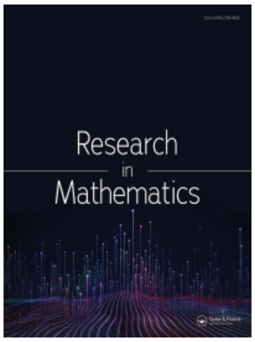

Research in Mathematics

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/oama23

Mathematics education: Promoting interdisciplinarity with science and technology

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RESEARCH IN MATHEMATICS
2022, VOL. 9, NO. 1, 2134628
https://doi.org/10.1080/27684830.2022.2134628

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APPLIED & INTERDISCIPLINARY MATHEMATICS | RESEARCH ARTICLE

Mathematics education: Promoting interdisciplinarity with science and technology

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ABSTRACT

This paper aims to investigate a way of integrating mathematics, science and technology in primary school, which is considered critical to better prepare students for the real-life challenges of modern world. To achieve this purpose, it is necessary to innovate teachers' practices being crucial to promote their professional development. This study employs the case study of two teachers who participated in a continuing professional development programme developed by the authors of this paper. With a qualitative methodology and an interpretative approach, it was verified that teachers were able to innovate their practices revealing knowledge and skills to create and develop mathematical interdisciplinary tasks in class with their students. In addition, teachers recognized impact on their students and that these practices promoted their interest to learn these subject matters. We argue that it was a collaborative context between teachers with the support of the educators that gave the teachers knowledge and skills to be able to develop this approach in class. We conclude that it is possible to promote interdisciplinarity with mathematics, science and technology in the context of a collaborative teachers' professional development programme.

ARTICLE HISTORY
Received 22 January 2021
Accepted 7 October 2022

KEYWORDS
Mathematics education; interdisciplinarity; professional development; hands-on; primary school

Introduction

Mathematics is part of our real world and it is a very important subject in the school curriculum being compulsory in primary and middle school around the world and in Portugal. Also, science is considered crucial to understand our real world and to gain skills to effectively participate in modern society, being the driving force of economic development and scientific literacy in most countries (Harlen & Qualter, 2014). The significance of mathematics and science is unquestionable, and this is the main reason why they are the focus of several international assessments such as the Programme for International Student Assessment (PISA) and the Trends in International Mathematics and Science Study (TIMSS). The TIMSS evaluates mathematics and science literacy of students of the 4th-grade and 8th-grade of primary school and 12 th-grade of secondary school. PISA evaluates 15-year-old students' skills in subject matters such as science and mathematics. One of the main objectives of PISA is to measure to what extent, students near the end of their compulsory education, have obtained essential knowledge and skills to achieve success, in order to meet the increasing challenges of modern societies.

Technology resources in primary education can promote children's attention, socialization, development of language and learning (Gimbert & Cristol, 2004). Moreover, they have a positive impact on students' motivation and meaningful learning, provide hands-on learning opportunities and can integrate school subjects like mathematics (Costley, 2014). Also, technology resources are efficient to catch children's attention and engage students in learning mathematics and science (Authors, 2017). In recent years, technology has been gaining prominence and, as a consequence, the PISA survey also includes latest advances of technology in mathematics and science, leading to research concerning these three subject matters.

In fact, there has been an increasing call to integrate mathematics, science and technology at school, namely through teachers' professional development, in order to better prepare students for real-life challenges (Kermani & Aldemir, 2015; Kim & Bolger, 2016). The emphasis on STEM (Science, Technology, Engineering and Mathematics) education in recent times is perceived by a growing number of authors as an opportunity for innovation in mathematics teaching (Fitzallen, 2015). This emphasis leads to a change of paradigm that creates

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the need for teachers to innovate their practices by designing and implementing interdisciplinary tasks in the classroom. But, despite all reforms and efforts to promote and integrate STEM, this is not an easy goal to achieve (Gillies & Nichols, 2015; Osborne & Dillon, 2008). Also, there is limited research about mathematics and science integration in the classroom (Treacy & O'Donoghue, 2014). These facts suggest the need to develop more studies about STEM integration.

This paper aims to investigate a way of integrating mathematics, science and technology in primary school. In particular, it highlights mathematical tasks applied at the classroom level that are related to science and technology. To achieve this purpose, we report the case of two teachers who participated in a Continuing Professional Development (CPD) programme with STEM contents consisting in designing and developing interdisciplinary tasks.

Literature review

In this section we refer to the decline in students' interest for STEM and to the need to begin by motivating them for these subjects in primary school. Also, teachers are the corner stone of any pedagogical intervention and it is crucial to promote their professional development.

The need for STEM skills in future careers and for an integrated approach

In 2007, the Rocard report pointed out to an alarming decline in students' interest for science and mathematics, which will compromise Europe's capacity for innovation (Rocard et al., 2007). Since then, other studies have been identifying the same problem. For example, the National Science Board (National Science Board, 2010) reported that the number of US high school graduates choosing STEM fields has been declining. This is a global problem, since many other reports and studies all around the world refer to this decline of students' interest for STEM, and also to an increasing need of STEM competencies and skills in future careers (Caprile et al., 2015; Commonwealth of Australia, 2015; Lyons, 2006; Marginson et al., 2013; National Science and Technology Council, 2013). In Portugal, the National Education Council report "State of education 2018" (CNE—Conselho Nacional de Educação [National Education Council], 2019), stated that the percentage of graduates in higher education in "Engineering, Transformation and Construction Industries" was 18,5 % and only 2,2% graduated in "Information and Communication Technologies". Moreover, it emphasized the need for digital and technological competencies in future careers, which has implications in education.

The growing call for STEM competencies and skills increases the importance of STEM education at elementary and middle school (English, 2017). In fact, several studies sustain that students' motivation for STEM needs to begin at the first years of primary school, by implementing hands-on activities (Lyons, 2006; Rocard et al., 2007), because they have a positive impact on students and promote their interest in these subjects (Osborne, 2009; Roberts, 2014; Spencer & Huss, 2013). Also, if students' interest is not formed in elementary education, it decreases around the age of fourteen (Archer et al., 2010), which will compromise science achievement and conceptual understanding (Goldston, 2017).

Roberts (Roberts, 2014) sustains that "engaging learners in science and mathematics at an early age has a positive effect on their perceptions of these subjects and increases their participation in science related subjects in secondary and higher education" [22,p.34]. Based on a programme that included STEM hands-on workshops for primary schools, Roberts (Roberts, 2014) concluded that the interest of the participants (primary school students) in STEM and in becoming a scientist or an engineer has increased.

An integrated approach with STEM can have a positive impact on student's achievement, especially at elementary school level (Becker & Park, 2011). Fitzallen (Fitzallen, 2015) sustains that STEM education can be a form of innovation for learning and teaching mathematics. For this reason, there is a greater need to understand the implications of STEM education in mathematics education (Fitzallen, 2015). Concerning the Mathematics Curriculum for Elementary School (Ministério da Educação [Ministry of Education], 2013] in Portugal, one of the objectives of this subject is to analyse the natural world. It states that Mathematics "is indispensable to an adequate understanding of much of the phenomena of the world around us (. . .)" [26,p.2] and "is essential for the study of phenomena that are dealt with in other subjects of the Elementary School curriculum" [26,p.2].

Promoting teachers' professional development

Mathematics education: Promoting interdisciplinarity with science and technologLinking mathematics with science has been widely advocated (Berlin & Lee, 2005) but it is not an easy goal to achieve (Baxter et al., 2014). In this regard, several authors refer to lack of research about STEM integration, especially with respect to the elementary and middle grades, including the need for more empirical studies (Becker & Park, 2011; English, 2017).

Also, Treacy and O'Donoghue (Treacy & O'Donoghue, 2014) indicated lack of research about integrating mathematics and science in the classroom, as well as a teaching model that can be adopted by everyone. In fact, it is a big challenge to develop a reasonable and realistic conceptualization of STEM integration for mathematics teachers and coaches (Baker & Galanti, 2017).

Despite all efforts and reforms in mathematics and science all over the world, many studies mention that teachers still teach traditionally (Baker & Galanti, 2017; Rocard et al., 2007). Citing [National Academy of Engineering (NAE) & National Research Council Committee (NRC) 2014], Baker and Galanti (Baker & Galanti, 2017) argue that especially mathematics continues to be taught in isolation with an emphasis on written skills and memorization and that "Designers of integrated STEM must seek to build a connectedness between mathematics and other subject areas" [29,p.2]. In fact, recommendations to promote STEM interdisciplinary tasks, lead to a change of paradigm that creates the need for teachers to innovate their practices. Cotabish, Dailey, Robinson, and Hughes (Cotabish et al., 2013) presented a study to assess a STEM intervention on the knowledge and skills of elementary school students through teachers' professional development and suggested that the intervention had a positive significant impact on the students.

Teachers are the corner stone of any pedagogical intervention. In this regard, it is crucial to promote their professional development to provide them with knowledge and skills to develop and implement innovative classroom tasks, with appropriate pedagogical approaches (Geiger et al., 2014; Hewson, 2007; Martins, 2006; Rocard et al., 2007). In order to achieve this goal, it is recommended to create a partnership with stakeholders such as teachers educators and researchers to motivate teachers to innovate their practices and to promote the sustainability of their professional development (Geiger et al., 2014; Hewson, 2007; Rocard et al., 2007). Moreover, teachers need to have the opportunity to learn and practise what they are expected to implement in classroom (Afonso et al., 2005; Ball, 2003), and it is crucial to support and guide them in the context of their classroom (Abd-El-Khalick, 2013; Authors, 2017; Zehetmeier et al., 2015). A professional development programme will only be successful if teachers are able to implement, in practice, with their students, what they learned and experienced during their training (Buczynski & Hansen, 2010). To be effective, innovations should be adopted by teachers and transformed into their own practice (Zehetmeier et al., 2015).

In order to facilitate an integrative approach to the teaching and learning of mathematics and science, there is "a need to ensure that the teachers are given an opportunity to acquire knowledge of the content of the mathematics and science lessons" [39,p.248]. Also, the same authors argue that "The importance of supporting the teachers at school level (...) is a major contributing factor to the successful implementation of the integrative approach" [39,p.248].

According to Kim and Bolger (Kim & Bolger, 2016), integrative curricula draws from multiple disciplines and have the potential to make the learning of science and mathematics more meaningful and coherent for students. For this reason, they advocate the implementation of a curriculum, in schools, that integrates mathematics, science and technology. In this regard, teachers should be encouraged to develop interdisciplinary lessons that are in line with this approach. In the same line, Kermani and Aldemir (Kermani & Aldemir, 2015) advocate the integration of mathematics, science and technology in the first years of school through teachers' professional development as well as the creation of well-designed materials to implement hands-on experimental activities. Ball (Ball, 2003) stresses the importance of giving learning opportunities to teachers, as well as the development of well-designed and managed courses, workshops and materials.

The international project "Promoting Inquiry in Mathematics and Science Education Across Europe" (PRIMAS, 2013) refers that resources can include science and mathematical tasks or the work developed by academics to be used in the classroom or in sessions to promote the professional development of teachers. According to Pepin, Gueudet and Trouche (Pepin et al., 2013), resources are crucial for teachers and they adapt them according to their individual preferences and personality, this being a process of interpretation and design of the resources. For Gimeno (Gimeno, 2000), tasks are teaching and learning activities carried out in school environments that are incorporated in the curriculum in action.

In summary, to integrate mathematics, science and technology in primary school, it is crucial to promote an adequate professional development programme for teachers that will enable them to design and develop interdisciplinary tasks to be implemented in the classroom.

Background and context of the study

In 2015, a group of university teachers designed a Continuing Professional Development (CPD) programme targeted to primary school teachers, with a partnership of local schools and a *Continuing Training Center*. This programme, with a total of 26 hours was proposed for an entire school year and included workshops with a 2–3 hour duration related to topics such as mathematics, science and technology. The topics were introduced relating theoretical contents with hands-on activities to be implemented at the classroom, according to primary school syllabus. In the workshops, teachers had the opportunity to practice hands-on and minds-on experiments addressed to their students and had contact with pedagogical methodologies to help implement these practices successfully (Figure 1). Also, several ideas and examples of interdisciplinary tasks were given during their training activities.

Teacher educators were university teachers and researchers in the areas of science education, electrical and computer engineering, mathematics, biology, physics, and chemistry. They were responsible for directing the workshops with the participant teachers and also for designing prototypes and experiments to be implemented in the classroom with primary students.

Teachers were encouraged to develop interdisciplinary tasks relating mathematics, science and technology. This CPD programme included visits of the educators to the teachers' classroom either to exemplify the implementation of hands-on activities or to support teachers while they implemented their own tasks. In the final stage, teachers provided a written report with a critical account about the CPD programme, and proposals and evidence of interdisciplinary tasks that they created and implemented with their students. Teachers were free to choose a theme such as astronomy, sound or electricity, amongst others, to design interdisciplinary tasks and implement them with their students.

Methodology

According to Yin (2005), a case study is an empirical research that looks at a phenomenon within its real-life context, allowing a generalization of the results obtained. In this study, we present the case study of two teachers, both aged 48 years and with 27 years of in-service experience, who participated in the CPD programme during the 2016/2017 and 2017/2018 school years. They chose the topic of sound to develop interdisciplinary tasks to implement in their classroom. At the end of the CPD, teachers presented written reports with the proposals of tasks to implement, as well as evidence of the activities developed in class with their students.

Using a qualitative methodology and an interpretative approach, data collection consisted in written reports presented by the teachers and observations of the teachers in action in the workshops and in their classroom (Cohen et al., 2007). Both in the written reports and in classroom observations, we searched for interdisciplinary tasks developed by the teachers and also how they implemented them with the students. First author of this paper was a participant observer and the two authors were responsible for the triangulation and validation of the collected data.

Data analysis and discussion

In this section we present the case study of teachers Anacleto and Micaela (fictitious names) who participated in the CPD programme. During the workshops with the other teachers, they had the opportunity to learn about sound and to perform hands-on experiments related to sound. The conduction of the sound workshops was the responsibility of electrical engineering lecturers who designed prototypes to reproduce and measure the sound, amongst others. They also used internet resources to provide the teachers with tools that they could employ with their students such as videos and free software. An example is the *Sound Meter* application that allows sound intensity measurements (in decibels) and can be used in a smartphone or tablet.

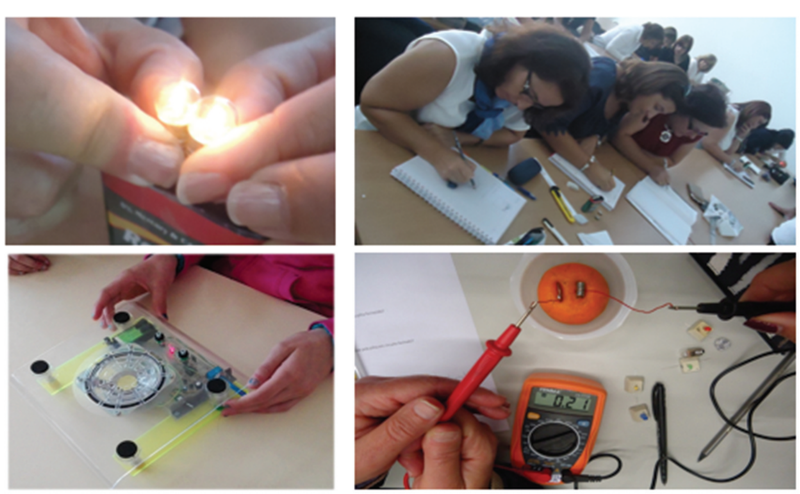

Figure 1. Prototype to "visualize" the sound of human voice.

Figure 2. Prototype to "visualize" the sound of human voice.

Interdisciplinary sound tasks designed and implemented by the teachers

During the 2016/2017 school year, both teachers worked together to design interdisciplinary tasks related to sound and implemented them in a second-grade class. At teacher Micaela's class, the lesson started with the following question: "What is sound?" Then the students discussed possible answers to the question. The discussion continued with more questions such as "What is sound for?" or "How is it produced?"

After listening to children's opinions and perceptions, teachers encouraged them to investigate to find answers to the questions. One of the resources used was the internet on a computer where they found the definition of sound and watched some films related to the topic. Sound is produced when something vibrates, which causes a wave that propagates in solid, liquid or gaseous media. For example, it may be produced by vocal chords or clapping hands. Several characteristics of sound may be highlighted such as frequency, intensity, wave length or propagation speed.

After this introduction, teachers carried out some hands-on activities with the students to illustrate some of the concepts defined above. For example, they built a prototype to "visualize" the sound of the human voice (like the one they learned at the sound workshop) and also simulated "wave propagation" (Figures 2) For example, when a student produces sound inside the prototype, the balloon vibrates and the laser in the mirror projects figures that may be visualized on the board or on the wall of the classroom (Figure 3).

This paper outlines some of the mathematical tasks developed by the teachers in class. With the purpose of exploring mathematics, several sound measurements have been done such as frequency (measured in hertz) and intensity (measured in decibels).

With the *Sound Meter* application in a mobile phone (Figure 3), the teachers asked each student to measure and record in a table the intensity (in decibels) of several sounds such as whispering, speaking, laughing, crying, screaming, singing and clapping hands (Table 1).

After each student has collected their own data, they shared it with the whole class. Together and with the help of the teachers, all the students have built another table with the global information (Table 2). For example, in line two and column three, the number "12" means that twelve students registered forty (40) decibels when they were whispering.

After all the data have been collected, several tables and graphics were built to promote organization and processing of data from the measurement results such as the amplitude of the hearing frequencies audition (in hertz) and sound intensity measurement (in decibels) of each student. For example, in Figure 4 each "face" represents two students who recorded the correspondent sound intensity measurement while they were talking.

Also, more problems involving calculations to work in the context of mathematics were explored with the students. In her final report, teacher Micaela argues that "it's possible to implement an interdisciplinary approach of contents relating mathematics to science and technology". With regard to her students, she points out that they "get motivated and commit much more easily in this type of tasks". Teacher Anacleto states that "students become more attentive and interested, collaborating in a more active and committed way, which is then reflected in the learning outcomes".

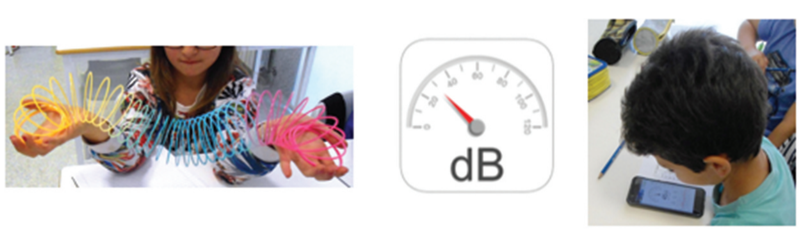

Figure 3. Wave propagation and sound intensity measurement.

Table 1. Each student registered the intensity of the sound in decibels

	30	40	50	60	70	80	90
Whisper		X					
Speak				X			
Laugh						X	
Cry						X	
Scream						X	
Sing						X	
Clap hands					X		

Table 2. Intensity measurements of the sound in decibels of all the students

	30	40	50	60	70	80	90
Whisper	0	12	4	0	0	0	0
Speak	0	0	0	4	9	3	0
Laugh	0	0	0	0	0	16	0
Cry	0	0	3	13	0	0	0
Scream	0	0	0	3	8	5	0
Sing	0	0	0	4	8	4	0
Clap hands	0	0	0	0	16	0	0

Another highly valued aspect of the training was the visit of the university educators to the teachers' classroom, either to help teachers or to implement hands-on experiments: "students will be able to learn/experiment with the help of accredited technicians and equipped with all the necessary materials" (Teacher Anacleto's report, June 2017).

In the end of the 2016/2017 school year, both teachers shared their work with their peers at the last workshop (the CPD has about 20 participants each year). Many of the other teachers mentioned this sharing of good practices in their reports such as the case of teacher Manuela: "The sharing of materials, ideas and activities was, for me, a very positive point" (Teacher Manuela report, June 2017).

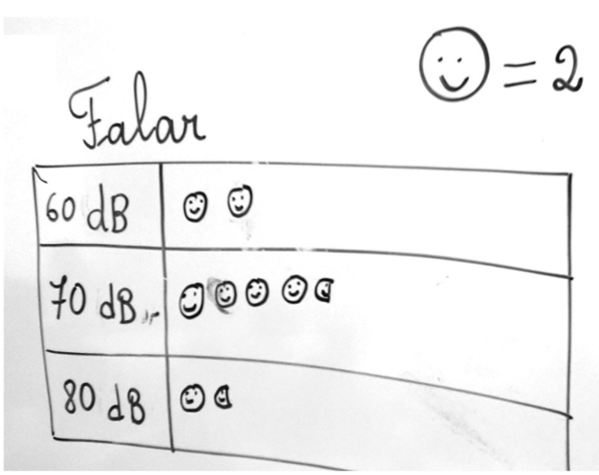

Figure 4. Organization and processing of data from sound measurements.
Source: Teachers' reports.

In the 2017/2018 school year, both teachers decided to carry out again more tasks related to the sound topic. In class, teachers asked the students to look for energy labels of home appliances to investigate the noise that they produced and bring the collected information to share with the colleagues. Figure 5 shows some examples of energy labels that it is possible to find on some home appliances such as washing machines or refrigerators, amongst others.

In class, all the information was organized by the students in a table (Table 3) with the teachers' supervision.

From the collected information the teachers created worksheets for the students to solve. Figure 6 gives an example of the work developed with the students.

In summary, teachers Anacleto and Micaela worked mathematics science and technology contents by developing exploratory and investigative tasks. Mathematical tasks included problems and exercises and also data organization and processing.

Below are two excerpts of the reflections made by the teachers in their final reports.

> I would like to emphasize that the training action has contributed to the acquisition of new knowledge that will allow me to improve the professional performance and to have a positive impact in the classroom, providing the students with diversified experiences of learning and development of scientific skills (Micaela's final report, June 2017).

> I believe that this training will bring to my learner practice a wider range of possibilities for new activities, to be carried out in the context of the classroom. The most interesting thing is that these new approaches, which we had in training, are mostly practical approaches, which is very good (Anacleto's final report, June 2017).

These teachers' perceptions show that participating in the CPD programme was a very positive experience with impact in their practices. They also recognize impact in their students and that these practices promote interest to learn these subject matters. The support of the university educators was very highlighted such as the hands-on activities performed at the workshops. Moreover, visits of the educators to the classrooms to perform experiments was very appreciated by the teachers and considered important to promote student learning.

In her final report, teacher Micaela stresses that: "these practices allowed to verify that it is possible to make an interdisciplinary approach of contents, relating mathematics, the environment, musical and dramatic expression" and "revealed that students are more motivated and engaged in this type of task". Teacher Anacleto argues

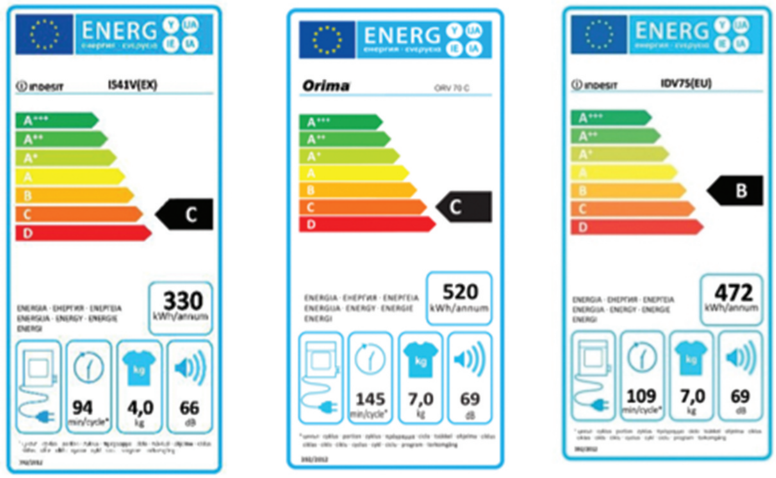

Figure 5. Examples of energy labels from some home appliances.
Source: Teachers' reports.

Table 3. Noise level of some home appliances according to the respective model

HOME APPLIANCE	MODEL	NOISE LEVEL
Clothes dryer	Indesit IS41V	66 dB
	Orima	69 dB
	Indesit IDV75	69 dB
Refrigerator-freezer	Bosh	41 dB
	Candy	43 dB
	LG	37 dB
Washing machine	AEG	39 dB
	Balay	50 dB
	Candy	43 dB
Vacuum cleaner	AEG	76 dB
	Balay	64 dB
	Siemens	81 dB
Extractor hood	Candy—CBT6240X	64 dB
	Candy—CBG 640X	67 dB
	Meireles	65 dB
Refrigerator	Hotpoint/Ariston	35 dB
	Indesit	45 dB
	Samsung	41 dB

that "students become more interested and engaged on the tasks collaborating in a more active and committed way, which has an impact on learning".

In sum, both teachers gained motivation and recognized changes in their practices in the context of this collaborative CPD programme. Also, they designed and implemented interdisciplinary tasks related to sound and recognized that this kind of approach promotes interest of their students to learn other subject matters such as mathematics.

Conclusions

In this study, we investigated a way of promoting interdisciplinarity by integrating mathematics, science and technology in the classroom. In order to develop this research, a collaborative CPD programme with STEM contents was designed. A case study of two teachers who participated in the CPD programme and implemented interdisciplinary tasks related to the sound topic was reported.

Despite reported difficulties in the literature related to STEM integration (Gillies & Nichols, 2015; Osborne & Dillon, 2008), it is possible to lead teachers to implement this approach in the context of a collaborative CPD programme. Our study is in line with other studies that refer the importance of supporting the teachers to develop an integrative approach (N et al., 2016) and to make them achieve greater gains in knowledge and skills related to the matters they teach (Capps & Crawford, 2013). In fact, teachers were supported by educators (university teachers) experts in mathematics, science and technology who collaborated in order to develop an integrated approach of these subject matters to implement in the context of the CPD programme. We argue that this was the context that gave the teachers knowledge and skills to be able to innovate their practices. Furthermore, Zehetmeier, Andreitz, Erlacher and Rauch (Zehetmeier et al., 2015) argue that innovations should be appropriated by those who implement them and transformed into their practice in order to have real effects. We believe this is what happened to the teachers who have designed and implemented tasks that were not part of their traditional practices for two school years.

Teachers recognized impact on their students and that these practices promoted their interest to learn these subject matters. Also, the support of university educators, namely visits to the classrooms, was very appreciated by the teachers and considered important to help them to innovate their practices and to promote student learning. In fact, teacher educators such as

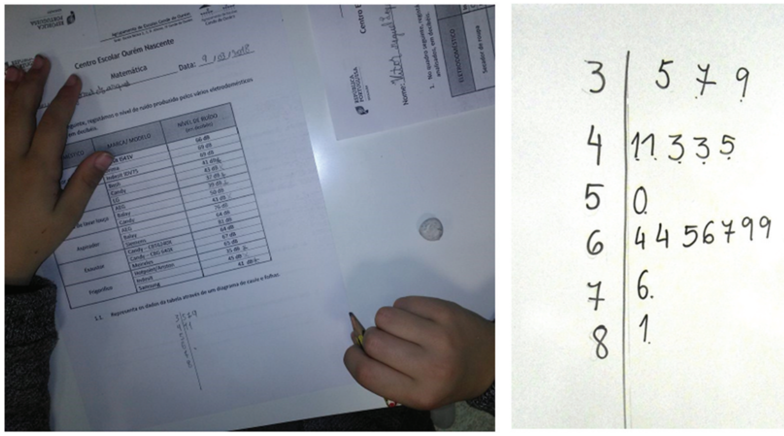

Figure 6. Representation of the data from the table through a stem-and-leaf diagram.
Source: Teachers' reports.

mathematicians and engineers collaborated in the workshops to help the teachers to develop interdisciplinary tasks. In addition, they went together to the teachers' classroom either to exemplify hands-on experiments or to support teachers while they implemented their own tasks with the students. With this collaboration teachers gained more motivation and also confidence to innovate their practices.

We verified that both teachers gained motivation and recognized changes in their practices in the context of this collaborative CPD programme. Also, they designed and implemented interdisciplinary tasks related to sound and recognized that this kind of approach promotes interest of their students to learn other subject matters such as mathematics.

In this study, we found that teachers innovated their practices revealing knowledge and skills to create and perform mathematical interdisciplinary tasks with their students in class. We conclude that it is possible to promote interdisciplinarity with mathematics, science and technology in the context of a collaborative teachers' professional development programme that supports the teachers in the implementation of interdisciplinary tasks in class.

Limitations of this study and future work

This paper is essentially based on the case study of two teachers who participated in a CPD programme and developed mathematical tasks related to sound. We believe that these are interdisciplinary tasks that can be included as good resources adequate to school syllabus. But we still need to develop more studies to validate the tasks before proposing them to the wider community. Our next step is to discuss these tasks with the other teachers in the CPD programme in order to improve and adequate them according to the participants' opinions and suggestions. Also, we want to implement them in the classroom of some of the teachers and compare the results with other groups to assess student learning outcomes.

Acknowledgements

This work is supported by national funds through FCT - Foundation for Science and Technology, I. P., in the context of the project PTDC/CED-EDG/32422/2017.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by the Fundação para a Ciência e a Tecnologia [PTDC/CED-EDG/32422/2017].

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