Doi: 10.26529/cepsj.1143

Science Teachers' Practices During the Pandemic in Portugal

Mónica Baptista*[1], Estela Costa[2] and Iva Martins[2]

This paper aims to examine how science teachers adapted their practices to the context of the Covid-19 pandemic and what they learned during the period of confinement.

The participants are fifteen science teachers who currently collaborate on a STEM research project. To collect the data, we used two techniques (individual interviews and teachers' individual written reflections), which have been analysed using an inductive content analysis approach. The results reveal that adjustments have been made in the design and management of classes. Synchronous classes using digital platforms and other communication infrastructure have been held; experimental distance activities have been implemented, and online courses based on a television programme have been taught. In addition, during the period of confinement, to enable distance learning, teachers developed pedagogical skills using technological skills. Finally, this study highlights the importance of teachers' role in crisis management, such as during the Covid-19 pandemic.

Keywords: pandemic context, science teachers, online teaching and learning, pedagogical skills, technological skills

1 *Corresponding Author. Institute of Education, University of Lisbon, Portugal; mbaptista@ie.ulisboa.pt.

2 Institute of Education, University of Lisbon, Portugal.

Prakse učiteljev naravoslovja med pandemijo na Portugalskem

Mónica Baptista, Estela Costa in Iva Martins

Članek poskuša preučiti, kako so učitelji naravoslovja prilagodili svojo prakso v luči pandemije covida-19 in česa so se naučili v obdobju zaprtja. Vzorec sestoji iz 15 učiteljev naravoslovja, ki trenutno sodelujejo pri raziskovalnem projektu STEM. Za zbiranje podatkov smo uporabili dve tehniki, in sicer individualne intervjuje in pisne refleksije učiteljev, ki smo jih analizirali z induktivnim pristopom analize vsebine. Rezultati kažejo, da so bile prilagoditve uperjene v oblikovanje in upravljanje z oddelki. Pouk je bil izveden sinhrono prek digitalnih platform in druge komunikacijske infrastrukture; realizirane so bile eksperimentalne dejavnosti na daljavo in spletni pouk, ki je temeljil na televizijskem programu. Poleg tega so med zaprtjem vzgojno-izobraževalnih ustanov učitelji razvijali svoje pedagoške kompetence, nanašajoče se na tehnološke veščine, zato da je bilo omogočeno učenje na daljavo. Končno, raziskava poudarja pomen vloge učiteljev v kriznem upravljanju, kot je na primer covid-19.

Ključne besede: kontekst pandemije, učitelji naravoslovja, spletno poučevanje in učenje, pedagoške kompetence, tehnološke veščine

Introduction

Science teaching has been the focus of several studies and debates regarding its aims and objectives. Dulsch (2008), in a literature review on this topic, highlighted that the purpose of science education could be organised around conceptual, epistemic, and social learning goals, which are brought together in the term 'scientific literacy', which can be conceptualised from two distinct viewpoints: (i) considering conceptual knowledge as crucial, based on scientific ideas fundamental to academic pathways and scientific careers; or (ii) seeing scientific literacy as related to its usefulness to society, aligning it with the development of life skills, and recognising its universality as a way of providing citizens with the ability to understand the changes and developments taking place in modern societies (Holbrook & Rannikmae, 2009).

Therefore, the definition of scientific literacy is not simple, and its more contemporary conceptualisation moves away from scientific content, tending to focus on understanding the context and nature of science (Bybee et al., 2009). Various definitions of scientific literacy can be found in the literature and have been reviewed (e.g., DeBoer, 2000; Roberts, 2007), such as the one referring to scientific literacy as 'the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity' (NRC, 1996, p. 22).

Thus, considering its importance, science teaching should be designed and delivered to ensure the development of the fundamental aspects of scientific literacy, which, according to the PISA report (OECD, 2006), consists of the competence to (i) identify scientific questions; (ii) explain phenomena scientifically; and (iii) use scientific evidence. In this sense, it is crucial to use diversified pedagogical approaches, such as practical and enquiry activities, grounded in everyday problems and authentic contexts. Thus, placing the student at the centre of the teaching-learning process promotes students' engagement and motivation to learn science. Several studies in the literature describe the benefits of these approaches on students' achievement, interest, and attitudes towards science topics (e.g., Anderson et al., 2021; Bruder & Prescott, 2013; Holstermann et al., 2010; Marshall et al., 2017; Sadi & Cakiroglu, 2011; Vlassi & Karaliota, 2013).

Moreover, in the previous two decades, the internet has also contributed to rethinking and adapting science teaching, since more and more institutions offer training based on online courses (Allen & Seaman, 2017; Bennett & Lockyer, 2004; Gemin & Pape, 2017). However, this adaptation is only possible and effective if teachers are trained to modify their instructional practices, requiring different skills than face-to-face teaching (Barbour, 2012). In this sense, it is necessary to ensure that teachers have access to programmes to develop the necessary skills for effective online teaching (Gachago et al., 2017; Walters et al., 2017).

Thus, taking into consideration that the Covid-19 pandemic forced the imposition of emergency remote teaching (Hodges et al., 2020), in a short period, teachers were faced with sudden and urgent response needs, associated with inevitable constraints and difficulties arising from the unpredictable nature of the pandemic situation, with no time to plan a response model to the emerging teaching-learning reality. This posed further challenges for science teachers, as the practical component and the associated processes that are necessary to understand the nature of science are difficult to implement online (Babinčáková & Bernard, 2020). In the meantime, several studies have been made on the reporting strategies that have been used by science teachers, and the difficulties they faced in the implementation of online science classes (e.g., Azhari & Fajri, 2021; Chadwick & McLoughlin, 2020; Khlaif et al., 2020). However, these studies do not describe what teachers have learned and how this knowledge can help them in unexpected new crises or simply in new waves of Covid-19. This research aims to contribute to this aspect and specifically to examine how science teachers adapted their practices to the pandemic context and what they learned during the period of confinement.

Theoretical framework

Thus far, from this pandemic scenario, in a literature review, Baran, Correia, and Thompson (2011) synthesised and critically analysed the role and skills required for online teaching. In this work, based on publications developed since 1990, the authors selected 11 articles and examined them in the light of the transformative learning theory, which states that teachers must have the skills required to assume several roles: managerial, instructional designer, pedagogical, technical, facilitator, and social. Thus, the role of teachers in online education must be dynamic and multidimensional. Furthermore, professional development programmes must prevent teachers from 'leaning on their traditional teaching practices as reference points' as 'the affordances and limitations of online environments will pose new challenges for them as they try to operate within their existing sets of beliefs and practices' (Baran et al., 2011, p. 435).

In a review developed by Kebritchi et al. (2017), based on 104 published articles, three main categories were identified regarding the problems affecting online teaching: issues related to online learners, teachers, and content development. Issues related to teachers were structured into four categories: role change, transition from face-to-face to online, time management, and teaching styles.

Thus, the authors determined that for teachers it is a challenge to move from teacher-centred to student-centred education to ensure proper communication and use of technology. Moreover, for many teachers, it is difficult to deal with the lack of eye contact with their students, which is a communication barrier. In addition, teachers tend to bring their traditional teaching styles to online classes, and usually do not use the available tools, nor do they take into consideration the most appropriate way to help students achieve their learning goals.

Regarding online science teaching, almost all the studies described in the literature concern higher education, where the number of online courses is growing (e.g., Fischer et al., 2019; Hill et al., 2015; Ramlo, 2016; Swinnerton et al., 2016; Venkateswaran, 2016), and which, according to some authors (Clary & Wandersee, 2010; Johnson, 2002), provide environments that promote learning equitably. As for pre-university education, where attendance is compulsory, there are few studies that focus on the distance learning modality as a frequent practice. This lack of studies makes one wonder what is happening with the laboratory component, whose importance lies in the need to get students to learn not only manual techniques but also to make the link between theory and practice, to solve problems, interpret data, reach conclusions, and similar. Furthermore, engaging students in real laboratory activities also allows them to develop motor skills, learn to assemble apparatus and experiment with the use of measuring instruments (Burkett & Smith, 2016; Olympiou & Zacharia, 2012; Son et al., 2016). In face-to-face teaching, it is common to use various resources available online, such as virtual laboratories and simulations, and remote laboratories, to illustrate and promote a deeper understanding of theoretical concepts, and as a complement to laboratory activities. Although they do not promote the development of some of the skills acquired in the manipulation of real materials and equipment, these resources have the advantage of providing alternative representations of aspects not visible from a macroscopic point of view, as well as providing the possibility of performing experiments under ideal conditions (Zacharia & Anderson, 2003, Zacharia & Jong, 2014). Furthermore, they also enable the use of multiple representations (verbal, numerical, pictoral, and graphical), which facilitates a deeper understanding of the phenomena (Ainsworth, 2006).

Although not specifically about distance learning, there are several studies that describe the use of these resources by elementary and high school students. For example, Sullivan et al. (2017) carried out a quasi-experimental study, with 100 eighth-grade students, which involved the use of a virtual laboratory to carry out experiments related to pulleys. The results led to the conclusion that virtual laboratories can be an alternative to real laboratories, whenever access to them is limited, because virtual laboratories facilitate the learning of some physical concepts, such as work and mechanical advantage.

In this sense, it is worth to highlight a study that consisted of the use of virtual laboratories on pulleys by 6th-grade students (N = 115) divided into two groups (an experimental group and a control group). The control group students, who performed the laboratory activity in a physical laboratory, had greater participation in discussions related to assembling the devices, performing measurements, and calculating outputs. The students who carried out the activity virtually were focused more on predictions, establishing patterns of relationships between variables, and interpreting the phenomenon. According to the authors, both modalities are complementary in terms of the development of skills and knowledge in the students involved (Puntambekar et al., 2020).

In the chemistry area, Ambusaidi et al. (2017) describe a study carried out with 69 students (grades 5–10), who used virtual laboratories for chemical experiments. By applying an achievement test and two questionnaires on attitudes towards science and virtual labs, students had a positive attitude towards virtual laboratories, and using them had no effect on academic achievement. Remote labs differ from virtual/simulation labs because they are real-time interactive learning environments that allow students to control, perform and observe real distance experiences (de Jong et al., 2014; Tho & Yeung, 2014).

In a study carried out with 32 students (grades 7–9) with eight remote experiences on sound, electrical circuits, plant growth factors, plant respiration, and solar energy, researchers concluded that it was appropriate (i) to extend/enhance the existing e-learning practices (with virtual/simulation experiments only) and (ii) that doing so largely induce students' favourable views and perceptions in their learning (Tho & Yeung, 2018).

Similarly, in the physics area, a study by Evangelista et al. (2017) on the use of remote laboratories for studying electrical circuits by 37 secondary school students, showed that these were a powerful tool for students' learning and in promoting their interest and motivation.

With the Covid-19 pandemic, online teaching, and, particularly, science online teaching, became of utmost importance to the education scientific community. Therefore, at the end of the first semester of 2020, several educational researchers reflected on the impacts of these sudden and drastic changes in school communities, and numerous scientific journals have edited special issues on the theme. There are lessons to be learned from this new reality and experiences. Once shared, they can support a better understanding of how teachers and students have adapted themselves, the difficulties they have experienced, the strategies that have been used, and the ones considered the most effective.

Initially, the main difficulties faced by teachers and students were related to the selection and use of technologies that allowed the implementation of distance learning or, at least, that allowed the communication with the students. In a study carried out in Indonesia, with 353 mathematics and science teachers of primary and secondary education (Azhari & Fajri, 2021), through surveys and interviews, it was concluded that teachers did not feel prepared for distance learning. However, they felt motivated and committed to their mission. Another aspect that stood out from this study was the lack of guidance and technical support felt by teachers and students. The limited access to the internet caused several constraints and inequalities in the learning process. Most teachers chose to use applications with which they were already familiar, such WhatsApp (72%), although other applications (ZOOM Meetings, Google Classroom, Webex, etc.) were also used. One explanation for the prevailing use of WhatsApp was the financial difficulties of the students' parents, which made it impossible for them to have stable access to the internet and purchase computers. Moreover, Azhari and Fajri (2021) determined that teachers' confidence in the implementation of distance learning has increased, during this period, and pedagogically it had a positive effect, although requiring a great sense of initiative and creativity. As some teachers mentioned in the interviews, they overcame their difficulties individually and shared experiences with their peers. In addition to being forced to deal with platforms and overcome constraints, such as students who live in places without access to the internet, teachers also made use of state television and radio channels.

Another study, by Chadwick and McLoughlin (2020), conducted with 269 Irish science teachers (primary and secondary levels), explored, through surveys, the impact of the Covid-19 crisis on teaching and learning and assessment in science, the use of learning technologies to support distance learning in science, and the facilitation of practical activities in science. The results revealed a negative impact of Covid-19 on student teaching, learning, and assessment, with teachers recognising difficulties in supporting student learning, meeting specific student needs, and providing feedback. A particularly critical point that denotes teachers' problems about online teaching, was practical activities, whose implementation decreased dramatically, with more than a third of secondary school teachers not doing any. When implementing practical activities, primary teachers generally chose more hands-on activities. In contrast, second-level teachers used mostly technology-based solutions, such as video demonstrations and interactive simulations.

Method

In this study, we followed a qualitative research methodology, based on an interpretive approach (Cohen et al., 2007). Interpretative research is a powerful tool for examining teachers' meaning construction and thinking. This is particularly important within this study, as it aims to examine how science teachers adapted their practices to the context of the Covid-19 pandemic and what they learned during the confinement period.

The Portuguese context

The Portuguese education system is organised into three sequential levels: early childhood education and care, primary education, and secondary education. As in other OECD countries, pre-school education is offered to children between 3 and 5 years of age. Compulsory education usually starts at age 6, when children enrol in elementary schools. Compulsory basic education is organised into three cycles of studies, with varying lengths. At the end of the third cycle, students (typically aged 15) transit to (upper) secondary education. Secondary education is compulsory and organised in both general and vocational education pathways. Students choose one of four curricular areas in secondary education: science and technologies, social and economic sciences, languages and humanities or visual arts. Formal schooling, in Portugal, is compulsory for students until 18 years old or until the completion of upper secondary if students complete their studies before the age of 18 (Liebowitz, et al., 2018). Physics as a subject starts in grade 7 along with chemistry; the same teacher teaches both subjects.

Participants

The participants in this study are fifteen science teachers who collaborate on a research project that aims to understand the effects of implementing STEM activities on the learning and motivation of students and their interest in pursuing scientific careers. The project started in 2019 and it will end in 2022; it is funded by the Foundation for Science and Technology.

All teachers had graduated in teaching science or in science and/or a postgraduate in the same area. Their ages ranged between 37 and 62 years old, and their professional experience between 8 and 36 years. Teachers belonged to several schools within the Lisbon district. They were all science teachers and teaching students aged 12 to 18 (from 7^{th} to 12^{th} grade) (Table 1).

Table 1
Teachers' attributes

Teacher	Age	Gender	Teaching experience	Formal education	Science subjects (grades) taught during the project activities
1	41	F	8	Master's degree in teaching physics and chemistry	Physics and chemistry 8th grade
2	46	F	21	Bachelor's degree in teaching physics and chemistry	Physics and chemistry 7th grade
3	60	F	32	Bachelor's degree in chemistry engineering	Physics and chemistry 8th grade
4	37	F	10	Bachelor's degree in teaching physics and chemistry	Physics and chemistry 9th grade
5	59	M	36	PhD science education	Physics and chemistry 12th grade
6	55	F	29	Bachelor's degree in chemistry	Physics and chemistry 11th grade
7	55	F	32	Master's in chemistry	Physics and chemistry 12th grade
8	42	F	19	Bachelor's degree in teaching physics and chemistry	Physics and chemistry 9th grade
9	54	F	25	Bachelor's degree in chemistry engineering	Physics and chemistry 10th grade
10	55	M	30	Bachelor's degree in chemistry engineering	Physics and chemistry 9th grade
11	61	F	19	Master's in science education	Physics and chemistry 10th grade
12	62	F	30	Bachelor's degree in chemistry engineering	Physics and chemistry 11th grade
13	39	F	15	Bachelor's degree in teaching physics and chemistry	Physics and chemistry 7th grade
14	54	F	22	Bachelor's degree in chemistry engineering	Physics and chemistry 8th grade
15	49	F	26	Bachelor's degree in teaching physics and chemistry	Physics and chemistry 7th grade

The fifteen teachers were involved in the project's activities when the confinement period started, and they simultaneously volunteered to be part of the present study. The anonymity of the participants and the confidentiality of personal data were guaranteed. They signed an informed consent agreement to participate in the study and were informed about the goals and the nature of the research and about their right to leave the research at any time.

Data collection and analysis

The data collection instruments were semi-structured interviews and teachers' individual written reflections. Each interview lasted 30 minutes and was conducted online, using the ZOOM platform and video recording. The interview script consisted of two dimensions (class design and management, and teachers' learning) and included the following five open questions: *How did you adapt to distance learning? How did you develop the work with your students during the confinement period of the pandemic? How did you conduct experimental activities? How did you use #EstudoEmCasa with your students? What did you learn with distance teaching?* These questions were conceived by the researchers with the purpose of collecting data for this study. In July 2020, teachers also did individual written reflections that enabled triangulating the data obtained from the interviews (Patton, 1990). Therefore, they were asked to reflect on the work with students during the pandemic (i.e., distance work, the infrastructure they used, experimental activities, the media) and the learning they did with distance learning. These individual written reflections were emailed in July 2020.

To analyse the data, the first author of the present paper started reading the interview transcripts. After that, the text was segmented, and each segment was assigned a code and a category. After an initial categorisation, the reports were reread, and the first author inductively created subcategories (Strauss & Corbin, 1998) (Table 2). Then, the third author analysed the transcripts of the interviews and based on the descriptive categories and subcategories, created interpretive codes. The two researchers compared their codes and discussed a consensus coding scheme, which was 0.88 (Cohen et al., 2007). Considering the agreed codes, the researchers independently analysed the transcripts of the interviews and the recorded data. This procedure generated the categories and subcategories shown in Table 2. In addition to the transcripts of the interviews, the written reflections were also examined by the two researchers, who autonomously analysed the content of the reflections, considering the categories and subcategories already defined in the interviews, thus comparing their analyses. Disagreements and doubts were discussed to reach a consensus. The inter-rate reliability measured with Cohen's kappa coefficient was close to 0.85 (Cohen et al., 2007), after a second researcher coded 10% of the teachers' written reflections.

Table 2
Categories and sub-categories of analysis

Categories	Sub-categories
Class design and management	Synchronous classes
	Experimental activities conduction
	Television lessons
Teachers' learning	Pedagogical skills
	Technological skills

Results

Class design and management

Science teachers have adapted their lessons plans and class management to the context of the confinement. During the interviews and in written reflections, teachers have mentioned they have developed synchronous classes, using digital platforms and other communication infrastructure, conducting experimental activities, and developing courses making use of a television programme. Thirteen teachers reported having developed synchronous classes, eight reported that they performed experimental activities in a context of confinement, and eleven teachers highlighted the use of the television programme (Table 3).

Table 3
Identification of class design and class management mentioned in the interviews and written reflections

Teacher	Class design and management		
	Synchronous classes	Experimental activities	Television programme
1		X	X
2	X		X
3	X	X	X
4	X	X	X
5	X		
6		X	X
7	X	X	X
8	X		
9	X		X
10	X		

Teacher	Class design and management		
	Synchronous classes	Experimental activities	Television programme
11	X		
12	X	X	X
13	X		X
14	X	X	X
15	X	X	X

By analysing Table 3, it is possible to verify that the teaching experience and the age of the teachers do not seem to influence the way they designed and managed the class.

In the next subsection, examples of interviews with teachers and written reflections are presented for each subcategory, enabling us to know how, in the perspective of teachers, they have adapted their lesson plans and class management to the confinement context. The selected examples are representative of the types of responses obtained.

Synchronous classes

Thirteen teachers, from the most experienced to the least experienced, used digital platforms, such as ZOOM or Microsoft Teams, to carry out synchronous sessions with their students. ZOOM was considered very important to monitor the students' activities and overcome the difficulties experienced during the confinement. In this regard, for example, one of the interviewees mentioned:

> *My school took a while to react and define a plan for this situation. When I started working with students in a context of total confinement and without access to synchronous interaction, I began to realise that it was impossible. It was difficult to assist the pupils, they had many doubts and doing it by email was not enough to clarify them. The pressure on our school started to increase to ensure the quality of students' learning, and the school management has taken action. If there is an issue, a difficulty, we can resolve it at that moment […], most of my students, even the most disadvantaged, had been in class and enjoyed those moments. It was important to them. (Interview)*

Teachers said that synchronous classes have been crucial. Still, it was problematic to manage students from more disadvantaged, socio-economic contexts or belonging to minorities because of the lack of resources (computer and internet), as a teacher stated:

> *Microsoft Teams was very important for kids to have real-time classes, and my school had already developed a digital technology plan. Not everyone had access to computers and the internet. In my class, with more economic difficulties, there were still four or five. The school lent them computers to guarantee access to classes, and our municipality was also spectacular and arranged some computers for the kids. […]. These things are difficult to achieve without interaction with the student ... and the use of the platform was good for giving feedback instantly, and seeing the difficulties, accompanying the student. (Interview)*

Moreover, interviewees reported that they used distance learning platforms and other technological infrastructure that allowed them to communicate in sync with students and, above all, ensure that all students had access to the materials provided.

The digital infrastructure they have used to communicate were email, WhatsApp, Moodle, mobile phones, and videos. According to one of the interviewees:

> *Students had difficulties in accessing the platform, especially in the first weeks, some of them simply did not even have the internet at home or a computer […], but everyone has a mobile phone and mobile data, so I used to send materials via WhatsApp, and answered the students' questions. It was the strategy I used and that they used with me to make sure that everyone had contact with me and access to the materials. (Interview)*

One teacher highlighted other digital infrastructure that made it possible to ensure that everyone was able to access the proposed activities:

> *When I developed the class, I had to consider that there are kids who don't have access to the computer and think about strategies to manage this […] I used the mobile phone a lot to create synchronous moments with these students. Everyone had a mobile phone, and I called to accompany them on the subject, ask questions […] the kids went to school to check the materials and then left them at school for the teachers to correct. Still, it is different if we can interact with them by phone, they feel more accompanied. (Interview)*

Conducting experimental activities

Experimental activities are critical in science teaching. In this sense, various resources have been used so that students could perform experiments at a distance, using mobile phone applications to measure variables (e.g., sound level) and assembling and carrying out experimental activities, using bottles, balls, marbles, boxes, wood, etc. Videos were also used to make simulations, animations, and remote laboratory activities.

In this regard, one teacher declared that her students had developed an experimental activity on sound, at home, using a mobile phone application to measure the sound level in one room of their homes or the surrounding area:

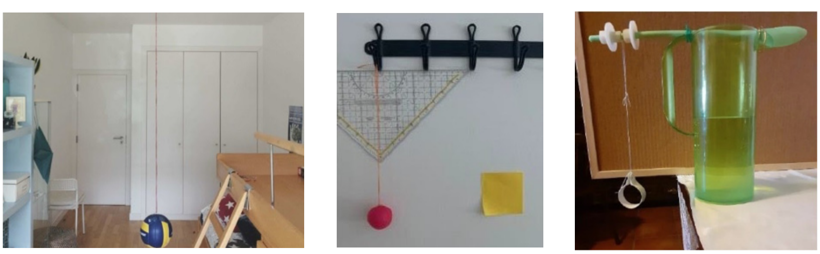
> *I asked students to make sound level measurements in the area where they live, placing the sonometer installed on the phone at the window at different times of the day. Each student identified areas of their home where the noise produced is highest and took measurements at other times. They took measurements for three days a week and recorded them for later treatment. They organised the data in a table, performed the calculations of the averages of the collected values and constructed the noise map of the area where they live or of the area of the chosen house, using the same scale of the maps analysed initially. (Written reflection)*

Moreover, most teachers have stated how they encouraged their students to use daily life materials to carry out experimental activities. As an example, we describe the case of a teacher who developed the gravity pendulum activity. As she mentioned in the interview:

> *The students made pendulums at home with their materials and the most creative ways they could imagine. They used balls and wires attached to the ceiling of their rooms, squares and hangers with a string and a ball, kitchen materials [...] they made videos with the experience and the parents helped, so the families got involved [Figure 1]. [...] The students made a very positive evaluation of the activity and motivated them a lot. (Interview)*

Figure 1

Gravity pendulums built by students at home



In her written reflection, the teacher pointed out that with the pendulums already built, students were able to control variables and make measurements:

> *The students built a pendulum, carried out experimental determinations and communicated the results obtained through a scientific article, scientific poster and even a video about the work. They had to build tables and graphs, do treatment of the results obtained. (Written reflection)*

Teachers also used videos and other external representations (e.g., simulations, animations, remote laboratory) for students to explore experimental activities. As one of the teachers revealed:

> *In Sciences, there is an experimental component, and this part has been heavy during confinement. We didn't have a laboratory, and we had to think about how to get the experiences to the students' homes. I used PHET simulations and several animations available on the internet. I showed videos to make observations. (Interview)*

During the interview, there was a teacher who reiterated that she used a remote laboratory to develop experimental activities with students:

> *The remote lab played an important role during the confinement. Students were able to launch the experiment in real time, control variables and collect data. It is not the same as carrying out the activity in the classroom, but it was an important resource in this pandemic context. (Interview)*

Television class

One of the Portuguese government's measures was creating a television broadcast (#EstudoEmCasa) for students to be able to access the contents of the subjects. The interviews showed us three types of uses of television classes: (i) teachers who did not suggest to their students to watch #EstudoEmCasa; (ii) teachers who had recommended it to complement the contents; (iii) teachers who, in synchronous classes, explored the subjects covered in the programme, but also used other activities and strategies. For example, one of the teachers who recommended #EstudoEmCasa to complement the subjects of the discipline mentioned:

> *It was an option taken by my school cluster. We give our synchronous classes, send the materials to the students; those who have no chance of accessing synchronous classes, because they do not have a computer or internet, they come to schools and pick up the materials, and then use #EstudoEmCasa as a supplement. In my discipline, the television programme concentrates two years of schooling at the same time. So, I only use it as a complementary activity. If I developed my work with them based on the*

programme, it would accentuate the inequalities, because students with support at home can follow the programme and then study; those who don't have it, need the materials that the teacher gives them and that guides them in their study. (Interview)

Moreover, several teachers chose to explore, in synchronous classes, subjects discussed in the #EstudoEmCasa, having also resorted to other activities:

I think, in this context, #EstudoEmCasa was important because, in some way, it had given access to all students to classes. The most disadvantaged students, from socio-economic backgrounds, with more problems, have accessed the contents and classes on television. […] parents may not have a computer (as in either case), but all students have a television. So, it was an important initiative so that the gap is not so big […] in my classes, I explored the subjects of #EstudoEmCasa, but I also did other things. I used different materials, I put them to experiment with materials they had at home. (Interview)

Teachers' learning

In the interviews and written reflections, teachers recognised that they have learned at the level of pedagogical skills and multimedia skills during the confinement period, due to their experiences in remote teaching. More specifically, seven teachers mentioned having developed pedagogical skills and twelve mentioned learning related to technological skills (Table 4).

Table 4

Identification of teachers' learning mentioned in the interviews and written reflections

Teacher	Teachers' learning	
	Pedagogical skills	Technological skills
1		X
2	X	X
3		X
4	X	
5		X
6		X
7		X
8	X	
9	X	X

Teacher	Teachers' learning	
	Pedagogical skills	Technological skills
10		X
11		X
12	X	X
13	X	
14		X
15	X	X

In the next subsection, examples of interviews with teachers and written reflections are shown for each subcategory. The selected examples are representative of the types of responses obtained in relation to what teachers learned during the pandemic.

Pedagogical skills

From the teachers' perspectives, they have developed their skills to design tasks adapted to distance learning during the pandemic period, which has involved students in their own learning. For example, one of the teachers said:

> *The adjustment of STEM activities to this context was one thing that I learned. I had no experience in online teaching, and I had to build and adapt activities that would suit this new situation of total confinement, in which students are at home, having online teaching. […] I think I have learned to use the platforms and develop activities that focus the students' attention and motivate them. (Interview)*

Another teacher also mentioned what she learned in the development of STEM activities during the confinement.

> *The transition from face to face to online was not easy and it was necessary to rethink the way of teaching. What changes should be made to STEM activities to be developed in this context? Will it work? Yes, I had difficulties that I gradually got over, and I feel I've learned something. For example, at that time, I found myself thinking about the best way to teach the sound. I had to think of new strategies and chose to use the cell phone. (Interview)*

Moreover, in her written reflection, one teacher highlighted she had also learned to develop activities appropriated to distance learning (e.g., virtual exhibitions), and to vary students' ways of working (e.g., using group work).

> *[I learned that] in a distance learning context, students can present their work to the class and get to know the work developed by each other [using*

the online platform]. [I also learned that] the final products can be organised to form a virtual exhibition to be presented on the group's website. (Reflection)

In the interview, one of the teachers also corroborated the learning referred in the two previous examples:

We had to adapt the best we knew to the new situation, and the challenges were countless. We had to move quickly from face to face to online, and it was different […] I had to learn which activities did work in this context and for my students. (Interview)

Technological skills

Teachers recognised that learning has been developed mainly in two domains: the skills to use digital platforms and the skills to select and use digital resources. Regarding the use of digital platforms, one of them stated:

At the beginning of the pandemic, I didn't know how to use the digital platform and I frequently have used the cell phone, which was very well accepted by the students. I had to gain this skill to be able to use it and make the most of the platform, because I recognise that it is an important tool to help students […] I think I have been able to develop this ability and that now I am able to work and make more effective use of the platform. (Interview)

Another teacher mentioned that:

The correct word is ignorance about platforms, I had never used them before, and we had to quickly get used to using them and the students too. And this is something that I had to learn and explore. The school cluster made a platform option, we have used Teams and in the first days I have explored it and then I have managed to use it in a more profitable way, and it was certainly a learning experience. (Interview)

Teachers also recognised that they have learned to select and use digital resources appropriate to the tasks they have proposed to their students:

I already used simulations and videos in my classes, but not that way. Teaching exclusively at a distance is another way of looking at teaching and learning, which involved developing my own skills to use resources in other way. I give as an example a PHET simulation that I used to explore orally, in the classroom, but now I had to think about how they could use this at home, and which questions I could ask them to explore. (Interview)

Discussion

This study aimed to examine how science teachers have adapted their practices to the pandemic context and what they have learnt during the confinement. The results showed several adaptations related to class design and management: the development of (i) synchronous classes using digital platforms and other communication infrastructure; (ii) experimental distance activities; (iii) classes based on a television programme.

Concerning the first adaptation, *synchronous classes using digital platforms and other communication infrastructure* teachers considered the use of digital platforms essential to monitor students learning. However, they faced several challenges associated with students with socio-economic difficulties, who are more vulnerable or belonging to minorities, which is related to the lack of computers and the internet. To overcome these difficulties, teachers used other technological infrastructure that allowed them to communicate in sync with their students. These results are in line with research developed in other countries, during the confinement period showing inequalities in access to education for students from underprivileged contexts (Chadwick & McLoughlin, 2020; Fore, 2020; Fox, 2016). Also, in the study of Khlaif et al. (2020), developed with science teachers, the constraints were overcome, resorting to other communication infrastructure, more familiar to students (email, WhatsApp, Moodle, mobile phone, and videos).

Regarding the development of *experimental activities*, the results show that the closure of schools impacted the way teachers carried them out. In the science subject, teachers encouraged students to do practical activities in their homes by using everyday materials, mobile phone applications, videos, among others, which facilitated the teaching of experimental science at a distance. From the teachers' perspective, carrying out activities with materials that the students had at home (e.g., in their kitchens) allowed them to increase their engagement and the involvement of families. Likewise, in other studies that intended to examine the impact of Covid-19 on teaching science, during online classes, it was demonstrated that teachers also developed hands-on activities with students, such as kitchen science and fieldwork, video demonstrations, and interactive solutions (Chadwick & McLoughlin, 2020).

Regarding the television programme *#EstudoEmCasa*, most of the interviewees considered it a means for all students to have access to classes, because it reaches all families, especially those from the most disadvantaged socioeconomic classes. Similarly, a study conducted by Azhari and Fajri (2021) shows that the use of public television to access science classes was crucial to support the learning of students with financial difficulties (they could not obtain stable access to the internet or buy computers) In addition, it is noteworthy that the present study shows that teachers adopted *#EstudoemCasa* differently: some teachers did not suggest that students watch the programme; other teachers recommended it as a complement to the classes; some teachers explored the programme's subjects through synchronous classes, among other strategies. None of the adopted solutions seem to be better than the others. They are just different ways of reaching students, as in the case in which students, not having internet at home, went to schools to get the materials, using #EstudoemCasa as a complement.

During the pandemic, the interviewees revealed what they have learnt related to pedagogical and technological skills. At the beginning of the confinement, the technological skills influenced the pedagogical practices, and teachers recognised that they made efforts to become accustomed to a new way of teaching, integrating, and exploring digital resources. The use of digital platforms was at first a challenge for teachers. Moreover, most teachers recognised that they did not know how to work with platforms and that they had learned to use them for their students' learning's sake. Other studies have also shown positive results in this domain, highlighting the importance of teachers in responding to the pandemic to support their students (Delcker & Ifenthaler, 2020) and the gradual development of self-confidence in the implementation of ICT during the Covid-19 pandemic (Azhari & Fajri, 2021).

Conclusions

The sudden closure of schools in Portugal in March 2020 made teachers respond rapidly to ensure their students' learning. In this sense, most teachers resorted to distance learning platforms, developed experimental activities with their students through everyday materials and other digital resources and resorted to home study. However, to make this possible, teachers recognised that they had to develop their own learning. Given these results, some recommendations emerged: the need for schools to develop distance learning plans to guide teachers and the educational community in times of crisis; the need to involve teachers in professional development programmes that allow them to develop knowledge about online teaching; the need to support science teachers to develop their pedagogical skills on experimental distance learning; the need to ensure that all students have access to resources that enable them to learn at a distance. Finally, this study showed teachers' importance and role in managing this unpredictable crisis in their schools.

Thus, this study has enabled listing pedagogical implications for post-Covid education: the importance of teachers using digital resources with their students, either face-to-face or remotely, allowing them to develop digital skills; the importance of teachers carrying out open experimental activities with their students to develop their autonomy, essential in crisis situations, such as Covid-19, with students planning the experiments, selecting materials, carrying out the experiments and drawing conclusions. In the future, in a post-pandemic context, what kind of measures can be taken to enhance the science curriculum and support teachers in unforeseen situations like the one we are experiencing. Public authorities and policymakers also would find in this study the motivation to go further in the training of teachers in STEM areas, creating training contexts and promoting programmes to prepare teachers for the unpredictability of modern times. This crisis has made clear the need to think about science teaching taking place not only in a physical space, but also in a virtual space, and all that this implies in new strategies and activities that allow for the promotion of inclusion and the development of student learning in virtual educational environments. The study contributed to thinking about new ways of teaching that could be put into practice by teachers in the current context and maintained in a post-Covid period.

This study had some limitations, which should be considered when interpreting its results. First, only fifteen teachers participated, so the results cannot be generalised. The second is that all data were self-reported by the teachers, that is, the researchers did not observe teachers' practices during the pandemic and, therefore, the results stem from the teachers' perspectives. In future research, it is important to collect data directly from teachers' classes.

Acknowledgements

This work is supported by National Funds through FCT - Portuguese Foundation for Science and Technology, I.P., under the project number PTDC/CED-EDG/31480/2017.

References

Ainsworth, S. (2006). Deft: A conceptual framework for considering learning with multiple representations. *Learning and Instruction, 16*(3), 183–198.

Allen, I. E., & Seaman, J. (2013). *Changing course: Ten years of tracing online education in the United States*. Babson Survey Research Group and Quahog Research Group LLC.

Ambusaidipictorial, A., Musawi, A. A., Al-Balushi, S., Al-Balushi, K. (2017). The impact of virtual lab learning experiences on 9th grade students' achievement and their attitudes towards science and learning by virtual lab. *Journal of Turkish Science Education, 15*(2), 13–29.

Anderson, A., Kollmann, E. K., Beyer, M., Weitzman, O., Bequette, M., Haupt,G., & Velázquez, H. (2021). Design strategies for hands-on activities to increase interest, relevance, and self-Efficacy in Chemistry. *Journal of Chemical Education, 98*(6), 1841–1851. https://doi.org/10.1021/acs.jchemed.1c00193

Azhari, B., & Fajri, I. (2021). Distance learning during the COVID-19 pandemic: School closure in Indonesia. *International Journal of Mathematical Education in Science and Technology.* 1–21. https://doi.org/10.1080/0020739X.2021.1875072

Babinčáková, M., & Bernard, P. (2020). Online experimentation during COVID-19 secondary school closures: teaching methods and student perceptions. *Journal of Chemical Education, 97*(9), 3295–3300. https://dx.doi.org/10.1021/acs.jchemed.0c00748

Baran, E., Correia, A.-P., & Thompson, A. (2011). Transforming online teaching practice: critical analysis of the literature on the roles and competencies of online teachers. *Distance Education, 32*(3), 421–439. https://doi.org/10.1080/01587919.2011.610293

Barbour, M. K. (2012). Training teachers for a virtual school system: A call to action. In D. Polly, C. Mims, & K. Persichitte (Eds.), *Creating technology-rich teacher education programs: Key issues* (pp. 499–517). IGI Global.

Bennett, S., & Lockyer, L. (2004). Becoming an online teacher: Adapting to a changed environment for teaching and learning in higher education. *Educational Media International, 41*(3), 231–248. https://doi.org/10.1080/09523980410001680842

Bruder, R., & Prescott, A. (2013). Research evidence on the benefits of IBL. *ZDM Mathematics Education, 45(6)*, 811–822. https://doi.org/10.1007/s11858-013-0542-2

Burkett, V. C., & Smith, C. (2016). Simulated vs. hands-on laboratory position paper. *Electronic Journal of Science Education, 20*(9), 8–24.

Bybee, R., McCrae, B., Laurie, R. (2009). PISA 2006: An assessment of scientific literacy. *Journal of Research in Science Teaching, 46*(8), 865–883. https://doi.org/10.1002/tea.20333

Chadwick, R., & McLoughlin, E. (2020). Impact of the COVID-19 crisis on science teaching and facilitation of practical activities in Irish schools. https://doi.org/10.35542/osf.io/vzufk

Clary, R. M., & Wandersee, J. H. (2010). Science curriculum development in online environments: A SCALE to enhance teachers' science learning. In L. Kattington (Ed.), *Handbook of curriculum development* (pp. 367–385). Nova Science Publishers.

Cohen, L., Manion, L., & Morrison, K. (2007). *Research methods in education*. Routledge/Taylor & Francis Group.

de Jong, T., Sotiriou, S., & Gillet, D. (2014). Innovations in STEM education: The Go-Lab federation of online labs. *Smart Learning Environments, 1*(1), 3. https://doi.org/10.1186/s40561-014-0003-6

DeBoer, G. E. (2000). Scientific literacy: Another look at its historical and contemporary meanings and its relationship to science education reform. *Journal of Research in Science Teaching, 37*(6), 582–601. https://doi.org/10.1002/1098-2736(200008)37:6<582:AID-TEA5>3.0.CO;2-L

Duschl, R. A. (2008). Science education in three-part harmony: Balancing conceptual, epistemic, and social learning goals. *Review of Research in Education, 32*(1), 268–291. https://doi.org/10.3102/0091732X07309371

Education group (n.d.). http://files.eric.ed.gov/fulltext/ED576762.pdf

Evangelista, I., Farin, J. A., Pozzo, M. I., Dobboletta, E., Alves, G. R., García-Zubía, J., Hernandez, U., Marchisio, S.T., Concaris, S. B., & Gustavsson, I. (2017). Science education at high school: a VISIR remote lab implementation. IEEE Proceedings of the 4th Experiment@ International Conference. https://recipp.ipp.pt/handle/10400.22/11371

Fischer, C., Zhou, N., Rodriguez, F., Warschauer, M., & King, S. (2019). Improving college student success in organic chemistry: impact of an online preparatory course. *Journal of Chemical Education, 96*(5), 857–864. https://doi.org/10.1021/acs.jchemed. 8b01008.

Gachago, D., Morkel, J., Hitge, L., van Zyl, I., & Ivala, E. (2017). Developing eLearning champions: A design thinking approach. *International Journal of Educational Technology, 14*(1), 1–14. https://doi.org/10.1186/s41239-017-0068-8

Gemin, B., & Pape, L. (2016, November 30). *Keeping pace with K-12 online learning, 2016*. Evergreen Education. https://eric.ed.gov/?id=ED576762

Hill, M., Sharma, M. D., & Johnston, H. (2015). How online learning modules can improve the representational fluency and conceptual understanding of university physics students. *European Journal of Physics, 36*(4). https://doi.org/10.1088/0143-0807/36/4/045019

Hodges, C., Moore, S., Lockee, B., Trust, T., & Bond, A. (2020). The difference between emergency remote teaching and online learning. *Educause Review*. https://er.educause.edu/articles/2020/3/the-difference-between-emergency-remote-teaching-and-online-learning

Holbrook, J., & Rannikmae, M. (2009). The Meaning of Scientific Literacy. International *Journal of Environmental & Science Education, 4*(3), 275–288.

Holstermann, N., Grube, D., & Bögeholz, S. (2010). Hands-on Activities and Their Influence on Students' Interest. *Research in Science Education, 40*(5), 743–757. https://doi.org/10.1007/s11165-009-9142-0

Johnson, M. (2002). Introductory biology on-line. *Journal of College Science Teaching, 31*(5), 312–317.

Kebritchi, M., Lipschuetz, A., & Santiague, L. (2017). Issues and challenges for teaching successful online courses in higher education. *Journal of Educational Technology Systems, 46*(1), 4–29.

Khlaif, Z. N., Salha, S., Affouneh, S., Rashed, H., & ElKimishy, L. A. (2020). The Covid-19 epidemic: teachers' responses to school closure in developing countries, *Technology, Pedagogy and Education, 30*(1), 95–109. https://doi.org/10.1080/1475939X.2020.1851752

Liebowitz, D., González, P., Hooge, E., & Lima, G. (2018). *OECD Reviews of School Resources: Portugal 2018*. OECD. https://doi.org/10.1787/9789264308411-en

Marshall, J. C., Smart, J. B. & Alston, D. M (2017). Inquiry-Based Instruction: A Possible Solution to Improving Student Learning of Both Science Concepts and Scientific Practices. *International Journal of Science and Mathematics Education, 15*(5), 777–796. https://doi.org/10.1007/s10763-016-9718-x

NRC (National Research Council). (1996). National science education standards. National Academy Press.

OECD (2006). Assessing scientific, reading and mathematical literacy: A framework for PISA 2006. OECD.

Olympiou, G., & Zacharia, Z. C. (2012). Blending physical and virtual manipulatives: An effort to improve students' conceptual understanding through science laboratory experimentation. *Science Education, 96*(1), 21–47.

Patton, M.Q. (1990). *Qualitative evaluation and research methods*. Sage Publications.

Puntambekar, S., Gnesdilow, D., Tissenbaum, C., Narayanan, N.H., & Rebello, N.S. (2021). Supporting middle school students' science talk: A comparison of physical and virtual labs. *Journal of Research in Science Teaching, 58*(3), 1–28, 392– 419. https://doi.org/10.1002/tea.21664

Ramlo, S.E. (2016). Students' views about potentially offering Physics courses online. *Journal of Science Education and Technology, 25*(3), 489–496. https://doi.org/10.1007/s10956-016-9608-6

Roberts, D. A. (2007). Scientific literacy/science literacy. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research in science education* (pp. 729–779). Erlbaum.

Sadi, O., & Cakiroglu, J. (2011). Effects of hands-on activity enriched instruction on students' achievement and attitudes towards science. *Journal of Baltic Science Education, 10*(2), 97–97.

Son, J., Narguizian, P., Beltz, D., & Desharnais, R. (2016). Comparing physical, virtual, and hybrid flipped labs for general education biology. *Online Learning, 20*(3), 228–243.

Strauss, A., & Corbin, J. (1998). *Basic of qualitative research. Techniques and procedures for developing grounded theory*. Sage Publications.

Sullivan, S., Gnesdilow, Puntambekar, S., & Kim, J.-S. (2017). Middle school students' learning of mechanics concepts through engagement in different sequences of physical and virtual experiments. *International Journal of Science Education, 39*(12), 1573–1600. https://doi.org/10.1080/09500693.2017.1341668

Swinnerton, B. J., Morris, N. P., Hotchkiss, S., & Pickering, J. D. (2017). The integration of an anatomy massive open online course (MOOC) into a medical anatomy curriculum. *American Association of Anatomists, 10*(1), 53–67. https://doi.org/10.1002/ase.1625

Tho, S. W., & Yeung, Y. Y. (2014). Remote laboratory (RL) system for technology-enhanced science learning: The design and pilot implementation in undergraduate courses. In C. C. Liu, H. Ogata, S. C. Kong, & A. Kashihara (Eds.), *Proceedings of the 22nd International Conference on Computers in Education, ICCE 2014*, pp. 260–262.

Tho, S.W., & Yeung, Y.Y. (2018). An implementation of remote laboratory for secondary science education. *Journal of Computer Assisted Learning*, *34*(5), 629–640. https://doi.org/10.1111/jcal.12273

Venkateswaran, R. (2016). Evaluating the use of learn smart and connect in introductory general chemistry classes: The pros and cons of an online teaching and learning system. In M. Schultz, S. Schmid, & T. Holme (Eds.), *Technology and Assessment Strategies for Improving Student Learning in Chemistry; ACS Symposium Series 1235* (pp. 83–599). American Chemical Society: Washington, DC.

Walters, S., Grover, K. S., Turner, R. C., & Alexander, J. C. (2017). Faculty perceptions related to teaching online: A starting point for designing faculty development initiatives. *Turkish Online Journal of Distance Education, 18*(4), 4–19.

Zacharia, Z. C., & Anderson, O. (2003). The effects of an interactive computer-based simulation prior to performing a laboratory inquiry-based experiment on students' conceptual understanding of physics. *American Journal of Physics, 71*(6), 618–629.

Zacharia, Z. C., & de Jong, T. (2014). The effects on students' conceptual understanding of electric circuits of introducing virtual manipulatives within a physical manipulatives-oriented curriculum. *Cognition and Instruction, 32*(2), 101–158.

Biographical note

Mónica Baptista, PhD, is an associate professor, researcher and deputy director at the Institute of Education, University of Lisbon, where she coordinates the master program on Physics and Chemistry teaching. She earned her Ph.D. in Science Education. She has been involved in EU projects named STEMKey, 3C4Life, LOOP, IntTT, SAILS, IRRESISTIBLE and she is the coordinator of a national research project, focused on STEM Education and funded by the national agency. She is the representative member of the Mediterranean countries of IOSTE and she is vice-president of Portuguese Physics Society. She has published and been involved in research related to Physics and Chemistry Education, inquiry-based science education and its association to competences development, lesson study and preservice teachers and teachers' professional development.

Estela Costa, PhD, is an assistant professor, researcher and deputy director at the Institute of Education, University of Lisbon. She coordinates the M.Ed. in School Management and Administration, and an external consulting team of 'Educational Territories of Priority Intervention schools' (TEIP), in partnership with the Ministry of Education. She holds a PhD in Educational Administration and Policy. She has been involved in EU projects named KNOWandPOL, ONTP, Polycentric Inspection, LOOP, and 3C4Life. She conducts evaluation studies on political programs and consultancy activities in Portugal and abroad. Currently, she is the Portuguese national expert at the European Commission Independent Experts in Education and Training. She has published and been involved in research related to education policy, school evaluation, leadership, innovation and school improvement.

Iva Martins, PhD, is a Doctoral Researcher and an Invited Assistant Professor in the Master's Course in Teaching Physics and Chemistry at the Institute of Education, University of Lisbon. Her research interests are STEM Education, Inquiry, PCK and Professional Development of Science Teachers. She collaborates in several research projects, including teachers training programs.