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Lesson Study in Initial Teacher Education to Stimulate Pedagogical Content Knowledge on the Speed of Sound

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ABSTRACT

Background: Lesson Study is a collaborative model of teacher professional development that has received increasing international attention from many points of view. **Objectives:** This research aim to contribute to understand the effect of Lesson Study on the pedagogical content knowledge of the pre-service teachers on the speed of sound, at 8th grade. **Design:** This research is a qualitative and interpretative study. **Setting and Participants:** The participants were all pre-service teachers attending the first year of a master program in teaching education in Physics and Chemistry. The Lesson Study comprises two cycles and took place over twelve sessions, in a total of 36 hours of work. **Data collection and analysis:** Data were collected from participant observation of all sessions using field notes and video recording, individual interviews and individual and group written reflections made by the pre-service teachers. **Results**: The results show that this Lesson Study stimulated the PCK in the speed of sound of the pre-service teachers because after diagnosing students' previous knowledge they used this information to the lesson plan; because after the pre-service teachers established a relationship between the thunderstorm phenomenon and students' difficulties they acknowledged that the phenomenon was not suitable for teaching the speed of sound at 8th grade; because after the pre-service teachers established a relationship between the nature of the topic and the students' difficulties they understood the prior knowledge which is required for student learning the topic. **Conclusions:** Results encourage further research towards the generalised use of Lesson Study in initial teacher education.

Keywords: Lesson Study; pedagogical content knowledge; pre-service physics teachers; initial physics teacher education; speed of sound.

Estudo de Aula na Formação Inicial para Estimular o Conhecimento Pedagógico de Conteúdo na Velocidade do Som

RESUMO

Contexto: O Estudo de Aula é um modelo de desenvolvimento profissional que tem sido alvo de uma atenção crescente. **Objetivos:** Esta investigação teve como objetivo contribuir para

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a compreensão do efeito de um Estudo de Aula no conhecimento pedagógico de conteúdo (PCK) na velocidade do som, 8.º ano, dos futuros professores. **Design:** Tratou-se de uma investigação qualitativa com orientação interpretativa. **Ambiente e participantes:** Os participantes foram todos os futuros professores a frequentar o primeiro ano do curso de mestrado em ensino da Física e Química. Este Estudo de Aula teve dois ciclos, compreendendo doze sessões, num total de 36 horas. **Coleta e análise de dados:** Os dados foram coletados por observação participante através de um diário de bordo e registo vídeo de todas as sessões, reflexões escritas individuais e em grupo e entrevistas individuais aos participantes. **Resultados:** Os resultados mostraram que este Estudo de Aula estimulou o PCK na velocidade do som, 8.º ano, dos futuros professores porque após diagnosticarem o conhecimento prévio dos alunos, usaram esta informação para planear a aula sobre o tópico. Também, porque depois de relacionarem as dificuldades dos alunos no tópico com o fenómeno da trovoada, reconheceram que este fenómeno não era o mais adequado para o ensino da velocidade do som, no 8.º ano. Noutra situação, porque ao relacionarem as dificuldades dos alunos na tarefa do tópico com a natureza abstrata do tópico, compreenderam a extensão de conhecimentos prévios que os alunos do 8.º ano precisam de possuir para aprender o tópico. **Conclusões:** Os resultados incentivam a realização de mais estudos sobre Estudos de Aula para o seu uso generalizado na formação inicial.

Palavras-chave: Estudo de Aula; conhecimento pedagógico de conteúdo; futuros professores de física; formação inicial de professores de física; velocidade do som.

INTRODUCTION

Pre-service teachers need to know how to support students in learning science. Achieving this goal is essential because what is taught and how it is taught impacts on what students learn (National Commission on Teaching and America's Future, 1996). Therefore, in initial teacher education, pre-service teachers should develop pedagogical content knowledge (PCK), that is, the knowledge they need to make scientific concepts understandable to students (Shulman, 1986; 1987). The nature of this knowledge has been under scrutiny for several authors. For example, Park and Oliver (2008) consider that PCK encompasses teacher knowledge of the subject content, as well as how to make it understandable to students. Van Driel, Verloop and de Vos (1998) characterize it as the knowledge of scientific and pedagogical concepts integrated in the specificity of teaching practice. Bishop and Denley (2007) emphasize that it is an understanding involving an intricate relationship between the teacher knowledge base and how this is mobilized in the classroom to answer students' questions in an effective way. Considering these broad concepts and approaches, during the 2015 Summit, several researchers proposed a consensus model (Gess-Newsome, 2015) of teacher professional knowledge and skills including PCK. This knowledge is required to plan and teach a lesson about a given topic and grade, and how these are put into practice during a classroom to a specific group of students.

The literature acknowledges that PCK is dynamic and develops as a consequence of the teacher involvement in lesson planning, lesson delivery and subsequent reflection on the teaching methods used and the students' achievements (e.g., de Jong & van Driel, 2004; Gess-Newsome et al., 2017). Nilsson and Loughran (2012) justify that it is difficult

to promote the pre-service teachers' PCK since they are not used yet to reflect about the relationships between the instructional strategies and the students' achievements. In fact, in a study which included twenty-two pre-service science teachers from four countries (Finland, England, Greece and The Netherlands), de Jong et al. (2007) showed that when planning a lesson on combustion, pre-service teachers were able to anticipate some of the difficulties experienced by the students. Nonetheless, when teaching, they did not take this into account. Another barrier to the development of the PCK of pre-service teachers is that they typically still follow a teacher-centered approach and they tend to choose closed tasks for the students (Uşak, 2009). Therefore, it is necessary to support pre-service teachers to plan a lesson and to elaborate effective tasks.

There is evidence that an organized and well-structured combination of the initial teacher education syllabus alongside with school activities promote significant professional development (Cochran-Smith & Lytle, 2009; Zeichner, 2010). This combination is complex, and it is not always feasible. As such, this is a reason why some teacher education programs are not very successful (Zeichner, 2010) in the development of pre-service teachers' PCK (Nilsson and Loughran, 2012). Accordingly, initial teacher education trainings need reinforce the collaboration between the university and the school.

Lesson Study is a lifelong teacher professional development model widely used in the Japan (*jugyo kenkyuu*) (Stigler & Hiebert, 1999). Previous investigations showed that its use as a teacher education process for pre-service teachers is promising to enhance PCK (e.g., Munthe, Bjuland, & Helgevold, 2016; Conceição, Baptista, & Ponte, 2019). However, the results that support these findings are still scarce. This research aims to contribute to a better understanding on the effect of Lesson Study on the pre-service teachers' PCK on the speed of sound, at 8th grade.

THEORETICAL BACKGROUND

After Shulman (1986) conceptualized PCK and Magnusson, Krajcik and Borko (1999) highlighted its importance for teacher professional knowledge, many studies about PCK of pre-service science teachers have been conducted over the last three decades. Currently, is widely accepted the importance of supporting pre-service teachers' PCK on student learning achievements (e.g., Cochran-Smith & Lytle, 2009, Zeichner, 2010) on their relationship with the teachers' instructional strategies (Capps, Crawford, & Constas, 2012). However, it has also been reported that, typically, pre-service teachers still do not assimilate the required PCK. For example, Käpylä, Heikkinen and Asunta (2009) referred that pre-service teachers do not pay enough attention to the students' learning difficulties. Uşak (2009) found that most pre-service teachers explored the cell starting from the microscale to the macroscale, i.e., from the cell to organism, rather than the opposite way. Therefore, Uşak argues that pre-service teachers need to learn how to plan a lesson.

Thus, it is very important that pre-service teachers improve their skill planning lesson ability since their initial teacher education considering different key aspects such as students' previous conceptions as well as teaching strategies, learning goals and the student assessment methodology. Ottesen (2007) argues that educators need to support pre-service teachers through intentional questioning since this systematic and reflective technique allows them to develop their PCK and should become a standard practice throughout their professional activity as teachers. Indeed, Akerson and Donnelly (2010), also reinforce that a reflective attitude is essential for the development of PCK.

Lesson Study is a collaborative, reflective, student-centered model of professional development for teachers originating in Japan (Fujii, 2016). It has since been adapted to other cultural contexts and to the initial education of pre-service teachers (Conceição, Baptista, & Ponte, 2019). In this model, typically, the starting point for the PCK development is related with students' learning difficulties. From this point onwards, participants devise a detailed lesson plan aiming to mitigate that difficulties, lecture the research lesson, carry out an in-depth analysis on the students learning results and reflect on their teaching decisions (Fernandez & Yoshida, 2004). For this reason, Lesson Study has been highlighted in the literature as a promising teacher education model for the development of pre-service teachers (Stigler & Hiebert, 1999). Sometimes, Lesson Study includes a second cycle comprising the research lesson and the corresponding reflection (Fernandez & Yoshida, 2004).

More investigations on Lesson Study of the pre-service teachers' PCK in science are required. Kartal, Ozturk and Ekici (2012) investigated a microteaching Lesson Study during the initial teacher education and found that the pre-service teachers improved their PCK on the topic of energy and temperature, which is known to be challenging for teachers and students. This study assessed PCK based on the pre-service teachers' strategies to help students to minimize their difficulties and misconceptions about the topic. Juhler (2017) concluded that pre-service teachers developed a more student-centered teaching approach after involved in a Lesson Study in physics since their lesson plan start considering more the students' difficulties, misconceptions, preferences and evaluation rather than simply focusing on student behavior. In addition, Akerson et al. (2017) explored the development of PCK in teaching the nature of science in a Lesson Study conducted with pre-service primary teachers and concluded that the participants gave good suggestions about how to teach the topic in the classroom. However, they revealed difficulties in implementing the suggestions. A way to help the pre-service teachers to tackle this difficulty is to promote them to observe an experienced teacher teaching a lesson in the scope of a Lesson Study and to discuss the adopted teaching strategies and their impact on the students' learning.

METHODOLOGY

Participants. The participants of this study were all the pre-service teachers (Christine, Robson and Susan), attending the first year of the master program in teaching

education in Physics and Chemistry. In Portugal, it is required to have a master's degree in teaching to be a teacher. Table 1 presents a summary characterization of the pre-service teachers.

Table 1
Participant characterizations

	Age	Academic graduation	Professional experience
Christine	35	Major degree in Chemistry with a minor in Physics	Private study center
Robson	42		Private school (less than two years)
Susan	34		Private school (less than two years)

Lesson Study adaptations. In this investigation, we attempted to closely follow the Lesson Study model conducted in Japan (Fujii, 2016). However, in the scope of the initial teacher education, Lesson Study requires adaptations since the pre-service teachers were still at an early stage of their teaching career (Conceição, Baptista & Ponte, 2019). Therefore, the sessions of this Lesson Study involved several educators including a professor of the initial teaching training and two researchers from the University that offers the master program as well as an experienced cooperating teacher (Emily) who taught the two 8th grades classes involved in the Lesson Study .The two research lessons were taught by Emily and the pre-service teachers were observers. Since Emily had a deeply knowledge of the students, she played a fundamental role regarding the topic's teaching decisions adopted.

Lesson Study organization. This Lesson Study comprised two-cycle that took place over twelve sessions and a total of 36 hours of work. Table 2 presents the summary of the session activities.

Table 2
Summary of Lesson Study sessions

Session #	Summary
1	Presentation of Lesson Study to the pre-service teachers and topic selection. (*Note*: The topic selected was the speed of sound, 8th grade)
2	Analysis on how the topic is explored in curriculum documents and textbooks and its relationship with other curricular concepts. Analysis of scientific papers about student conceptions of the topic (misconceptions, difficulties, underdeveloped ideas).
3	Solving challenging tasks about the topic anticipating students' learning, their potential difficulties, and their reasoning processes as well as considering meaningful contexts that make science appealing to the students. (*Note*: Challenging tasks are understood as those that may be solved through multiple paths, which may have more than one response, or allow for different problem-solving processes).
4	Development a diagnostic task to evaluate the students' prior knowledge.
5	The cooperating teacher implemented the diagnostic task with the students. (*Note*: This occurred in the 8th grade classes under pre-service teachers' observation).

Session #	Summary
6	Analyses of the answers of students' diagnosis. Identification of previous students' knowledge.
7	Elaboration of the students' task about the speed of sound, for the research lessons. The phenomenon adopted to context the task was a thunderstorm since it is an appealing topic for the students.
	Discussion of the role of the classroom communication in a three-part lesson: task introduction, students' autonomous work, collective class discussion and synthesis (following Chapman, 1997).
8	Development of the lesson plan considering the previous sessions (following Roback, Chance, Legler & Moore, 2006)
9	Teaching the 1st research lesson by the cooperating teacher. (*Note*: Pre-service teachers observed and took notes)
	Analysis of students' learning during the research lesson (session #9) based on the video records segments, students' written productions and the pre-service teachers' field notes.
10	Analysis of students' reasoning and their learning difficulties.
	Elaboration of instructional strategies adjusted to students' needs.
	Improvements of both the students' task and lesson plan.
11	Teaching the 2nd research lesson by the cooperating teacher to another class following the improved plan and task (section #10) (*Note*: Pre-service teachers observed and took notes).
	Analysis of students' achievements during the research lesson (session #11).
12	Analysis of students' reasoning and their learning difficulties.
	Elaboration of instructional strategies adjusted to students' needs.
	Improvements of both the students' task and lesson plan.
	Reflection on the implemented strategies to improve students' learning
	Evaluation of the Lesson Study experience focusing on its strengths and opportunities for the pre-service teachers' PCK.

Figure 1 shows the structure and main activities of the Lesson Study.

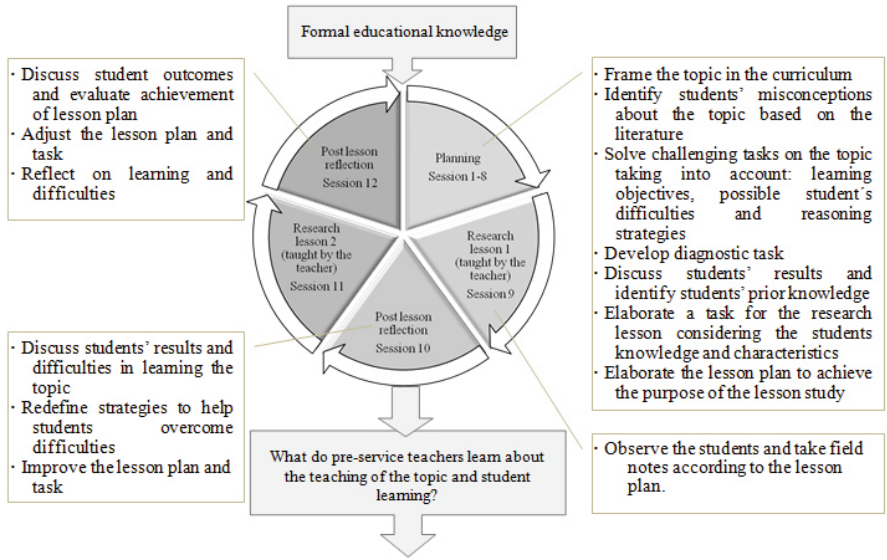


Figure 1. Structure and main activities of the Lesson Study.

Research method. This research follows a qualitative research methodology with an interpretative orientation (Erickson, 1986). That included the data collection from participant observation of all sessions using field notes and video recording (VR). Moreover, data was collected from individual interviews (IIntv) conducted with pre-service teachers at the end of the Lesson Study, from individual written reflections (IWR) by pre-service teachers carried out at the end of the planning stage, and from a group written report (GWR) by pre-service teachers developed at the end of the Lesson Study.

The data analysis underwent three stages. The first stage entailed identifying indicators for coding the data. In the second stage, using the analytical method of constant comparative analysis, key concepts were constructed by identifying categories that would emerge from this analysis (Straus & Corbin, 1998). In the third stage, there was a selection of representative episodes for each category by combining data sources. Our option was intended to search for meanings in the progress of events. Table 3 shows the categories that emerged from the data analysis. The NVivo 11 Professional software was used for data analysis.

Table 3
Analyses categories

Category	Description	Example
Pre-service teachers' learning progress about students' prior knowledge and its implication for teaching the topic.	Pre-service teachers use students' prior knowledge of distance and time interval to anchor student learning at speed of sound.	*"the students already know what distance is. Therefore, we can use this understanding to explore the distance of sound propagation in the task of the students"* (Robson, VR)
		"it is important to know that the thunder propagation time corresponds to a time interval i.e., from 0 to 3 s, because the students often consider that it was the 3 s instant" (Christine, VR)
Pre-service teachers' learning progress about real world phenomena, and implications for student learning.	Pre-service teachers use the thunderstorm phenomenon to engage students in learning the topic.	*"the context chosen for the task was the thunderstorm phenomenon, because we wanted something that students already knew to motivate them to complete the task"* (Christine, IWR)
	Pre-service teachers establish a relationship between the thunderstorm phenomenon and student difficulties	*"in fact, in the first research lesson, I think that identifying the sound source proved to be almost as difficult as the topic itself, thereby making learning difficult, rather than facilitating it"* (Susan, IIntv)
Pre-service teachers' learning progress about other student difficulties and its implication for teaching the topic.	Pre-service teachers elaborate strategies to help students deepen the topic.	*"the students calculate, i.e., they divide the distance by time and cannot grasp the meaning [of the speed of sound]"* (Christine, VR). Robson's strategy to help students understand the meaning of the concept was: *"In 1 s what is the distance covered by sound? Then tell the students that is the meaning of speed"* (Robson, VR)
	Pre-service teachers establish a relationship between the nature of the topic and student difficulties.	*"Looking back, I think it was a difficult topic because the sound is not visible. For students it is difficult to understand that sound propagates in space and takes time. They only learn the topic in depth when they understand the concept of sound wave and how the sound propagates"* (Christine, IIntv)

RESULTS AND ANALYSES

Pre-service teachers' learning progress about students' prior knowledge and its implication for teaching the topic. During the planning sessions (see Methodology, Figure 1) the pre-service teachers diagnosed the students' previous knowledge. About the students' results in the diagnostic task, the pre-service teachers said:

Christine: The strategies used by the students to determine the distance travelled by the ball were diverse. Some multiplied 2 m × 6 units and others added up.

Robson: Yes, and they had a very appropriate reasoning. Almost all students calculated the distance travelled by the ball (VR).

According to the pre-service teachers' perspective, the students showed understanding about one essential concept to understand the speed of sound that is the distance. Therefore, when pre-service teachers designed the task, they considered to use this concept as an anchor for the teaching of the topic. For example, Robson said: "the students already know what distance is. So we can use this understanding to explore the distance of sound propagation in the task of the students" (VR). Accordingly, Christine suggested "the students know the concepts: source and receiver of sound. In addition, as we saw in the diagnostic task, they know to calculate the distance covered by the ball. Therefore, I think they will be able to calculate the distance of the sound propagation autonomously" (VR). Robson's and Christine's suggestion of helping students, to use their prior knowledge to calculate distance of the sound propagation, was very highly considered by the group. Therefore, it was taken into consideration in the design of the task.

During the design of the task, there was also a discussion about how to explore the time of sound propagation. From the perspective of the pre-service teachers, this concept should be explored in a challenging way, since the students showed they understood what it meant when they calculated the speed of a ball in the diagnostic task. According to the pre-service teachers, one way would be to work this concept through a graphic representation as shown in Figure 2 below:

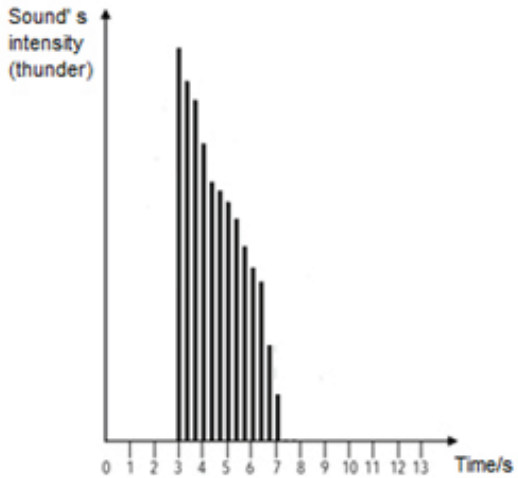


Figure 2. Suggestion for exploring the time interval in the task

For Robson, "the interpretation of the graph makes the whole task more stimulating and more like resembling the resolution of a problem" (IIntv). His suggestion to include a graph in the task in order to explore one of the topic concepts showed that he is more prepared to use challenging tasks in Physics lessons. For Susan, the graph "also represents added value because the students have to interpret it; therefore it is a way to develop other skills" (VR).

Likewise, on the strategy of exploring the time interval through a graph, the pre-service teachers pointed out other aspects that they valued in the teaching of the topic. For example, for Christine "it is important to know that the thunder propagation time corresponds to a time interval i.e., from 0 to 3 s, because the students often consider that it was the 3 s instant" (VR). Agreeing with Christine, Robson added, "with the graph, the distinction between instant and time interval is much more visible to the students and this is necessary for determining the speed of sound" (VR). During the discussion about how to explore the time interval in determining the speed of sound, Christine and Robson showed that they developed PCK on the speed of sound.

In short, students' prior knowledge of distance and time interval has led pre-service teachers to make two important decisions in the task of the students: (1) explore the topic by asking a question in the task related with the distance covered by the sound; (2) explore the time interval in the task in a more challenging way for the students. That is PCK on the speed of sound.

Pre-service teachers' learning progress about real world phenomena and, implications for student learning. In the planning phase (session #3), the context of the task was discussed. This moment enabled pre-service teachers to recognize the importance of starting the task by using everyday contexts. For example, in the IIntv, Robson commented, "the context of the task was chosen with the specific objective of coming from the students' own experiences". Indeed, the pre-service teacher highlighted that learning a concept drawing on situations that are familiar to the students is a way to help them learn the topic in a more meaningful way.

Moreover, in her individual reflection, Susan stated, "contextualizing the learning of the topic with the students' daily life will be helpful for the students". As this pre-service teacher acknowledged the importance of contextualizing learning, she showed understanding of how to make the topic more accessible to her students.

Pre-service teachers also valued the students' motivation in certain contexts. For example, in GWR, they commented that "the students' everyday context encourages them to complete the task" and Christine said, "I think the context for engaging students and allowing them to learn meaningfully is important" (VR). In fact, the pre-service teachers recognized that students' everyday life encourages them to carry out classroom activities, as it allows them to establish connections between science and situations they already know. In addition, as pre-service teachers said, without the involvement of the students, it would be difficult for them to learn the topic in depth.

Subsequently, teachers selected the context of the students' task. Christine, for example, mentioned that "the context chosen for the task was the thunderstorm phenomenon, because we wanted something that students already knew to motivate them to complete the task" (IWR). In fact, lightning and thunder, are everyday phenomena and therefore, in their perspective, they are likely to motivate the students to learn about the speed of sound. Moreover, as Christine mentioned in the IIntv, "we reckoned this would be the ideal context as in this phenomenon of thunderstorm there is a time difference between lightning and thunder which corresponds to the time of sound propagation"

(IIntv). As she referred, one of the topic concepts can be explored from the thunderstorm, which makes it easy to understand why the pre-service teachers have selected it for the context of the task.

The investigation of the students' results, in the first research lesson (session #9), promoted the deepening of the pre-service teachers' knowledge about the thunderstorm phenomenon used to teach the topic. For example, Robson commented that "the major difficulty of students is clearly the sound source, identify the sound source" (VR). In the IIntv, Susan concluded, "in fact, in the first research lesson, I think that identifying the sound source proved to be almost as difficult as the topic itself, thereby making learning difficult, rather than facilitating it". Actually, pre-service teachers admitted that identifying the sound source of the thunderstorm is complex and it was very difficult for the students.

This has initiated a discussion about the strategies that could help students overcome its difficulties. In one of these discussions, Robson remarked that:

> What was intended for the students was that they realized that the distance travelled by the sound corresponds to the distance from the sound source to the sound receiver (...). If the sound source is identified in the text of the task, the issue of sound source identification no longer exists (VR).

Robson's suggestion to help students to overcome difficulties was highly considered by the group. Accordingly, it was decided to clarify the sound source in the introductory text of the task.

Furthermore, the context raised other difficulties that were also relevant for the pre-service teachers. For example, in the IIntv, Susan said:

> The students would be expected to realize that the moment they saw the lightning, the sound had also started, but they did not hear the sound at that moment, they only heard it later. I think that failing to notice this is a problem. This is what often happens with the atoms in chemistry. What they cannot see is much more difficult to understand.

Learning about the difficulties of the students raised by the thunderstorm encouraged the pre-service teachers to redefine their teaching strategies, as they tried to make the topic more comprehensible to the students.

This was also visible, for example, when Robson commented that "I had already pointed out that one of the aspects to be included in the classroom, more precisely in a collective discussion, was the simultaneity of the lightning and thunder phenomena for the understanding of what happens at the $t = 0$ instant". Likewise, Robson also suggested that given the "importance of realizing whether students understood that the two phenomena,

thunder and lightning, began at the same time (...), the task should include a question related to this fact" (IWR).

Thus, identifying the difficulties the students had regarding the thunder phenomenon when learning the speed of sound and trying to understand what caused such learning difficulties led the pre-service teachers to discuss strategies to help the students. These activities allowed pre-service teachers to develop their PCK in the topic.

The knowledge that pre-service teachers have deepened about the students' difficulties (e.g. with regard to the sound source of the thunderstorm and in recognizing that sound had been produced when it had not yet been received) allowed them to develop a critical perspective on the context of the thunderstorm for the teaching of the speed of sound. For example, when asked about their suitability, Susan noted, "this context adds to the difficulty of teaching the topic" (IIntv). In her opinion, it would be possible to change the context by "choosing a context where the sound source was easier to perceive" (GWR). Furthermore, in the IIntv, Robson mentioned that they "ended up taking the context of the thunderstorm on because it was too complicated to start the whole process all over again, but if we could go back, we might have chosen a different context".

In short, the discussion about the context for the teaching and learning the topic enabled pre-service teachers to recognize its importance in science teaching. What they learned led them to select the thunderstorm as the context of the students' task. The in-depth analysis of student learning enabled the pre-service teachers to understand that the context (flash and thunder) raised difficulties, which made them look for strategies to help the students. These activities enabled pre-service teachers to develop their PCK in the topic. This knowledge was again visible when they reflected on the suitability of the context for the teaching of the speed of sound, recognizing that the nature of the phenomenon did not help students learn the topic as expected.

Pre-service teachers' learning progress about other student difficulties and, its implication for teaching the topic. The diagnosis of the students' knowledge (session #6) allowed the pre-service teachers to identify difficulties evidenced when determining the speed of a ball. For example, with regard to a question of the diagnostic task, Christine mentioned that:

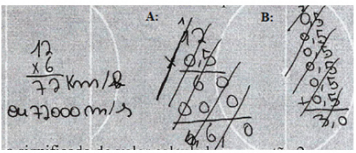
"He started by identifying the concepts, distance (12m) and time (0.5s). After that, he multiplied the two values instead of dividing them. In the end, he crossed out the answer [A], later he tried to add all of the seconds adding up 0.5 six times [B] (...), but he still felt that it is not correct, so then he ends up doing 12 × 6. I don't really understand the six value. Shall be the 6 divisions of the scale? And then he puts the result in kilometres per hour and just stops there" (VR).	Question 2. Determine the value of the speed when the ball entered the goal. Show all of your calculations.  Solution: The speed of the ball when it entered the goal was 72 km. (Student written production)

Figure 3. Sample video recording and student written production

By realizing that the student's attempts to calculate the speed of a ball were not successful, Christine showed she was aware of his difficulties regarding a key concept of the topic. Reflecting on the difficulties of the students in the diagnostic task was new for the pre-service teachers. In addition, enabled them to identify the essential concept of the topic the students were struggling with and to discuss strategies that the cooperating teacher could use before the research lesson (session #9). By the way, in his individual reflection, Robson stated that:

> It was decided that the cooperating teacher would have to start a collective discussion about the students' difficulties in the diagnostic task. Especially concerning the determination and the meaning of speed. Understanding the speed concept is critical to learn the speed of sound.

In the first post-lesson reflection session (session #10), the analysis of the students' results in the task evidenced difficulties.

In the first lesson reflection session (session #10), students showed difficulties in the topic. According to Christine, "they calculate, i.e., they divide the distance by time and cannot grasp the meaning" (VR). As such, the strategies that could help the students were discussed. Robson suggested one of these strategies, when he said that after the students calculated the speed of sound, the cooperating teacher could start a collective discussion by asking the following question to the students and allowing thinking time:

> In 1 s what is the distance covered by sound? Then tell the students that is the meaning of speed. Then reinforce that if in a second the sound travels 340 m, this means that in 2 s it will travel... twice as much and so forth. In addition, take the opportunity to emphasize the constant value of the speed of sound in the air (VR).

Robson's strategy to help students understand the meaning of the speed of sound has shown that he values student reasoning and in-depth understanding of the topic. In addition, Robson acknowledged that teacher questioning was one of the strategies to use in teaching the topic.

However, according to the pre-service teachers, the difficulty in understanding the concept of speed had not been completely overcome by the students, despite a long teacher discussion about possible strategies to help them understand the concept of speed. Some of which were actually put into practice in both the research lessons. As Christine mentioned in the IIntv:

> We also discussed how we could improve the task, the formulation of the last question about the meaning of the speed of sound, but we concluded that there is no other way of asking this question and that it was important.

Issues such as those that raised by Christine on student difficulties, which have left the pre-service teachers without strategies, showed them how much knowledge students need develop for the understanding of a new concept. In his reflection, Robson was sensitive to this fact as he commented "the set of concepts that are necessary to learn subject content makes it difficult for the students to learn what is expected from them".

Moreover, pre-service teachers have also developed a broader understanding of the topic and of student learning needs. This was also evident, for example, in the IIntv, when Christine acknowledged that: "Looking back, I think it was a difficult topic because the sound is not visible. For students it is difficult to understand that sound propagates in space and takes time. They only learn the topic in depth when they understand the concept of sound wave and how the sound propagates". By recognizing links between the topic and other complex curriculum concepts, which the students are learning now to only deepen later (e.g. the concept of wave, what sound is and how sound propagates), Christine deepened her PCK in the topic.

In the IIntv, Robson also showed that he had become more knowledgeable when he referred that "putting myself in their place [the students'], helped me understand what concepts to focus on and how I should work with the students so as to mitigate their difficulties".

In short, the students' achievement provided evidence that it was hard for them to determine speed and understand its meaning. This situation enabled pre-service teachers to acknowledge the fact that they needed to help students learn this concept prior to the research lesson. Following the lesson study, the analysis of the students' results in the task showed to the pre-service teachers that the students continued to have difficulty understanding the meaning of speed. Such a situation led the pre-service teachers to discuss teaching strategies to help students. Having found out that certain difficulties persisted despite their efforts, allowed pre-service teachers to develop a broader understanding of the topic and, of the learning needs of the students.

DISCUSSION

The results of this study show that the pre-service teachers developed the PCK on the topic at different moments of the Lesson Study. This was shown in different phases: planning phase when pre-service teachers used students' prior knowledge to develop instructional strategies on the topic; in the post-lesson reflection phase when they connected the instructional strategies and the nature of the topic with students' difficulties. These results are consistent with those obtained by Kartal, Ozturk and Ekici (2012) in a microteaching lesson study and by Akerson et al. (2017) in other teacher education model. In these two studies, pre-service teachers also made relevant suggestions to help students learn a science topic. In the present study, the results go further, as they showed how pre-service teachers developed their PCK on the topic.

A factor that stimulated the pre-service teachers PCK on the topic was the analysis of the student written production. For example, the analysis of the diagnostic task allowed the pre-service teachers to recognize that the students understood two basic concepts: distance and time interval. This led the pre-service teachers to suggest strategies for the teaching of the topic. One of the strategies was to start the teaching the topic with a question about distance. Another strategy was to make the task more challenging by applying the time interval through a challenging representation in the task of the students. A second example, the analysis of the student achievement in the task of the topic raised the pre-service teachers' awareness of the need to find strategies to help the students understand the speed. Having found out that the understanding of this concept had raised learning difficulties, regardless of the pre-service teachers' efforts to help the students, enabled these pre-service teachers to better understand the extent of prior knowledge that is required for student understanding the topic. A third example, the analysis of the students' difficulties in the phenomenon of the task led the pre-service teachers to understand that this phenomenon (a thunderstorm) was not appropriate for teaching the topic.

In studies in other teacher education models, pre-service teachers also identified student difficulties (e.g., Nilsson & Loughran, 2012), nonetheless they found it difficult to define strategies to promote student learning. This shows the potential of the lesson study in developing pre-service teachers' PCK on the speed of sound. These findings evidence the potential of researching a lesson focusing on the students, thus bringing together research and classroom practice (Abell, 2007). This liaison, supported by empirical evidence, is consistent with the study by Fernández (2005) in a microteaching lesson study with future mathematics teachers. In this study, the author also concluded that lesson planning, observation and reflection upon the student results, as done in the present study, facilitated the connection between research and teaching practice.

In this Lesson Study, the support of the educators to the pre-service teachers proved important for the development of their PCK on the speed of sound, at 8th grade. In some sessions, more support was necessary. This was provided, for example, through more persistent questioning in order to identify and include the previous knowledge of the students in the lesson plan, and in aspects related to the communication of the cooperating teacher (such as questioning, feedback, and whole-class discussion). More support was also provided in the development of the task for the students (such as using more open questions), in the more detailed analysis of the results of the students in the task, and in the broader reflection on their difficulties. These findings are consistent with those from previous research in Lesson Study (e.g. Sims & Walsh, 2009) which show that it is necessary to support pre-service teachers in their learning process.

The sessions of the post-lesson reflection phase, were carefully prepared to show sensitive aspects of student learning to the pre-service teachers, by using in-depth questioning. Given that, in this study the findings indicate that the pre-service teachers developed their PCK on the topic as well as a more reflective attitude about the teaching of the topic and student learning (Akerson & Donnelly, 2010). Therefore, the intentional guided questioning conducted by the educators, i.e., cooperating teacher, professor of the

initial teacher training and researchers proved to be effective. In previous studies, pre-service teachers had difficulty in developing a reflective attitude (Myers, 2014), which shows that the deep questioning about students' results conducted by the educators in this study was appropriate.

During the sessions, the pre-service teachers were encouraged to participate actively and their suggestions were always valued and taken into consideration even in situations where there was no consensus. According to the pre-service teachers, the ethos of the sessions was pleasant and motivating and they felt they were active members of the group. These findings are in line with those obtained by Cajkler et al. (2015) with regard to a Lesson Study with beginning teachers and teachers of mathematics and modern languages, in which the participants also developed a sense of belonging to a professional community.

CONCLUSIONS

PCK is a fundamental teachers' knowledge (e.g., Shulman, 1986, 1987; Nilsson, & Loughran, 2012). This study showed that Lesson Study is a promising tool to develop the teachers' PCK since the initial teacher education. This Lesson Study comprised twelve sessions and involved three pre-service teachers supported by educators (an experienced teacher, a professor of the initial teacher training and two researchers). The data collected included field notes and video recording (from participant observation) as well as pre-service teachers' individual interviews and written reflections. These data revealed that the pre-service teachers learned: to devise a lesson plan on a topic, considering students' previous knowledge; to analyse students' written productions; to identify students' learning difficulties and to support students' learning progress on the topic.

In this Lesson Study, pre-service teachers observed two research lessons taught by an experienced teacher. This is considered a very enriching learning experience for them (Isoda, 2010). However, in future investigations on Lesson Studies, pre-service teachers should also teach research lessons. Moreover, it will also be necessary to better understand the role of both the experienced teacher and of the professor in the PCK enhancement in a Lesson Study. In brief, the results encourage further research towards the generalised use of Lesson Study in initial teacher education.

AUTHORS' CONTRIBUTIONS STATEMENTS

JP and MB supervised the project. TC and MB conceived the presented idea. TC developed the theory. TC and MB adapted the methodology to this context, created the models, conducted the activities, and collected the data. TC and MB analyzed the data. All authors discussed the results and contributed to the final version of the manuscript.

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DATA AVAILABILITY STATEMENT

The data supporting the results of this study will be made available by the authors, TC and MB, upon reasonable request.

REFERENCES

Abell, S. (2007). Perspectives: Action research: Inquiring into teaching and learning. *Science and Children, 45*(1), 64-65. Retrieved from http://www.jstor.org/stable/43173047

Akerson, V., & Pongsanon, K., Rogers, M., Carter, I., & Galindo, E. (2017). Exploring the use of lesson study to develop elementary pre-service teachers' pedagogical content knowledge for teaching nature of science. *International Journal of Science and Mathematics Education, 15*(2), 293–312. https://doi.org/10.1007/s10763-015-9690-x

Akerson, V.L., & Donnelly, L.A. (2010). Teaching nature of science to K-2 students: What understandings can they attain? *International Journal of Science Education, 32*(1), 97-124.

Bishop, K., & Denley, P. (2007). *Learning science teaching: Developing a professional knowledge base*. McGraw-Hill Education (UK).

Cajkler, W., Wood, P., Norton, J., Pedder, D., & Xu, H. (2015). Teacher perspectives about lesson study in secondary school departments: a collaborative vehicle for professional learning and practice development. Research Papers in Education, *30*(2), 192-213. https://doi.org/10.1080/02671522.2014.887139

Capps, D., Crawford, B., & Constas, M. (2012). A Review of empirical literature on inquiry professional development: Alignment with best practices and a critique of the findings. *Journal of Science Teacher Education, 23*(3), 291-318. https://doi.org/10.1007/s10972-012-9275-2

Chapman, O. (1997). Metaphors in the teaching of mathematical problem solving. *Educational Studies in Mathematics, 32*(3), 201-228. https://doi.org/10.1023/A:1002991718392

Cochran-Smith, M., & Lytle, S. (2009). *Inquiry as a stance: Practitioner research in the next generation*. New York: Teachers College Press

Conceição, T., Baptista, M., & Ponte, J. P. (2019). Lesson study as a trigger for preservice physics and chemistry teachers' learning about inquiry tasks and classroom communication. *International Journal for Lesson and Learning Studies, 8*(1), 79-96. https://doi.org/10.1080/09500690902717283

De Jong, O. & Van Driel, J. (2004). Exploring the development of student teachers' PCK of the multiple meanings of chemistry topics. I*nternational Journal of Science and Mathematics Education, 2*, 477. https://doi.org/10.1007/s10763-004-4197-x

De Jong, O.D., Ahtee, M., Goodwin, A., Hatzinikita, V., & Koulaidis, V. (2007). An international study of prospective teachers' initial teaching conceptions and concerns: The case of teaching 'combustion'. *European Journal of Teacher Education, 22*(1), 45-59. https://doi.org/10.1080/0261976990220104

Erickson, F. (1986). Qualitative methods in research on teaching. In M. C. Wittrock (Ed.), *Handbook of research on teaching*. New York, NY: Macmillan.

Fernandez, C., & Yoshida, M. (2004). *Lesson study: A Japanese approach to improving mathematics teaching and learning*. Mahwah, NJ: Lawrence Erlbaum.

Fernández, M. L. (2005). Exploring "lesson study" in teacher preparation. In H. L. Chick, & J. L. Vincent (Eds.), *Proceedings of the 29th PME International Conference* (pp. 305-310). Melbourne.

Fujii, T. (2016). Designing and adapting tasks in lesson planning: a critical process of Lesson Study. *ZDM Mathematics Education, 48*(4), 411–423. https://doi.org/10.1007/s11858-016-0770-3

Gess-Newsome, J. (2015). A model of teacher professional knowledge and skill including PCK. In A. Berry, P. Friedrichsen, & J. Loughran (Eds.), *Re-examining pedagogical content knowledge in science education*, pp. 28-42. London: Routledge Press.

Gess-Newsome, J., Taylor, J., Carlson, J., Gardner, A., Wilson, C., & Stuhlsatz, M. (2017). Teacher pedagogical content knowledge, practice, and student achievement. *International Journal of Science Education, 41*(7), 944-963. https://doi.org/10.1080/09500693.2016.1265158

Isoda, M. (2010). Lesson study: Problem solving approaches in mathematics education as a Japanese experience. *Procedia – Social and Behavior Sciences, 8*, 17-27. DOI: 10.1016/j.sbspro.2010.12.003

Juhler, M. V. (2017). The use of Lesson study combined with content representation in the planning of physics lessons during field practice to develop pedagogical content knowledge. *Journal of Science Teacher Education*, *27*(5), 533-553. https://doi.org/10.1007/s10972-016-9473-4

Käpylä M., Heikkinen, J., & Asunta T. (2009). Influence of content knowledge on pedagogical content knowledge: The case of teaching photosynthesis and plant growth. *International Journal of Science Education, 31*(10), 1395-1415. https://doi.org/10.1080/09500690802082168

Kartal, T., Ozturk, N., & Ekici, G. (2012). Developing pedagogical content knowledge in pre-service science teachers through microteacthing lesson study. *Procedia-Social and Behavioral Sciences 46*, 2753-2758. https://doi.org/10.1016/j.sbspro.2012.05.560

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature sources and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome & N.G. Lederman (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education* (pp. 95-132). London: Kluwer Academics.

Munthe, E., Bjuland, R., & Helgevold, N. (2016). Lesson study in field practice: a time-lagged experiment in initial teacher education in Norway. *International Journal for Lesson and Learning Studies, 5*(2), 142-154. https://doi.org/10.1108/IJLLS-12-2015-0047

Myers, J. (2014). Creating reflective practitioners with preserves' lesson study. *International Journal of Pedagogies and Learning, 8*(1), 1-9. https://doi.org/10.5172/ijpl.2013.8.1.1

National Commission on Teaching & America's Future (1996). *What Matters Most: Teaching for America's Future*. Retrieved July 8, 2019 from: https://files.eric.ed.gov/fulltext/ED395931.pdf

Nilsson, P., & Loughran, J. (2012). Exploring the development of pre-service science elementary teachers' pedagogical content knowledge. *Journal of Science Teacher Education 23*(7), 699-721. https://doi.org/10.1007/s10972-011-9239-y

Ottesen, E. (2007). Reflection in teacher education. *Reflective Practice, 8*(1), 31-46. https://doi.org/10.1080/14623940601138899

Park, S., & Oliver, J.S. (2008). Revisiting the conceptualisation of pedagogical content knowledge (PCK): PCK as a conceptual tool to understand teachers as professionals. *Research in Science Education, 38*(3), 261-284. https://doi.org/10.1007/s11165-007-9049-6

Roback, P., Chance, B., Legler, J., & Moore, T. (2006). Applying japanese lesson study principles to an upper-level undergraduate statistics course. *Journal of Statistics Education, 14*(2). https://doi.org/10.1080/10691898.2006.11910580

Shulman, L.S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4-14. https://www.jstor.org/stable/1175860

Shulman, L.S. (1987). Knowledge and teaching foundation of the new reform. *Harvard Educational Review, 57*(1), 1-23. https://doi.org/10.17763/haer.57.1.j463w79r56455411

Sims, L. & Walsh, D. (2009). Lesson Study with preservice teachers: Lessons from lessons. *Teaching and Teacher Education: An International Journal of Research and Studies, 25*(5), 724-733. Elsevier Ltd. Retrieved July 8, 2019 from https://www.learntechlib.org/p/195558/.

Stigler, J.W., & Hiebert, J. (1999). *The teaching gap*. New York, NY: Free Press.

Strauss, A., & Corbin, J. (1998). *Basic of qualitative research. Techniques and procedures for developing grounded theory (2ª ed.)*. Thousand Oaks, CA: Sage Publications.

Uşak, M. (2009). Pre-service science and technology teachers' pedagogical content knowledge on cell topics. *Educational Sciences: Theory & Practice, 9*(4), 2033-2046. Retrieved Decembre 2, 2019 from https://files.eric.ed.gov/fulltext/EJ867376.pdf

Van Driel, J.H., Verloop, N., & de Vos, W. (1998). Developing science teachers' pedagogical content knowledge. *Journal of Research in Science Teaching, 35*(6), 673-695. https://doi.org/10.1002/(SICI)1098-2736(199808)35:6%3C673::AID-TEA5%3E3.0.CO;2-J

Zeichner, K. (2010). Rethinking the connections between campus courses and field experiences in college-and university-based teacher education. *Journal of Teacher Education, 61*(1-2), 89–99. https://doi.org/10.1177/0022487109347671