ISSN 1392-0340 (Print)
ISSN 2029-0551 (Online)
https://doi.org/10.15823/p.2023.149.4

Pedagogika / Pedagogy
2023, t. 149, Nr. 1, p. 82–104 / Vol. 149, No.1, pp. 82–104, 2023

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Teachers' Professional Knowledge to Develop STEM Integrated Tasks

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Annotation. This study presents developments on the professional knowledge needed to implement STEM hands-on tasks by teachers. Research was developed in the framework of a teachers' professional development programme designed to provide knowledge for them to be capable of implementing this kind of tasks. With a qualitative methodology, we verified that teachers need to attain a specialized theoretical and technical knowledge to develop STEM integrated hands-on tasks and effectively implement them in class.

Keywords: *professional development, teachers' knowledge, STEM, hands-on, primary school.*

Introduction

STEM (Science, Technology, Engineering, and Mathematics) education has been gaining prominence in international school curricula all around the world, in order to better prepare students for the 21st century challenges (e.g., Baker & Galanti, 2017; Kim & Bolger, 2017). In fact, there is an international agreement about the need to promote STEM education to meet the growing needs of professionals in these areas (English, 2017; European Schoolnet, 2018; Office of the Chief Scientist, 2016). In this regard, recommendations are to provide integrative approaches among STEM subjects; i.e., approaches that promote interdisciplinarity amongst Science, Technology, Engineering, and Mathematics (Reynante et al., 2020). In fact, integrative approaches between all the STEM subjects have positive effects on student's attainment, with better results in elementary school (Becker & Park, 2011; Roehrig et al., 2021). In this sense, it is crucial to begin in the first years of school in order to better motivate students to learn about these matters (DeJarnette, 2012; Roberts, 2014; van Tuijl & van der Molen, 2016).

However, the literature identifies difficulties about the implementation of STEM integration by teachers, especially in primary school (Breiner, 2012; English, 2017; Margot & Kettler, 2019). In fact, to design STEM tasks, teachers need to acquire a robust Content Knowledge about the subject matters to be integrated (English, 2017; Fitzallen, 2015; Kim & Bolger, 2017). For this reason, it is necessary to design a teachers' Professional Development Programme (PDP) that provides teachers with knowledge and skills to achieve this goal (Costa et al., 2020; Costa et al., 2022).

Concerning teachers' professional knowledge, the literature presents several studies that include subject matter content knowledge and pedagogical content knowledge (Shulman, 1986) related to the subject matters to teach (Ball et al., 2008; Magnusson et al., 1999; Mishra & Koehler, 2006). In this study, we intend to contribute to research by presenting new developments on the knowledge needed to implement STEM integrated hands-on tasks in primary school, which leads to the question: What is the professional knowledge essential to effectively implement STEM integrated hands-on tasks?

By "effectively implement" we mean implementation of tasks that include all the subjects involved in the STEM acronym through hands-on practices that promote meaningful learning in students. The characterization of this knowledge is an important contribution to better understanding how to promote STEM education in schools and PDP related to STEM.

Next, we present the revision of literature and theoretical background of the study. After, we describe the context of the study including the PDP. The following sections concern methodology, teachers' professional knowledge and analysis of data, based on six participant teachers and one case study with the teacher in action. Finally, conclusions are presented.

Literature Review and Theoretical Framework

To promote students' interest for Science and STEM, several authors sustain the need to intervene in the early years of schooling in order to motivate students to learn these subject matters (DeJarnette, 2012; European Schoolnet, 2018). In this regard, it is crucial to develop hands-on experiments in the classroom to lead students to achieve significant improvements in performance and to produce positive attitudes towards STEM (Mathers et al., 2012; Roberts, 2014; van Tuijl & van der Molen, 2016). According to Çorlu et al. (2014), STEM education is an interdisciplinary approach that embraces the need to teach Science, Technology, Engineering, and Mathematics in an integrated manner.

However, despite efforts and reforms to promote STEM education, achieving this goal continues to be a challenge (Breiner, 2012; Margot & Kettler, 2019). One of the main reasons related to teachers' difficulties in integrating STEM is a lack of having enough Content Knowledge about the subject matters to integrate (English, 2017; Fitzallen, 2015; Kim & Bolger, 2017). To face these shortcomings, teachers must be provided with an adequate PDP that enables them to innovate in class. In this regard, a PDP will only be successful if teachers gain skills to implement what they learn in the classroom (Buczynski & Hansen, 2010).

Some studies are related to teaching knowledge. For example, Shulman (1986) distinguishes three categories of Content Knowledge (CK): Subject Matter Content Knowledge (SMCK), Pedagogical Content Knowledge (PCK) and Curricular Knowledge (CuK) and refers that besides presenting curricula to students, teachers must be capable of explaining concepts and to relate theory and practice (Shulman, 1986, p. 9).

Concerning Subject Matter Knowledge (SMK), Shulman (1986) argues that teaching requires more skills and preparation than the mere knowledge of a subject matter. For this author, teachers' understanding of SMK includes "not only understand *that* something is so; the teacher must further understand *why* it is so, on what grounds its warrant can be asserted, and under what circumstances our belief in its justification can be weakened and even denied" (Shulman, 1986, p. 9). Concerning PCK Shulman includes "the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations – in a word, the ways of representing and formulating the subject that make it comprehensible to others" (Shulman, 1986, p. 9). Regarding the curriculum, it:

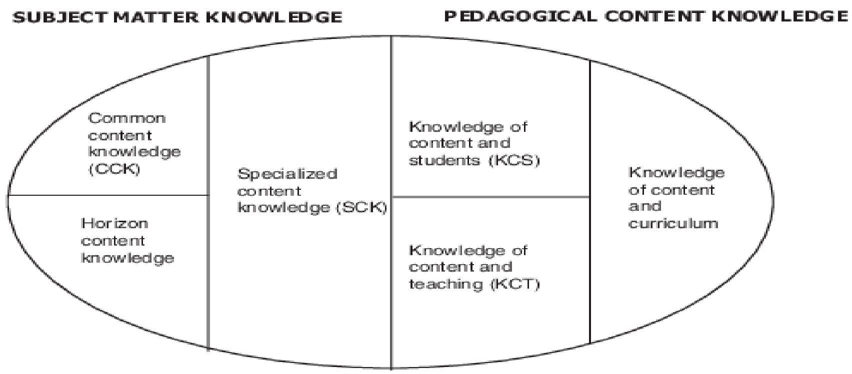
> (…) is represented by a full range of programs designed for the teaching of particular subjects and topics at a given level, the variety of instructional materials available in relation to those programs, and the set of characteristics that serve as both the indications and contraindications for the use of particular curriculum or program materials in particular circumstances" (Shulman, 1986, p. 10).

According to Young (2010), teachers need the curriculum "to guide them in what they have to teach (…). Curriculum designers rely on teachers to motivate students and make those concepts a reality for pupils" (p. 24). Teachers "have to take account of the experiences and prior knowledge that students bring to school and what initially motivates them" (Young, 2010, p. 24). These observations are related to PCK. In fact, this author expresses that it is the responsibility of teachers and not the designers of curriculum to "draw on pupil's everyday knowledge" to help them to engage and to see the relevance of curriculum (Young, 2010, p. 25). Also, Young (2010) refers to the fact that "knowledge stipulated by the curriculum must be based on specialist knowledge developed by communities of researchers" (Young, 2010, p. 25).

Young (2007) sustains that "powerful knowledge" is focused on the curriculum and is the knowledge that a country considers important for their students to acquire. For this reason, it is the school responsibility to provide the opportunity for students to achieve that knowledge. In modern societies this powerful knowledge is becoming a specialized knowledge that the teachers need to obtain (Young, 2007). In fact, as Ball (2003) argues, curriculum does not "teaches itself" and is dependent on the professionals who use it. In addition to specialized knowledge about the content to teach, it is up to every teacher to know how to convey this knowledge to their students, which includes the need of PCK. In this line, teaching goes far beyond the knowledge of the Curriculum Content, teaching requires interpreting, explaining, justifying, analysing errors, generalizing and defining; requires knowing the ideas and procedures in detail and knowing them well enough to represent them and explain with skill in more than one way (Ball, 2003).

Based on Shulman's notion of CK, Ball et al. (2008) investigated the competencies essential to teach and develop an empirical approach to determine the CK needed for teaching mathematics. In this empirical study, the authors research characterises different types of knowledge related to SMK and PCK (Figure 1). With respect to SMK, Ball distinguishes *Common content knowledge*, *Horizon content knowledge* and *Specialized content knowledge*. PCK includes: knowledge of content and students; knowledge of content and teaching; and knowledge of content and curriculum. Ball et al. (2008) refer that PCK "offers a way to build bridges between the academic world of disciplinary knowledge and the practice world of teaching (…) by identifying amalgam knowledge that combines the knowing of content with the knowing of students and pedagogy" (p. 398).

Figure 1
Mathematical Knowledge Needed for Effective Instruction (Ball et al., 2008, p. 403)

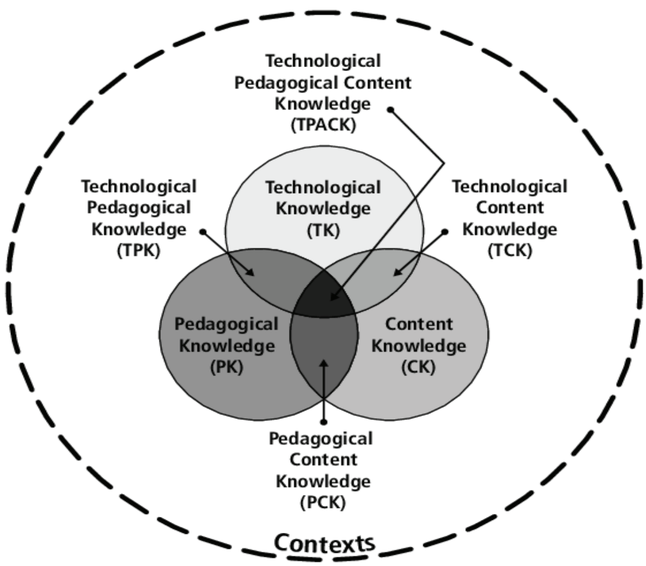


Also, by building on Shulman' s formulation of PCK, Mishra et al. (2006) propose a conceptual framework for educational technology that they called TPCK (Technological Pedagogical Content Knowledge). In this study, they identify the teacher knowledge essential to teach with technology. The same authors argue that "teaching is a highly complex activity that draws on many kinds of knowledge (…) including knowledge of student thinking and learning, and knowledge of subject matter" (Mishra et al., 2006,

p. 1020). According to Mishra et al. (2006) PCK exists at the junction of content and pedagogy, and it is how SMCK is transformed to teach. In addition, he states that "This occurs when the teacher interprets the subject matter and finds different ways to represent it and make it accessible to learners" (Mishra et al., 2006, p. 1021).

A few years later, Mishra and Cain (2013) refer to the fact that teaching depends on knowledge in a number of fields: knowledge about student learning and reasoning, curriculum content, and the increasing knowledge of technology. In this regard, they argue that the interaction between several forms of knowledge such as CK, Pedagogical Knowledge (PK) and Technological Knowledge (TK) results in TPACK (Technological Pedagogical Content Knowledge), which they claim as the necessary knowledge to integrate technology with success (Figure 2).

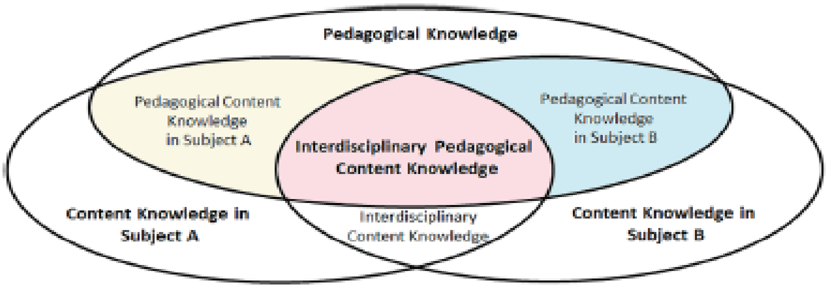
Figure 2
Technological Pedagogical Content Knowledge (Koehler, Mishra, & Cain, 2013, p. 15)



An (2017) sustains that "PCK is a general skillset that collectively focuses on the overlap part between the PK and CK – specifically, how individual topics of subject knowledge are systematized, modified, and exemplified for classroom teaching" (p. 238). Concerning mathematics and science integration, she extends PCK to Interdisciplinary Pedagogical Content Knowledge (IPCK) by referring to IPCK (Figure 3), which "is specified as an explicit knowledge of interdisciplinary pedagogy" (An, 2017, p. 238).

Figure 3

Interdisciplinary Pedagogical Content Knowledge (IPCK) (An, 2016, p. 239)



However, any knowledge background for STEM integration was found. For this reason, we believe there is the need to characterize the necessary knowledge for teachers to be capable of developing STEM tasks in class. With this in mind, in our study, we intend to design a knowledge framework for STEM integration based on preliminary studies about this subject.

Context of This Study

There are four grades of primary school with students aged 6 to 9 years old, from the first to the second grade, where curricular units such as Portuguese, Mathematics or Study of the Environment are lectured by the same teacher. Science themes such as Physics or Biology are included in Study of the Environment together with Geography or History, among others (Costa & Domingos, 2018b).

But, in Portugal, as in many other countries all around the world (e.g., Abd-El-Khalick, 2013), the reality of many classrooms is still traditional teaching, using textbooks and giving priority to disciplines such as mathematics or the native language without promoting interdisciplinarity (Carvalho et al., 2004). For this reason, there is the need to promote teachers' professional development in order to innovate their practices (Costa & Domingos, 2017; Costa et al., 2020).

In the framework of a broader pedagogical project (Costa et al., 2020), since 2015 several Continuing Professional Development Programmes (CPDP) have been designed through a partnership between universities, a local teachers' training centre and elementary schools. All the programmes were approved by the Pedagogical Scientific Council of Continuing Education, which is responsible for the accreditation and evaluation of CPDP in Portugal (Costa et al., 2022). We will discuss data from the first two programmes. The first one consisted of 26-hour face-to-face course with educators from higher education

(Table 1). The second has 13-hour face-to-face course with the educators and more 13 hours of work developed autonomously by the teachers in class (Table 2). In the 2017/2018 school year (same format of the 2016/2017 school year), 38 teachers participated in the CPDP.

Table 1
Topics of Teachers' Workshops, 2015/2016 School Year

Workshops	Participants	Duration
Mathematics & Science: an experimental approach	14	4h
Energy for all: doing maths in nature	13	3h
Discovering sound mysteries	14	3h
MiMa: Mathematics in the making	12	4h
Astronomy	13	3h
Math and science web free games	13	3h
Creative robotics	12	2h
Day to day challenges with units	13	2h
Sharing of good practices	13	2h

Table 2
Topics of Teachers' Workshops, 2016/2017 School Year

Workshops	Participants	Duration
STEM for all: doing maths in nature	38	3h
Technologies to promote STEM learning	39	3h
Discover the mysteries of sound	37	2h 30 min
Discover the mysteries of electricity	38	2h 30 min
Methodologies and sharing of good practices	38	2 h

Both CPDP include sustained duration because they occur for a whole academic year and include a total of more than 20 hours, which according to Darling-Hammond, Hyler, Gardner and Espinoza (2017) is one of the characteristics of effective PD. In addition, teachers need to have the opportunity to explore and experiment with the content to be developed in class in a reflective, collaborative environment where they feel supported (Afonso et al., 2005; Darling-Hammond et al., 2017). Our CPDP is in line with these recommendations because it promotes a collaborative learning environment that supports the teachers during their training. This support is extended to teachers in their classes, either to develop STEM practices, either to see them in action with students.

The CPDP consists of workshops with a duration of two to four hours (Tables 1 and 2). At the end of each CPDP, teachers present a portfolio with a critical account on the CPDP context and about the impact of the training course on their practices, including their proposals and evidence of STEM tasks implemented by them in the classroom with their students (Costa et al., 2020; 2022). About 90 teachers of 15 primary schools aged 35–61 and with more than ten years of teaching experience, attended our CPDP until 2018.

Methodology

In this paper, we use documentary analysis based on the literature and a qualitative methodology with an interpretative approach (Cohen et al., 2007). Data collection consists of participant observation, both during the workshops with teachers in their class and also the portfolios presented by them at the end of each CPDP (Costa & Domingos, 2017; 2019). Moreover, a focus group and semi-structured interviews were carried out to better understand data. First author was a facilitator of the CPDP, which is why she was present in all the workshops. The validity and reliability of the results was ensured based on different sources of data collection and also through triangulation with the second author who is also a researcher and teacher educator.

Participants in this study are six 1st to 4th grade in-service teachers who participated in the CPDP taking place throughout 2015/2016, 2016/2017 and 2017/2018 academic years. Table 3 provides information about six teachers who participated in this study. All names in the table as well in the next sections are fictitious.

Table 3
Characterization of the Participant Teachers in the Study

Name	Age*	Years of Service*	Grade (number of students) *	School Year*
Aurea	62	42	2nd grade (22)	2016/2017
Marisa	48	27	2nd grade (16)	2016/2017, 2017/2018
Anita	52	30	3rd grade (24)	2016/2017, 2017/2018
Luisa	56	37	3rd grade (25)	2015/2016
Mariana	52	30	3rd + 4th grade (16)	2015/2016, 2016/2017
Josefina	42	18	3rd + 4th grade (12)	2016/2017

* Data correspond to the first year of participation of the teachers in the CPDP

In particular, one case study about teacher Josefina will be presented to highlight the knowledge related to STEM integration that she used when implementing tasks in class.

Designing a Knowledge Framework for STEM Integration

The STEM acronym includes the following contents: Science (S), Technology (T), Engineering (E) and Mathematics (M) as observed in Figure 4.

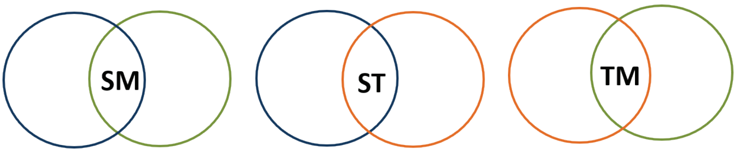
Figure 4

The Four Areas That Integrate the STEM Acronym

Literature presents some examples of interdisciplinarity between some of these contents (Baker, & Galanti, 2017; Ríordáin et al., 2016; Treacy & O'Donoghue, 2014), as shown in Figure 5.

Figure 5

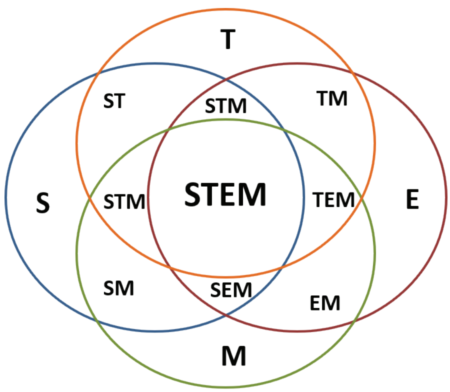
Interdisciplinarity Between Some of the STEM Contents



In our research, we intend to integrate all the STEM contents, which brings increasing challenges since it requires a specialized knowledge related to all of them (Figure 6).

Figure 6

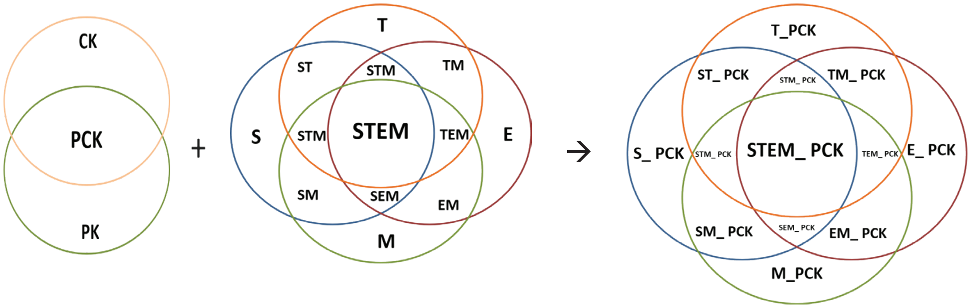
STEM Integration



In preliminary studies developed by the authors of this paper (Costa & Domingos, 2017; 2018), it was found that without SMCK about the content to teach, teachers will not innovate their practices. Also, teachers need to be able to transform the SMCK in order to provide students' learning, which requires PCK (An, 2017; Ball et al., 2008; Mishra et al., 2006; Shulman, 1986). In fact, PCK has been studied regarding several subject matters such as mathematics (Ball et al., 2008), science (Luft et al., 2015; Park & Oliver, 2008), or technology (Koehler et al., 2013). However, we did not find any knowledge background for STEM integration. Based on literature and on our preliminary works, we propose the following Knowledge categories that are necessary to promote STEM integration in primary school (Figure 7).

Figure 7

Knowledge Categories for STEM Integration



Based on research from the CPDP, in the following sections we develop the above model to characterize the knowledge that is necessary for primary teachers to be able to implement STEM integrated handson tasks in class.

Data Analysis and Discussion

This section describes the insights of teachers about the CPDP and presents teacher Josefina's case study to highlight how she developed STEM hands-on tasks in her class and understand what knowledge she used in that context.

Insights of Teachers on the CPDP

In this subsection, we take into account participant observation and teachers' portfolios that include their reflections and evidence of the work undertaken in class with their students. Teacher Aurea reflects about the impact of the workshops of the PDP (Table 2):

It was essential to attend a training programme to fully configure the way to operationalize content, perhaps wrapped in some opacity, mitigate or resolve some gaps in my scientific theoretical knowledge and that would give me a reflection on Mathematics, Science and Technology themes by meeting with other teachers and theoretical-practical experts, to be capable of designing a better teaching strategy to increase student success. (Aurea, Reflection, January 2017).

In view of this excerpt from the report, it appears that the teacher recognizes that it is crucial to attend such training. The justification for recognizing this fact has to do with "content (…) wrapped in some opacity" which implies the need to update her "scientific theoretical knowledge". From this point of view, there is reference to a theoretical knowledge related to this theme (SMCK), which is apparently unclear to teachers and therefore the need to acquire this knowledge is recognized. Also, it is necessary to "configure the mode of operationalizing content", which justifies the relevance of a practical theoretical format, as mentioned by the teacher. In this way, Aurea refers to the trainers as "theoretical-practical experts", which reflects the context of the CPDP where theoretical content is introduced while teachers perform hands-on practical activities. The "hands-on practical activities" is an important dimension that characterizes the programme. Finally, the teacher states that she intends to "design a teaching/learning trajectory for my class (…) enhancer of the success of my students". This quotation has to do with Pedagogical Knowledge (PCK), since her objective is to adapt the practical theoretical knowledge in order to make it meaningful to her students. This reflection from the teacher implies, not only the reference to a specialized Theoretical Knowledge, but also Practical Theoretical Knowledge and Pedagogical Knowledge to transform SMCK to make sense to the students, promoting their learning about the topics covered. In her final report (June 2017), she concludes by saying that:

> I have reinforced the knowledge necessary to improve my performance in the classroom, using the variations and modulations that were offered to me and that the context of the class requires to be able to develop in the students the idea that we learn by doing and that mistakes are intermediate skills for success (Aurea, Final report, June 2017).

The previous excerpt is illustrative of the acquisition of knowledge to teach, both in terms of SMCK and PCK. Students' knowledge is also taken into account as there is a concern to consider the class context as well as developing students' ideas.

Teacher Marisa, who participated in the CPDP in the school years 2016/2017 and 2017/2018, highlights an "innovative intervention in experimental science teaching" which is related to the integration of "theory and practice during the exploration of activities":

> (…) this action leads teachers to an innovative intervention in the experimental teaching of science in the early years of schooling. This is crucial because it integrates theory and practice while exploring activities, leading teachers to transfer learning from the training context to the application context (classroom) (Marisa, Final report, June 2017).

In the above quote, the integration of "theory and practice" is once again mentioned, which suggests the importance of having an approach that includes this integration. In addition, it is also noted that the teacher states that this CPDP provided her with the ability to apply the knowledge learned "in the context of training to the context of (…) the classroom". This has to do with the impact of the formative context on teachers, which made them gain skills to implement the proposed approach in class. From this point of view, the teacher acquired SMCK and PCK, which allowed her to implement these practices with students.

The importance of developing hands-on experiments with students is also referred to by Anita:

> During the workshops, I realised the importance of performing with my students' activities that permits to build their own knowledge, in a constructive way, involving the manipulation of materials and the execution of tasks that they can observe, question, reflect, experiment and finally conclude (Anita, June de 2017).

Anita's reflection highlights handling materials, which has to do with the hands-on approach of the CPDP. In fact, the three teachers find important to develop this approach and refer to how the CPDP provided them with tactics to execute STEM experiments. Regarding the knowledge to teach, teachers referred to the theoretical practical component and/or integration of theory and practice, which allows to identify a pattern that has to do with the CPDP aimed at implementing hands-on STEM related activities. From this point of view, teachers recognize the need, not only for solid theoretical knowledge of the subjects to be taught, but also "practical" knowledge to implement hands-on tasks related to the topics covered. In addition, pedagogical knowledge is highlighted when they report the acquisition of skills to innovate their teaching practices in class to make the content comprehensible to students.

Based on a preliminary work, Costa and Domingos (2017) discuss the case study of teacher Luísa who participated in the CPDP at the school year 2015/2016 (Table 1). Luísa referred lack of SMCK to perform hands-on science experiments (e.g., electricity experiments) and insecurities about how to implement them: "I'm not comfortable to teach some of the content because I don't have full mastery of concepts and techniques and don't know how to apply them" (Focus Group, June 2016). Also, she was afraid of not being capable of handling "materials used in experimental activities", not knowing what to do if the experiments don't give the "expected results" and not having answers to student questions (Costa & Domingos, 2017).

Teacher Luísa concerns are primarily connected to SMCK but also include PCK since she shows insecurities about how to perform hands-on experiments with the students. In particular, her insecurities are related to a specific specialized knowledge essential to develop STEM hands-on experiments.

At a first stage, theoretical knowledge is critical, for example associated with chemistry, electricity, or biology: TheoCK_S (Theoretical CK essential for teaching Science). However, it is not enough to have TheoCK_S to be capable of implementing hands-on experiments. It is essential to have specialized knowledge to effectively develop hands-on tasks with the students. In this regard, they need to know the equipment and material to use and how to manipulate and complete the experiments. This is specialized technical knowledge, as mentioned by teacher Luísa when she refers "techniques (…) to apply": TechCK_S (Technical CK for implementing Science experiments).

Furthermore, it is not enough to have TheoCK_S or TechCK_S to implement hands-on tasks in class. For example, scientists have those two kinds of knowledge to develop sophisticated experiments in the laboratory, but it does not mean that they have the skills to make that knowledge accessible to students. In order to promote meaningful learning, teachers need to have PCK. In the particular case of this CPDP context, teachers need to have TheoPCK_S (Theoretical PCK essential for teaching Science) and TechPCK_S (Technical PCK for implementing Science experiments) to implement Science hands-on tasks in class and promote students' learning about the content they teach. Those are knowledge categories that are not visible in Lee Shulman or Debora Ball studies, which shows the need to develop research in this matter. Table 4 includes the new categories of knowledge framed in the SMCK and PCK knowledge definitions of the previous authors (Ball et al., 2008; Shulman, 1986).

Table 4

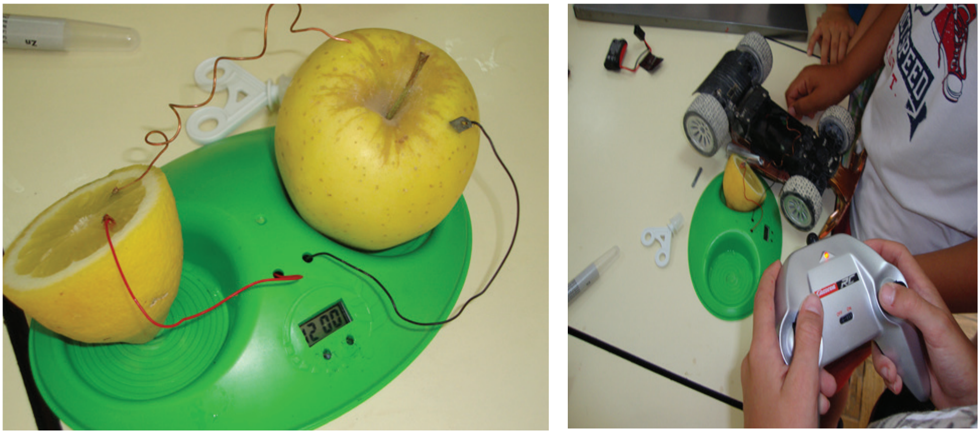
Knowledge Necessary to Implement Hands-On Science Experiments in Class: TheoPCK_S (Theoretical PCK Essential for Teaching Science) and TechPCK_S (Technical PCK for Implementing Science Experiments)

SMCK		**PCK**	
TheoCK_S	TechCK_S	TheoPCK_S	TechPCK_S

Based on the case study of teacher Luísa (Costa & Domingos, 2017), it was verified that she did not have enough TheoCK_S and TechCK_S to succeed in the implementation of science hands-on tasks in class. For this reason, her PK, that results from her 37 years of experience in teaching, was not enough to be able, for example, to develop electricity experiments in class. As a consequence, she also had lack of TheoPCK_S and TechPCK_S. Based on her example, the educators concluded that without TheoCK_S and TechCK_S teachers will not have motivation, confidence or skills to innovate their practices.

Teacher Mariana participated also in the CPDP in the school year 2015/2016. After participating in the workshop about electricity, she was able to perform some experiments with her students. Some of them included fruit to make some equipment work, such as watches and remote controlled cars (Figure 8).

Figure 8
Electricity Hands-On Experiments



One of the tasks developed by the teacher consisted of putting a digital scale to work with a biological battery built with an apple and a lemon, which was successfully performed (Figure 8). Another task was to try to get a remote-controlled car to run on a biological battery, built with half a lemon, but this time it was not successful. This shows that Mariana acquired some knowledge related to electricity. However, she also shows lack of TheoCK_S to implement the tasks effectively. Even seeing that the remote-controlled car didn't work, Mariana couldn't explain to the students why this happened. Despite knowing how to assemble the circuit (TechCK_S), the biological battery did not provide enough power to the remote-controlled car. This last experience reveals the importance of teachers acquiring subject-specific content knowledge to teach, in order to effectively implement practical hands-on science activities (TheoCK_S and TechCK_S). On the other hand, it also shows the need for educators to accompany trainers by promoting their specialized knowledge to carry out these approaches. Although Mariana lacked the theoretical knowledge related to electricity, she was convinced that she had it, so she was not afraid to perform experiments with the students. This is yet another aspect that seems to indicate that when teachers feel confident in teaching the content, they eventually reveal pedagogical knowledge to implement new tasks in class, at least if they have experience based on several years of service.

Mariana also made some reflections about the training course in her final written report:

> We acquired more knowledge to improve our practices in the teaching of science among students: With these practical activities the students could move and handle things and objects, think, reflect, plan, interpret, and discuss the studied situations (Mariana, June de 2016).

The pedagogical knowledge of teacher Mariana stands out when she states:

> We favoured the working group, making them more autonomous, more sociable, and responsible. We did not disregard all the knowledge and conceptions that the students had and that we should take into account as a starting point to any object of study (Mariana, June de 2016).

In this subsection, we discussed the specialised knowledge needed to effectively implement science hands-on experiments in class. All of them referred to the acquisition of new knowledge which will be reflected in class. This is in line with the literature that refers to difficulties with the implementation of STEM education (related to lack of SMCK) and about the need of PDP to help teachers to achieve this goal (Kim & Bolger, 2017; Margot & Kettler, 2019). Next, we present the case study of teacher Josefina, who developed STEM tasks related to electricity (Costa & Domingos, 2019). In the present paper research is about knowledge to teach.

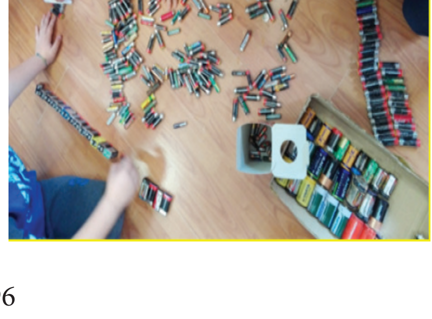
Case Study of Teacher Josefina

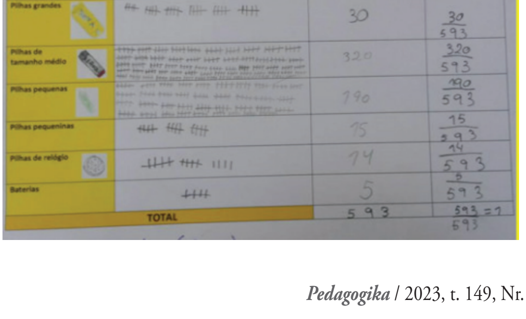
During her participation in the CPDP (Table 2), Josefina decided to develop hands-on tasks related to electricity in class with the educators help (Costa & Domingos, 2019). In the interviews, she referred to the fact that, after participating in the electricity workshop, she searched for more information on the Internet, namely using Wikipedia to find out information about Sustainable Development Goals (SDG). She also used the Internet to buy equipment such as LED lamps or multimeters.

In a first class, she introduced electricity with an emphasis on SDG and showed some videos to motivate them. Next, she asked them to bring old batteries from home that they did not use anymore, and invited students to look for patterns according to shapes and models and organize data on a table (Figure 9).

Figure 9

Collection, Organisation and Processing of Data from the Batteries (Costa & Domingos, 2019)



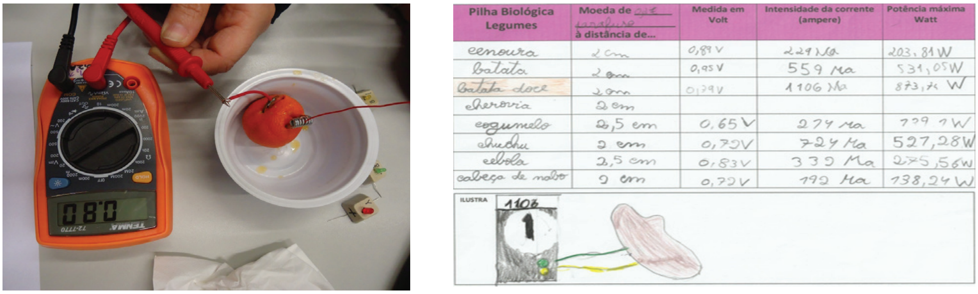


CATEGORIA (Pilhas recolhidas)	Contagem	Frequência Absoluta	Frequência Relativa (fracção)
Pilhas rectangulares		19	19/593
Pilhas grandes		30	30/593
Pilhas de tamanho médio		320	320/593
Pilhas pequenas		190	190/593
Pilhas pequeninas		15	15/593
Pilhas de relógio		14	14/593
Baterias		5	5/593
TOTAL		593	593/593 = 1

In a second class, she introduced theoretical information about electrical current or potential difference (p.d.). Also, students measured the electrical current and p.d. of each battery with multimeters. The batteries without energy were separated to go to the recycling plant and the rest were stored. More hands-on tasks were developed in other classes, such as building electric circuits and lighting lamps (where batteries saved in the previous class were used). Also, she asked students to register the battery's electrical current and p.d. Moreover, biological batteries (built with fruit or vegetables) were introduced, and students also made measurements (Figure 10).

Figure 10

Potential Difference and Intensity Measurements From Fruit and Vegetables (Costa & Domingos, 2019)



Pilha Biológica Legumes	Moeda de ... à distância de...	Medida em Volt	Intensidade da corrente (ampere)	Potência máxima Watt
cenoura	2 cm	0,89 V	229 Ma	203,81 W
batata	2 cm	0,95 V	559 Ma	531,05 W
batata doce	2 cm	0,79 V	1106 Ma	873,74 W
cherovia	2 cm			
cogumelo	2,5 cm	0,65 V	274 Ma	[illegible] W
chuchu	2 cm	0,72 V	724 Ma	527,28 W
cebola	2,5 cm	0,83 V	332 Ma	275,56 W
cabeça de nabo	2 cm	0,72 V	192 Ma	138,24 W

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The tasks were developed using inquiry, as exemplified in the excerpts from the dialogue between the teacher and students (Costa & Domingos, 2019). For example, she asked "What's the p.d. of the orange?". Students answered "0,51 volts" and she asked "How many do you need to get 1,5 volts?". Because the students answered "three", Josefina continued to ask questions and conduct tasks for them to interpret the results. She requested that students cut the fruit into several pieces and measure again. After measuring, students were very surprised with the results: "It's not possible; each piece has almost the same as the whole orange".

Based on the inquiry and experiments, the students concluded that three pieces of an orange were enough to have 1,5 volts. Moreover, students measured the p.d. of fruits and vegetables, and the teacher wrote the results on the board to ask students about the which ones had the highest or lowest p.d.

Based on the discussion above, Josefina was capable of developing STEM hands-on tasks. Indeed, Josefina developed hands-on tasks based on concepts and procedures from mathematics and science while incorporating the design methodology of engineering and using appropriate technology, which revealed SMCK related to STEM (Shaughnessy, 2013). Moreover, mathematics contents emerged when organizing and counting the batteries (Operations with numbers), organizing and drawing batteries with corresponding patterns (Geometry), building tables and organizing collected data (Figure 9). Furthermore, she was capable of leading and guiding students to make them understand SMCK as exemplified in the dialogues above, which reveals PCK. Table 5 shows STEM content developed by Josefina.

Table 5

Contents of the Tasks Implemented by Teacher Josefina (Costa & Domingos, 2019)

Science	Technology	Engineering	Mathematics
Electricity.	Internet Multimeters, lamps, among others.	To plan, design and perform experiments.	Measuring data from batteries. “Operations with numbers” when organising and counting batteries. “Geometry” by organizing batteries regarding patterns as well as drawing them. “Organising data” when registering and organising data collected from batteries.

Finally, in her report (Josefina, June 2017), she refers that she was capable of applying “new practices and methodologies in class” and that the CPDP “enabled me to acquire new knowledge in the context of the classroom”.

Therefore, it is verified that Josefina acquired knowledge to develop the STEM approach. Indeed, she developed several hands-on STEM integrated tasks of the Portuguese curriculum (CuK) included in themes such as Electric Circuits, Technology, “Operations with numbers”, “Geometry”, and “Organising data”. Given the above, teacher Josefina acquired specialized knowledge (SMCK), in order to be capable of introducing STEM integrated tasks related to electricity in class (TheoCK_STEM and TechCK_ STEM). On the other hand, Josefina was able to adapt the tasks in order to promote meaningful learning in her students, what reveals PCK related to STEM (TheoPCK_ STEM and TechPCK_ STEM). Table 6 includes these new categories of knowledge based on the already SMCK and PCK defined by other authors (e.g., Ball et al., 2008).

Table 6

Knowledge Necessary to Implement Hands-On STEM Experiments in Class: TheoPCK_ STEM (Theoretical PCK to Teach STEM) and TechPCK_ STEM (Technical PCK for Implementing STEM Experiments)

SMCK		PCK	
TheoCK_STEM	TechCK_STEM	TheoPCK_STEM	TechPCK_STEM

We argue that the new categories of knowledge identified in Table 6 include the specialized knowledge that is necessary for teacher to be capable of developing and implementing STEM integrated tasks in class with effectiveness.

Final Considerations and Conclusions

In this research, we developed an empirical study in the framework of a teachers' CPDP targeted to lead the teachers to gain knowledge and skills to implement STEM integrated hands-on tasks in primary school. Concerning teachers' professional knowledge, literature presents several studies that include SMCK and PCK related to subject matters such as mathematics, science, or technology (Ball et al., 2008; Magnusson et al., 1999; Mishra & Koehler, 2006). Nevertheless, we did not find any knowledge background for STEM integration. For this reason, research was conducted about the specialized professional knowledge that is necessary for teachers to effectively implement STEM integrated hands-on tasks in class.

In a first stage, based on preliminary works, we proposed a model that includes SMCK related to the subject matters contained in the acronym (Figure 6). In fact, to develop STEM integrated tasks, teachers need to have SMCK related to the subject matters to integrate (Costa & Domingos, 2017; 2018). But it is not enough to have SMCK, teachers need to be able to systematize, modify, and exemplify the individual topics of subject knowledge for classroom teaching, which requires PCK (An, 2017; Ball et al., 2008; Shulman, 1986). The association of these dimensions (SMCK related to STEM and PCK to teach) led to the model proposed on Figure 7.

In a second stage, based on an empirical study for three school years, we realized that the CPDP includes a specific context related to STEM hands-on tasks that requires specialized knowledge for teachers to implement them effectively. Our research revealed that several knowledge dimensions must be taken into account in this approach. First, there is a theoretical SMCK associated with science such as biology or electricity, among others: TheoCK_S (Theoretical PCK essential for teaching Science). Also, a specialized SMCK is needed to implement science hands-on tasks with the students because teachers must handle materials to build the experiments intended to make students understand the contents to teach. Therefore, TechCK_S (Technical PCK for implementing Science experiments) is required for developing this approach in class. For example, teacher Luísa referred to a lack of TheoCK_S and TechCK_S that made her feel insecure to perform science hands-on experiments (Costa & Domingos, 2017). Teacher Mariana revealed lack of TheoCK_S to explain why a certain practical activity did not work. It is not enough to have TheoCK_S or TechCK_S to promote students' learning of SMCK. Also, PCK is critical to make the SMCK comprehensible to students, leading to new categories of knowledge included in Table 4: TheoPCK_S and TechPCK_S.

Concerning the presented case study, we verified that Josefina was capable of developing integrated hands-on STEM tasks (Table 5) that are consistent with the Portuguese primary school syllabus (CuK). Indeed, she developed hands-on tasks based on concepts and procedures from mathematics and science while incorporating the design methodology of engineering and using appropriate technology (Shaughnessy, 2013). In fact, she effectively implemented STEM integrated hands-on tasks in class; i.e., tasks that include all the subjects involved in the STEM acronym through hands-on practices. Her example shows how to develop integrated STEM tasks. To successfully complete the tasks, she used specialized knowledge to implement them in class, as shown in Table 6. In fact, teacher Josefina acquired specialized knowledge in order to be capable of introducing STEM integrated tasks in class (TheoCK_STEM and TechCK_STEM). On the other hand, Josefina was capable of adapting the tasks to promote meaningful learning in her students, for example using inquiry, which reveals PCK related to STEM (TheoPCK_STEM and TechPCK_STEM).

Based on this research, we verified that, in a first stage, teachers need to acquire a specialized theoretical and technical knowledge to be capable to develop STEM integrated hands-on tasks. But in order to effectively implement them in class, they also need to use PCK to transform this specialized knowledge in order to make it accessible to their students. We argue that the new categories of knowledge identified in Table 6 include the specialized knowledge that is necessary for teacher to be capable of successfully developing STEM integrated tasks in class.

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Mokytojų profesinės žinios kuriant STEM integruotas užduotis

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Santrauka

Gamtos mokslų, technologijų, inžinerijos ir matematikos (toliau – STEM, angl. STEM – *Science, Technology, Engineering, and Mathematics*) integracijos į ugdymo procesą skatinimo tikslui pasiekti būtina organizuoti mokytojų profesinį tobulėjimą. Literatūroje pateikiama keletas tyrimų, kurie apima dalyko turinio žinias (angl. SMCK– *Subject Matter Content Knowledge*) ir pedagoginio turinio žinias (angl. PCK – *Pedagogical Content Knowledge*), susijusias su tokiais dalykais kaip matematika, gamtos mokslai ar technologijos, tačiau jokių žinių apie pačią STEM integraciją nepavyksta aptikti.

Šis tyrimas papildo mokslinius tyrimus, nes pateikiama naujų įžvalgų apie žinias, kurių reikia mokytojams įgyvendinant STEM praktines užduotis. Šiuo atžvilgiu trejus mokslo metus buvo vykdomas empirinis tyrimas pagal mokytojų kvalifikacijos tobulinimo programą, kurios tikslas – suteikti mokytojams žinių, reikalingų STEM pobūdžio užduotims įgyvendinti pamokose.

Tyrimui atlikti buvo naudojama dokumentų analizė ir kokybinė tyrimų metodologijos prieiga, turinti interpretacinį pobūdį. Dalyviai – šeši dirbantys mokykloje mokytojai, kurie trejus mokslo metus dalyvavo profesinio tobulinimo programose.

Šis atliktas tyrimas rodo, kad mokytojai turi įgyti specialių teorinių ir techninių žinių STEM praktinėms užduotims rengti. Vis dėlto, norėdami jas veiksmingai įgyvendinti pamokoje, mokytojai taip pat turi išnaudoti ir asmeninę kompetenciją, kad transformuotų specializuotas teorines ir technines žinias ir padarytų jas prieinamas mokiniams. Šiame tyrime nustatytos naujos žinių kategorijos apima specializuotas žinias, kurios yra būtinos mokytojams, kad jie galėtų sėkmingai pritaikyti STEM integruotas užduotis klasėje.

Esminiai žodžiai: *kvalifikacijos kėlimas, mokytojų žinios, STEM, praktiniai užsiėmimai, pradinė mokykla.*

Gauta 2022 02 15 / Received15 02 2022
Priimta 2023 03 24 / Accepted 24 03 2023