greater autonomy on the part of the students has been evident. This autonomy is related to the type of the STEM activity itself, which begins with a challenging problem for students to solve, and follows an inquiry methodology, and was also due to COVID's own context. Even in the classroom, when I propose such an activity, students are always waiting for my help. When in confinement, at home, this was not possible and they were forced to find solutions for the obstacles they encountered, they had to manage time, make their own decisions, i.e., be more autonomous, and this is positive" (interview, teacher 2).*

Teacher 1 also noticed the increment of students' autonomy during the performance of the STEM activity:

> *"I felt that students became more responsible for what they had to do in the activity in this pandemic situation. They did their time management, made their decisions, of course, within certain limits, because they knew that in synchronous classes, they had to present what they had done and the interaction with me was really important, even to reinforce their autonomy" (interview, teacher 1).*

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Challenges Faced by Teachers

The first challenge that was highlighted was the use of platforms for distance learning. Despite using technologies in their classes (e.g., videos, Moodle), these teachers mentioned that at the beginning of the pandemic, which was coincident with the implementation of the STEM activity, they were not familiar with distance learning, and they did not know how to do it and which platforms to use. This was highlighted in the written reflections and the interviews:

> *"Adding the troubled operation of the platform to a lack of full mastery of the tool, for my part, they made me use the phone frequently [at the beginning of the implementation of the activity], which was very well accepted by the students, as it was fast and effective" (reflection, Teacher 3).*

This teacher complemented this information during the interview, by stressing that:

> *"I had difficulties with the platform, I had never used it before, and it was an adaptation period for me and the students. The STEM activity about the sound was adapted to distance learning and I used the platform and, in addition, because I needed to help students, I used email, WhatsApp. It was a great challenge, but it also brought me learning. I developed my technological literacy (…) I was not prepared" (interview, Teacher 3).*

Likewise, in her written reflection, teacher 4 also mentioned that:

> *"Learning is confusion and uncertainty and I learned to use digital platforms, by using them in a way to be able to carry out synchronous classes with my students during the development of the activity and get new and rewarding learning from my students" (reflection, teacher 4).*

Moreover, Teacher 1, when referring challenges related to the use of technologies, she added that the adjustment of the STEM activity was also challenging. Regarding this issue, she stressed the value of having a support of a university team. According to her:

> *"Implementing a STEM activity in a context in which we do not have a pandemic is already a challenge, because it implies making changes in the way we teach and in our practice. But, implementing a STEM activity about the sound, in a pandemic context, was an added challenge. Many questions arose: how are we going to adapt the activity? Will it work? Then, we realize the importance of technologies. It was possible because we were able to continue it, in a different way, in our classes and through the interaction with students. We modified the activity and it made possible to develop it with the students, via platforms that we also had to learn to use and very quickly, a great challenge. (…) The change in activity was a challenge in itself, and your support was important [i.e., the support of the STEM project team]. Students had learned and enjoyed it and they learned different things because of the pandemic. A greater sense was given to the STEM integration, more specifically to the articulation of Science and Technology. They learned science with a strong integration of technologies and to say that I want to continue carrying out STEM activities with students" (interview, Teacher 1).*

Yet, another challenge that was emphasised was related to the students' problems in accessing computers and the internet for the development of the STEM activity at a distance, as reported in a written reflection:

> *"Responding to students' difficulties during the implementation of the STEM activity on sound, in this pandemic context, was a great challenge for teachers. In contrast to face-to-face teaching, in which, we can respond at the moment to the obstacles that students face, in distance learning it was not always possible to give instant feedback because, on the one hand, some students were conditioned by a series of constraints with emphasis on the inequality of technological conditions (they did not have personal computers and / or even a stable internet at home) and family support, which was also differentiated. Therefore, economic inequalities were reflected, mainly in the beginning of the implementation of the activity" (reflection, Teacher 2).*

Faced with this challenge, specially related to social and economic inequalities, teacher 1 decided, together with her school, to take measures so that the STEM activity was possible to be achieved. The new solutions were diversified as she mentioned in the interview:

> *"The beginning of the activity was the most difficult because we had to ensure that all students were provided with conditions for learning. We looked for solutions that included the use of mobile phones, tablets, the sharing of equipment by family members, the loan of computers. After ensuring the access to distance learning… these basic conditions, it was*

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possible to start the activity (…) seeing students to learn, and motivated day by day, gave us that strength that we were managing to involve them and, even in the context of pandemic, it was possible to carry out STEM activities with a high degree of challenge" (interview, Teacher 2).

Also, students' time management and the difficulties they felt on the activity were a challenge that teachers had dealt with, as have been said in a written reflection:

"Suddenly these students were left alone, in their homes, having to carry out a STEM activity almost autonomously. They experienced great difficulties in time management and had many questions. How to respond to this challenge in such a context? It was a challenge for us, physics teachers, as we also had to create several alternative channels for this purpose, along with synchronous classes, and using WhatsApp, chats, phone. (…) I make a positive balance because I feel that my students have learned" (interview, Teacher 3).

Despite the challenges faced by the teachers, whether centred on themselves or focused on the students, it is visible in the previous excerpts that they all make a positive balance of the online implementation of the STEM activity, with students' learning, interest and motivation being reinforced.

Discussion

This research raises awareness of the strategies used by teachers to carry out a STEM activity with their students, in a pandemic context. The first strategy was the use of online platforms for classes, through synchronous and asynchronous moments. During the synchronous classes, several tasks were developed, such as, for example, introducing the STEM activity to students, presenting and discussing assignments that students had developed, on their own, and creating parallel rooms for students to work in groups. In line with several studies that point to the benefits of feedback in distance learning, showing its crucial role in students' learning (e.g., Guasch et al., 2013), this research shows how relevant synchronous interactions of teachers with students are to simplify feedbacks and support students to overcome difficulties.

The second strategy concerned the use of other means of distance communication, such as the email and mobile phone. The teachers referred to two reasons to get alternative ways to communicate with students. The first reason was related to students' socioeconomic conditions. In fact, at the beginning of the pandemic, students with greater economic difficulties, coming from more underprivileged socioeconomic contexts, did not have a computer or internet access at home. In these cases, the mobile phone allowed teachers to follow up students until the school or the local authority was able to provide resources, thus guaranteeing the same conditions to all. The importance of all students having access to computers and the internet is mentioned by Fox (2016), according to whom, the lack of access to such resources is a problem for students with greater economic difficulties, leading to an inequity situation. Moreover, the author proves that the school efforts to provide conditions for disadvantaged students is essential to let all students develop their digital skills. The second reason involved teachers' own difficulties. At the beginning of the pandemic, teachers were not familiar with online teaching methods, having been forced to adapt themselves to the coronavirus's scenario, keeping in mind the need of not losing the contact and keeping interacting with their students. This made them be more pragmatic, by using diverse resources to communicate with students, such as emailing them and using the telephone.

The third strategy consisted of making changes to the activity, previously planned in a pre-COVID context. In addition to appealing to the ability of schools and teachers to adapt themselves to crisis contexts, by trying to lessen the pandemic effects (Boin et al., 2013), teachers took the lead in the process and jointly were able to redirect teaching activities and guiding students. This research shows how teachers' knowledge is crucial, in the sense that when reorienting the planned activity, they did not lose sight of its objectives. Therefore, they made changes in the STEM activity so that it could be developed at home, by students, under Thibaut et al. (2018a) framework, as was planned beforehand. Diverse adjustments were done. One of them was the context of the activity. So, the starting problem has been reformulated, thus making possible for students to do the activity in their homes, in confinement. Other changes were also needed to be made, namely, using mobile phone applications as a sound level measurement tool, building digital posters that were disseminated to the local community through social networks (e.g., Facebook) and the school website, and using and producing videos and developing a plan to build a model.

Likewise, the results confirm that the development of the STEM activity at distance has positive effects on students' learning. In fact, according to the teachers, the students were induced and directed to integrate scientific

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and technological knowledge, developing their scientific and digital literacy (e.g., they used the mobile phone, have broadened their knowledge in the use of excel and Word, and Paint for science learning and STEM areas). These results are in line with Lamanauskas (2011) thinking that technologies can be an important means for students' learning process. In fact, throughout the STEM activity, there were several challenges that teachers needed to face, whether centred on them or on students. One of the most relevant was online teaching and using digital platforms. This has already been pointed out in previous studies as, for example, by Lamanauskas (2011), who stresses that some of the difficulties that arise in digital education are related to the selection of proper teaching/learning contents and teachers' technological competences. It is, therefore, important to consider how and what type of training teachers should have in order to be prepared for unexpected crises such as the one caused by COVID-19.

Another effect of carrying out the STEM activity, in a pandemic setting, is the development of students' autonomy. Teachers were unanimous about it. Students showed a greater responsibility in their learning, on how to manage their time, and in taking decisions without teachers' help. The crisis and urgency scenario forced teachers to develop more creative, and often simple, skills and new ways of thinking, drawing on their professional knowledge to respond immediately to students and families. Following Smith and Riley's (2012) study about the characteristics and skills required for effective school crisis leaders, this research makes evident the importance of quite a few teachers' skills and attributes to face crisis situations. These teachers reacted to an extreme situation they were experiencing by having in mind that teaching in such a context was very different from having students in the classroom. Through synchronous classes, these teachers interacted with students, giving them confidence, and making them believe how competent they were in controlling their own learning process. These findings are in consonance with different authors (Archambault et al., 2009; Blumenfeld et al., 2006). Moreover, they show the importance of synchronous classes in the STEM area, which is perhaps one of the most stimulating and disturbing areas to teach at a distance. In fact, the results make it evident that the experimental and exact nature of STEM area requires the skills and the knowledge to reconfigure it to reach students with the same efficiency as in regular classes.

As in previous studies, this study shows that the successful implementation of the STEM activity depends on the teachers' work, namely, on lessening students' problems in managing time and difficulties when working autonomously. Likewise, these teachers made a positive assessment of their involvement in the STEM activity, stressing the importance of their students being involved and motivated to learn to develop more similar learning activities. Therefore, the study reveals that in a context of crisis, the awareness of teachers that students are motivated and involved in the activity, motivates them to carry out more regularly STEM activities in the classroom (see also Margot & Kettler, 2019; Stohlmann et al., 2012).

Conclusions and Implications

No one was prepared to deal with COVID-19 (Education International, 2020). In this context, this study allows to evidence ways of reacting to a sudden crisis, and how, despite everything, it is possible to carry out a planning that was carried out in a non-crisis context.

Furthermore, this research shows four Portuguese teachers dealing with the situation of coping with COVID-19 crisis, maintaining control over it, not losing students. Thus, as they managed to keep on developing the STEM activity with their students, they ensured that the objectives stipulated a priori were achieved.

Therefore, the results prove that, implementing a STEM activity, in such adverse scenarios, depends on teachers' skills, in finding new strategies and on their expertise on how to deal with the unexpected. It involves knowledge to create new teaching environments that allows students to learn in a situation that is new to everyone. Furthermore, it requires big changes in learning contexts. In fact, challenges caused by the pandemic must be learning opportunities for teachers and students. Teachers learned about using platforms for distance learning; how to profit from the use of other means of communication for remote education; how to adapt and implement a STEM activity at distance; and what can be gained by their students in an online teaching. According to them, students learned to integrate the scientific and technological knowledge, and to be autonomous.

Moreover, the results allow to make recommendations regarding STEM teaching in crisis situations. So, to cope with external and unpredictable situations, as in the COVID-19 pandemic, it seems to be necessary: (1) to guarantee that everything keeps running, albeit differently, which implies providing that contact with students is not lost; (2) to guarantee the principle of equity, ensuring that all students access learning and knowledge (e.g., internet, computers); (3) to keep in mind that teachers are key agents in crisis management and, consequently

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that it is critical that teachers (i) feel comfortable in distance learning using technologies, and (ii) have skills and mastery to adapt and shape the activities, without losing sight of the initial objective. Finally, one cannot forget that (iii) STEM teaching involves knowledgeable teachers able to redirect teaching activities and guide students, which (iv) requires from the teachers to be able to merge scientific and technological knowledge.

Although being circumscribed to four teachers, the study is illustrative of a set of solutions highlighted above to apply in teaching and particularly in STEM teaching in crisis situations. Moreover, it contributes to look at architects of new environments for STEM teaching. To conclude, it shows that it is possible to think about new ways of teaching and learning, and new approaches to STEM teaching that can be put into practice by teachers in the current context and desirably maintained in a post-COVID period.

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