The development of pedagogical content knowledge of prospective primary teachers in a lesson study

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Abstract

Purpose – To understand how lesson study (LS) can promote the development of pedagogical content knowledge (PCK) of prospective primary teachers. More specifically, to know what PCK prospective primary teachers develop during LS and how this development occurs.

Design/methodology/approach – Following a qualitative approach, this study took place in a teacher education institution where a LS was carried out during the last semester of the academic year with the participation of two prospective teachers, a teacher educator, a cooperating teacher and a researcher.

Findings – The results suggest that prospective teachers may develop PCK when they participate in LS, regarding lesson planning (goals and lesson plan), task design, students' difficulties and solving strategies, whole-class discussions and observation of student learning. This development occurs through the engagement in LS activities that allow prospective teachers to deepen their knowledge.

Originality/value – This study investigates how the development of prospective teachers' PCK occurs during LS, providing knowledge about how different activities of the LS help develop different aspects of PCK.

Keywords Lesson study, Prospective primary teachers, Pedagogical content knowledge, Initial teacher education, Mathematics

Paper type Research paper

1. Introduction

Initial teacher education (ITE) plays a key role in improving the quality of teaching and learning. Given its importance, research in this field has increased in recent years, seeking to promote higher ITE quality (Strutchens *et al.*, 2016). ITE aims to provide prospective teachers with knowledge, dispositions and skills to carry out and reflect on their practice, so they are prepared for the challenging context of change in which they will work in the future. Given that the experiences that are provided during ITE assume great relevance (Leavy and Hourigan, 2016), it is essential to seek to minimise the problems, namely the gap between theory and practice and between university and school (Cochran-Smith and Villegas, 2015). To overcome these problems, it is necessary to integrate effective teacher education processes in the development of prospective teachers, paying attention to the participants' interests and learning goals (Ponte *et al.*, 2017) and focusing on how prospective teachers develop their knowledge (Cochran-Smith and Villegas, 2015). Given that prospective teachers need appropriate training on mathematical and pedagogical content knowledge (PCK) to provide quality teaching and learning, it is important to investigate teacher education processes to be used in ITE that address these needs.

Lesson study (LS) is a formative process that may enhance the development of prospective teachers' PCK (Larssen *et al.*, 2018; Ponte, 2017). Through its reflective and collaborative nature, LS can promote discussions about many aspects of PCK. However, more research is

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needed to better understand the potential of LS for the development of prospective teachers' PCK (Hourigan and Leavy, 2019), particularly how PCK can be developed. This study therefore aims to understand how LS can promote the development of PCK of prospective primary teachers. More specifically, we seek to address the following research questions:

RQ1. What aspects of PCK of prospective teachers develop during LS?

RQ2. How does the prospective teachers' PCK develop during the LS?

2. Pedagogical content knowledge for mathematics teaching

Shulman (1987) indicated that, in their practice, teachers use knowledge about content, the curriculum, students and pedagogical content knowledge (PCK), and the development of this knowledge is fundamental during ITE (Ball *et al.*, 2008). Research by Krauss *et al.* (2008) also shows the importance and influence of PCK development in mathematics teaching.

More specific models of teachers' knowledge have been presented, in which PCK plays an important role. For example, the model of Ball *et al.* (2008) involves PCK and content knowledge, divided into several categories, describing the teacher knowledge and its connections. Seeking to improve this model, Carrillo-Yañez *et al.* (2018) presented the *Mathematics Teacher Specialized Knowledge* (MTSK), including *Mathematical Knowledge* (MK) and *Pedagogical Content Knowledge* (PCK), with *Beliefs* at the centre. The authors divided PCK into: (1) *Knowledge of Features of Learning Mathematics* (KFLM), (2) *Knowledge of Mathematics Teaching* (KMT) and (3) *Knowledge of Mathematics Learning Standards* (KMLS). KFLM concerns how students learn mathematics, including the teacher's knowledge of how students think when solving a task, knowledge of their difficulties in each topic and knowledge of the meaning of theories and perspectives to describe the teaching and learning process. KMT is the knowledge that the teacher needs to select strategies or teaching materials, including tasks, to set the students for them to learn a concept. KMLS is the knowledge regarding curriculum specifications, forms of assessment, standards and learning goals and progressions.

A fundamental aspect of PCK is knowledge about tasks. The analysis, solving, design, discussion and reflection about tasks and the solving strategies and difficulties that may arise, may enhance the development of knowledge about teaching and learning (Ponte *et al.*, 2017). In addition, if prospective teachers analyse students' answers to open-ended tasks, they can also develop their PCK. It is possible to analyse students' thinking by discussing and analysing solving procedures and strategies, leading prospective teachers to develop their knowledge of this aspect (Llinares and Krainer, 2006). Also, prospective teachers identify and recognise students' thinking that may create pedagogical opportunities (Leatham *et al.*, 2015) that are fundamental for the development of their knowledge, specifically about planning and leading lessons. However, there are aspects of PCK that are particularly difficult for prospective teachers to develop. One of these is communication in whole-class discussions (Stein *et al.*, 2008), which can begin with sharing students' work but must include opportunities for students to make connections and obtain new learning.

3. Lesson study in initial teacher education

Research by Clivaz and Ni Shuilleabhain (2019) shows the presence of all aspects of PCK for mathematics teaching through the LS cycle at different levels of their practice. According to Doig *et al.* (2011), in LS, teachers may engage in depth in the study of materials in lesson planning, namely with regard to tasks. According to Leavy and Hourigan (2016), LS is a promising formative process to integrate in ITE to develop prospective teachers' PCK for mathematics teaching. LS has great potential to be used in ITE since it focuses on student

learning, has a research lesson, is a reflective and collaborative process and may support the development of PCK from the perspective of "knowing-how-to-act within a particular classroom context" (Depaepe *et al.*, 2013, p. 22), as it encourages participation in contextualised discussions about teaching issues.

LS helps to minimise some of the challenges and problems of ITE as it creates links between theory and practice (Ponte, 2017). However, constraints may arise, such as available time, logistics and planning issues and the commitment of the participants (Schipper *et al.*, 2020). Previous research gives us some recommendations on how to integrate LS in ITE, such as: the teacher educator should have a clear and defined role and knowledge and experience with LS, the prospective teachers should be involved in the whole LS cycle and consider their learning as resulting from their integration in the process, and the LS should be included in a university module (Ni Shuilleabhain and Bjuland, 2019). However, when making adaptations it is essential to stick to the essence and purpose of LS (Ponte, 2017). Since LS is a complex process, more studies of LS in ITE are needed, namely to understand its impact on prospective teachers (Cajkler *et al.*, 2013).

4. Methodology

4.1 Context and participants

The LS was developed in 2021 in a teacher education institution, in Portugal. The participants were two prospective teachers (Barbara and Jessica), a cooperating teacher (CT), a teacher educator (TE) and a researcher (R) (first author). The prospective teachers were in the last semester of their combined programme for primary education (6–10 years old students) and mathematics and science middle school (11–12 years old students) teachers. They were attending a supervised teacher training practical course in primary school that began with two weeks of observation followed by seven weeks of practice. The prospective teachers decide who leads each lesson, depending on how comfortable they feel during their teaching practice.

The prospective teachers were selected based on the teacher educator's interest and availability to use LS as a formative process alongside the mentoring activity. The cooperating teacher was later contacted, indicating interest and availability to participate in the LS. When the LS began, the prospective teachers had been with the 2nd grade class (7–8 years old) for three weeks, guided by the teacher educator and the cooperating teacher. The prospective teachers only had teaching experience in ITE. As for the relationships between the participants, the teacher educator had mentored the prospective teachers on previous occasions and had worked with the cooperating teacher in a mentoring context. For the prospective teachers and cooperating teacher, this was the first time that they heard about LS.

4.2 LS structure and features

The LS consisted of four phases: (1) goal setting and preparatory study (session 1), (2) lesson planning (sessions 2, 3 and 4), (3) research lesson (session 5) and (4) post-lesson reflection (sessions 6 and 7). Session 1 was dedicated to introducing LS to the prospective teachers and selecting the topic and defining the goal of the lesson. In session 2, the prospective teachers selected, adapted and solved the task. In the next session, the group anticipated solving strategies and students' difficulties and organised the observation. The fourth session was to revise the lesson plan and make some final decisions about the lesson. After the research lesson (session 5), they had two sessions to reflect, session 6, that was immediately after the research lesson and the focus was on students' learning and the prospective teachers practice, and session 7, a week later, centred on the task, the students' answers and the students' learning.

During the sessions, the teacher educator played the role of facilitator, and the researcher was a participant-observer. The teacher educator and the researcher held regular meetings to discuss the ongoing process and to prepare the following sessions to ensure that the prospective teachers were involved in all the work.

Since the research took place during the Covid-19 pandemic, all sessions were online, except sessions 5 and 6. In the first session, the group decided that the research lesson would focus on numbers and operations, specifically on mental calculation, considering the school calendar and the prospective teachers' general plan for teaching practice work. The research lesson was taught by the prospective teachers and the decision on who would lead the research lesson was made at the end of session 3. During the supervised teaching practice, the prospective teachers were in pairs and planned the lessons together. However, they took turns to teach the lessons. Thus, in the research lesson, we decided to keep this methodology.

4.3 Data collection and analysis

This qualitative and interpretive research follows a participant observation design (Jorgensen, 1989). Data were collected by (1) video recording of the sessions (S*x*) and compiling a research journal, (2) semi-structured interviews with the prospective teachers before the LS (II) and semi-structured interviews with all the participants after the LS (FI) and (3) collection of the lesson plan and the final written reflection (FWR) that was carried out within the ITE course in which the LS was integrated.

Although all the data has been analysed, the focus here is on the lesson taught by Jessica, because it was an exploratory task and led to deeper discussions. First, the aspects of PCK that were developed through the process were identified. Then, based on the KMLS, KFLM and KMT elements of the Carrillo-Yañez *et al.* (2018) model and the data collected, five categories emerged: lesson planning – goals and lesson plan (KMLS), task design (KMT), knowledge of students' difficulties and solving strategies (KFLM), whole-class discussion, including prospective teachers' interventions and students' responses (KMT) and observation of student learning (KFLM). The interviews with the prospective teachers were analysed, trying to identify moments that showed a change concerning aspects of PCK that were discussed in the sessions The final interviews of the other participants were analysed to search for changes in the prospective teachers' practice. Finally, the lesson plan and the final written reflection were analysed as documents written by the prospective teachers that provide evidence of contributions to the results.

In this research the anonymity and confidentiality of the participants and institutions is guaranteed, and they participated in this study on a voluntarily and informed basis.

5. Results

5.1 Lesson planning: goals and lesson plan

Before the LS, the prospective teachers referred to the lesson plan as "limiting and sometimes harmful," as they spent "more time writing it down the right way than thinking about it," although they did not consider it "unnecessary" (Jessica, II). The lesson plan format that they usually used contains contents, goals, material, activity description, time and evaluation indicators, and they were guided by the curriculum documents and the textbook. According to Barbara, planning was necessary only when they have difficulty with the content.

During the LS, after deciding on the topic, the prospective teachers planned the lesson in detail, beginning with the definition of the goals and consulting and analysing the curriculum documents:

> Jessica: Maybe the [goal] "compare numbers and make plausible estimates of quantities and sums, differences, and products".

TE: Where were you looking at this?

Jessica: It's, for example, comparing 20 to 21 helps them to make a plausible estimate of the result.

TE: I am not sure that this is an estimation (. . .) It's not rounding to estimate a result, we want them to give the exact result.

Jessica: When they think, for example, "if I'm taking out more it's going to yield a smaller result", isn't that an estimation of the result?

(. . .)

TE: Eventually this can come up, but it's not a direct goal of the task [Figure 1]. (S3)

Barbara and Jessica clarified how to adapt and write the goals from these documents. They mentioned that there were concepts that, in their opinion, were not very clear. The learning goals established were: recognise and memorise basic facts of operations; use different mental calculation strategies including strategies that mobilise numerical relations and properties of operations; and express mathematical ideas orally explaining reasoning, procedures and conclusions. Through the LS, they discussed lesson plan details that they did not usually find important, such as forming pairs. They changed from student pairs based on gender or empathy to criteria related to the students' knowledge and learning, recognising that it is "much more advantageous for them" (Barbara, FI). Other aspects of lesson planning were discussed, such as anticipation of difficulties, solving strategies and whole-class discussion. However, when they wrote the lesson plan, they included broad information, such as "students solve the task, discussing it with their partner and solving the operations" (Lesson plan excerpt), not including most of the topics discussed, e.g. possible students' difficulties and solving strategies.

In the post-lesson reflection, the aspects to be improved in the lesson plan were discussed and they indicated that they continued to only include in the lesson plan what they considered necessary:

> We thought that it was not part of the plan, which we only had to indicate the topic, the general and specific goals, and the description of the activity. We never thought we needed to include all that, although it makes perfect sense (. . .) I think I do the planning for others, I don't do it for me, and this is awful. (Barbara, FI)

After the LS, the prospective teachers agreed that it was important to include more aspects in the plan because they were relevant for the development of the lesson. The activities carried out were important for the prospective teachers to understand "how a lesson should be planned and

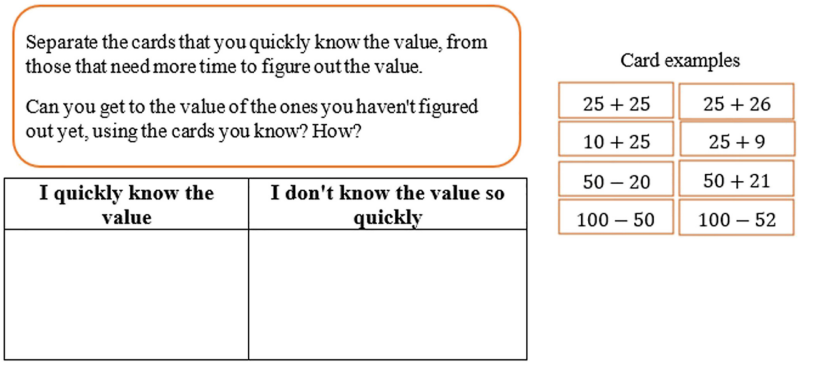

Figure 1.
"Cards with numbers" task and example of cards given to students

structured" (CT, FI) and enabled "greater awareness and reflection of small details that can make a difference" (TE, FI). The LS led to some changes in the prospective teachers:

> It didn't revolutionise the way I thought about lessons, but it showed that [if I planned] the lessons, they would go much better and hence the importance of thinking about the things we are going to do and them having a purpose. (Jessica, FI)

> It's going to change a little bit the way I'm going to plan the lessons from now on (. . .) I'm going to reflect more on what happened and what I can change, what I learned from it, and what I can still learn. (Barbara, FI)

Although the lesson plan was very general, the LS enabled some development in the prospective teachers' knowledge about how to adapt and write the goals and what aspects to pay attention to and include to make a lesson plan and their influence on the successful development of the lesson.

5.2 Task design

Before the LS, when asked about the characteristics of a good task, Barbara highlighted the use of manipulative materials and Jessica mentioned:

> To explore strategies (. . .) [the task] should be more in terms of guidance rather than providing specific instructions (. . .) I am speaking against me, one of our goals is to diversify mental calculation strategies and we thought of an activity where we specifically ask them to use a form of calculation (. . .) We discuss it together, [then] we give a similar situation to see if, using this strategy, they can reach the answer. (II)

The prospective teachers recognised the importance of exploratory tasks but revealed some difficulty in proposing such tasks.

During the LS, in session 1, the teacher educator addressed the characteristics of exploratory tasks. In the second session, each prospective teacher proposed a task that they considered appropriate for the lesson.

> Jessica: This task [cards with numbers–Figure 1] (. . .) I found it very interesting (. . .) A set of operations is given, they have two columns, "I know the value quickly" and "I don't know the value quickly". Depending on what they do, they distribute the operations (. . .) It has an exploratory nature, it's open-ended, they do it in pairs and use various strategies. (S2)

Jessica selected an open-ended task that requires students' reasoning (Figure 1) and development of mental calculation strategies for addition and subtraction, keeping in mind the discussion from the previous session when she searched for the task. After defining this task for the lesson, they solved it and analysed adaptations:

> Barbara: So, I know the value quickly, the 50 minus 20.
>
> Jessica: 50 minus 30.
>
> (. . .)
>
> TE: And do you think this magnitude is all right for the class?
>
> Barbara: They work well.
>
> Jessica: I think so.
>
> CT: I think we can diversify and differentiate levels, maybe two levels. (S2)

When adapting the task, the prospective teachers discussed the operations, the relationships between the cards and organised two groups of cards with different levels of complexity

(magnitude of numbers, operations involved and nature of expressions), as suggested by the cooperating teacher. They also deemed it necessary to reformulate of the wording:

> Jessica: [The statement] said, "I don't know the value quickly". Maybe "I don't know the value that quickly" which gives some encouragement that they can get there, but it's not that fast (. . .) For example, instead of "I don't know", write "more time needed to think to figure out the value".
>
> TE: It gets too big . . . Maybe "the ones you haven't figured out yet".
>
> Barbara: Yes, "haven't figured it out yet" sounds good. (S4)

The prospective teachers reformulated the statement, changing the initial wording as discussed. However, they did not modify the table much, placing only the word "so" in the right column.

The prospective teachers indicated that the research lesson allowed them "to see problems that we had discussed so many times about the task" (CT, S6). Namely, they realised that using "I know quickly" and "I don't know so quickly" was confusing for students despite the modifications made.

In the post-lesson reflection, the prospective teachers mentioned that they selected a task that allowed diversified strategies and introduced a new strategy without a closed task, something they initially reported not knowing how to do. They also discussed points for improvement in the statement.

After the LS, the prospective teachers emphasised the importance of the discussion about tasks for their development:

> This task was discussed in more depth, which also makes things to go better and be more grounded (. . .) I'm going to see what has already been done, what I can do, and see what proposal is more suitable for my class (. . .) Having done that work with that activity, I realised the importance of seeing it in all activities. (Jessica, FI)
>
> The search for activities that fit what we are looking for was one thing that improved (. . .) Involving tasks that have a lot of participation, group work, manipulating something, having a question, and exploring that and then bringing what they explored to the class brings richness to learning (. . .) But you must adapt. (Barbara, FI)

Although the prospective teachers had some knowledge about exploratory tasks, through the LS they developed new knowledge about how to select and propose such tasks and the importance of adapting the task to the context.

5.3 Knowledge of difficulties and solving strategies

Before the LS, when asked about their knowledge of solving strategies, the prospective teachers showed that their focus was on the different strategies that they, as teachers, could present to the students:

> We thought of this task to introduce this strategy, because we honestly can't think of any other way to introduce the strategy (. . .) If I see that a student didn't solve it that way, or that s/he solved it incorrectly, I probably won't give them a voice (. . .) Sometimes we have difficulties in dealing with errors. (Jessica, II)

Jessica mentioned her difficulty in showing students new strategies and exploring errors and different strategies; more than she had thought. Barbara agreed, stating that they had similar difficulties. As for finding out the students' difficulties, the prospective teachers stated that they tried to help students in the lesson when questions arose, looking for "where the problem is" (Barbara, II).

During the LS, the prospective teachers discussed these aspects. First, when they searched for tasks, Jessica mentioned that she looked up articles, reading about difficulties students

experienced and strategies they used. In addition, when they solved the task, they thought about different strategies, trying to anticipate students' solutions and possible difficulties:

> TE: Which of the expressions do you think students will have most difficulty with?
>
> Barbara: 52 minus 29.
>
> TE: On 52 minus 29, let's try to imagine the difficulties that may arise.
>
> Barbara: Difficulties ... Difficulties is in ... In transportation. They can switch (...) They can perform the operation backwards and do 9 minus 2, which is 7. (S3)

The teacher educator made a connection between anticipating difficulties and the solving strategies that students could use:

> TE: What strategy is that difficulty associated with?
>
> Barbara: Decomposition, to decompose.
>
> TE: The decomposition strategy (...) Let's think of another strategy.
>
> Barbara: There's that strategy, I don't know the name, but the teacher or my colleagues will help me, where they add one unit to 29 and it becomes 30, rounding I think (...) They make 52 minus 30 and then they forget to remove that rounding. (S3)

This kind of anticipation came up several times during two sessions, whenever the prospective teachers thought of a different strategy or a difficulty that the students might have.

In the post-lesson reflection, the group discussed the strategies used by the students, the cards they related, the dialogues among students about strategies and difficulties, the understanding of the strategy that was intended to be developed and some students' errors. The group also considered the difference between what the students discussed and what they wrote in their responses and the strategies and difficulties anticipated and not observed.

After the LS, the prospective teachers highlighted the contribution of anticipating strategies and difficulties and reflecting on what they observed on their development:

> To see the different things that could happen and the different ways they could think, knowing how those we are going to teach think helps us. Regarding the mental calculation strategies, I think it was positive, it helped to develop (...) [Anticipating] also ended up deepening the knowledge I had in this regard [solving strategies]. (Jessica, FI)
>
> I really liked working on subtraction strategies, seeing their productions (...) It was good to see that there are more subtraction strategies (...) We had thought that they would use that strategy, then they would come and use that one and use others, and it was very good to keep that in mind and see that because it focused my attention even more. (Barbara, FI)

The prospective teachers developed their knowledge about students' solving strategies and difficulties in the selected topic and understood the importance of anticipating these aspects, trying to do so in the following lessons, showing the contribution of the activities carried out in the LS for a significant change in their practice.

5.4 Whole-class discussion

Before the LS, Barbara and Jessica considered the whole-class discussion very important. They mentioned that they did not feel much difficulty, but mentioned that it was a struggle to manage the time and to guide the students without limiting them or taking away potential from the discussion:

Barbara: Not instructing them [too much] is one of the big difficulties.

Jessica: More [difficulties] . . . Ah, the time! The time management! Knowing that we thought we would last 10 minutes, but we are already going on 20. Is it worth feeding the discussion because it's proving fruitful? (II)

During the LS, although the prospective teachers showed confidence about the whole-class discussion, the teacher educator addressed this topic. They discussed points to pay attention to in the lesson planning that the prospective teachers admitted never having thought much about, starting with the organisation of the board:

Barbara: A good way to expose this is to divide the board into three parts . . . The first is the [cards] that they found easy (. . .) Have the column of the less easy ones to do and the third column of the operations that they used as well.

TE: The disadvantage of having the columns on the board as they are on the statement is that visually it doesn't support establishing the numerical relationships as much. I think it helps more not being columns side by side. (S3)

The prospective teachers realised the importance of planning how to organise the board to help students establish relationships. Then, they discussed the organisation of the discussion:

Jessica: To reinforce this aspect of compensation (. . .) [At the end] we can say that there are several strategies that we can use and explain how everyone can use compensation strategies. Moreover, it may be important to mention what we have already discussed in our sessions, that sometimes they have more difficulty operating when it is in the subtractive than when it is in the additive.

(. . .)

TE: The first card [to share] maybe could be one that they found difficult, but that you see is not as complex as others, following a sequence of complexity.

Jessica: To start with, a card that is easier and that not all pairs found difficult, and then the other cards get more discussion because more pairs found them difficult. (S4)

The prospective teachers clarified questions and ideas, deepening issues such as conducting the discussion, questions to ask students, ways to organise the board and the discussion, sequencing the sharing of strategies and organising the final synthesis.

In the research lesson, Jessica led the whole-class discussion paying attention to what was discussed in the lesson planning. However, she could not engage the whole class and relate the different students' contributions in order to create discussion among them.

In the post-lesson reflection, the group indicated what they felt and what they had observed, as well as strategies for improvement. For Jessica, it was difficult to manage everything that happened and she said that she could have further involved the class in the discussion:

Although it was an enriching sharing experience, from which interesting conclusions and records were drawn, these discoveries and the learning did not reach the rest of the classmates due to the way the communication was carried out. (Jessica, FWR)

However, Barbara felt that her colleague managed the discussion well.

After the LS, this exchange of ideas and opinions led the prospective teachers to analyse their practice:

Aspects that I believe are important to pay attention to in my practice (. . .): To promote moments that involve mathematical communication (. . .) To encourage sharing of strategies, through the implementation of tasks that involve presenting, justifying, and discussing strategies (. . .) To

> promote the development of students' communicative skills (. . .) To mediate students' oral interactions in order to ensure that the communicative message reaches all students. (Jessica, FWR)

The planning of and reflection on the whole-class discussion were important for a meaningful development of the prospective teachers' knowledge about their difficulties and aspects they had not previously thought of, such as the organisation of the board and of the discussion. It also allowed Jessica to reflect on her practice and strategies for improvement in the future.

5.5 Observation of student learning

Before the LS, the prospective teachers mentioned what they focused on when observing student learning:

> Barbara: On their faces (. . .) that's what I try to focus on the most and then their productions that help us understand if the knowledge [was acquired]. (II)

> Jessica: I agree with Barbara (. . .) [but] it's very complicated, even if it's our focus [observing students], it's very complicated (II)

The prospective teachers also mentioned the construction of a table to be filled in at the end of the lesson, with "evaluation indicators" consisting, for example, of "understands the task" and "performs operations using strategy X". They showed concern for observing whether the students understood what they are explaining, but do not pay attention to the student's learning process, only to the final product.

During the LS, the teacher educator asked: "how are we going to do the observation?" (TE, S3). Even though it was decided to take field notes and that each observer would focus on a set of students, the discussion did not continue, showing that the prospective teachers apparently felt comfortable doing the observation. However, in the next session, they were confused about how and what to observe:

> Jessica: In the case of the task that I saw, that had been published, the observers followed up a pair, to do a survey of the strategies, of some of the phrases that they say, is that what those who are observing will do? Or is it just in general?

> TE: We will take notes of things that we hear (. . .) We may ask some questions, to understand the reasoning and the strategies they are using (. . .) To understand how they thought or why, because then they verbalise and we take note of the strategy they are using (. . .) Our focus will be what the students are doing (. . .) What strategies they used, which cards they found difficult . . . (S4)

The prospective teachers clarified what they should focus on in their observation, how they could do it and what stance to adopt.

In the research lesson, Barbara, who was observing, focused on two pairs of students and took notes, considering that this moment "was very enriching" (S7). Jessica, who taught the lesson, photographed the students' solutions at the end, to consult later.

In the post-lesson reflection, they shared their field notes. The discussion addressed the solving strategies students used, difficulties they experienced, relationships established between cards, pair dynamics, students' prior knowledge and then moved on to possible changes that could be made to improve student learning based on what they had observed.

After the LS, the discussions about observation, both in planning and in post-lesson reflection and the possibility of putting what was discussed into practice in the research lesson, enabled a change in the prospective teachers' attitude towards observing student learning:

> It is advantageous for them and for us, to understand where they stand (. . .) To understand what they learned from the activities and I think it is good to talk about what went well and what did not go well for them, what can be improved. (Barbara, FI)

> This part is interesting discussing "look, I noticed that such student did it this way and the other one did it that way" (. . .) To look afterwards at what they learned, how they discussed and, okay, this is what we wanted them to achieve, okay, this is not [what we should do], this yes, this is also very important. (Jessica, FI)

The prospective teachers attributed greater importance to observation and how to do it, focusing on the processes used by the students, rather than on facial expressions and final productions, as they initially reported, showing significant development.

6. Discussion

In this LS, the prospective teachers had the opportunity to develop aspects of Carrillo-Yañez *et al.*'s (2018) three elements of PCK. They developed knowledge about KFLM, through the discussions about difficulties and solving strategies of students and the observation of student learning; about KMT, when they analysed task design and whole-class discussion; finally, about KMLS, through the discussions regarding the curriculum guidelines in lesson planning.

Concerning lesson planning, the prospective teachers did not include all the points discussed in the sessions in the plan. However, the detailed planning of the lesson and subsequent reflection allowed them to realise the importance of including the discussed aspects in future lesson plans.

As for task design, the development of the prospective teachers' knowledge was not as significant because of what they already knew. However, the activities carried out allowed them to improve their knowledge about how to select, adapt and propose exploratory tasks. Ponte (2017) indicates that working on tasks may enhance the development of knowledge about teaching and learning. Through solving the task, analysing the statement and discussing adaptations, the prospective teachers understood the importance of this work for teaching and learning and considered doing it in the future.

At the beginning of the study, the prospective teachers did not anticipate students' difficulties and considered it difficult to include new strategies. In the LS, by researching and solving tasks, anticipating possible solving strategies and difficulties, observing in practice what they discussed and reflecting on students' solutions, the prospective teachers recognised the benefits of these activities for the development of exploratory lessons that value the students' work.

The whole-class discussion was an aspect in which the prospective teachers had difficulty, as is the case with many teachers (Stein *et al.*, 2008). Through the discussions in the planning phase, the practice and the reflection on what happened and what could be improved upon, the prospective teachers identified their difficulties and reflected on points for improvement. This happened especially with Jessica, who conducted the discussion.

Before the LS, the prospective teachers had never given much thought to observation of student learning. When the teacher educator suggested planning the observation, the prospective teachers discussed what they could observe and how. The reflection on what they observed added to their awareness of the value of observing student learning.

The adopted LS structure allowed its integration into a course while maintaining the essence and purpose of this process (Ponte, 2017). The prospective teachers experienced, in practice, aspects discussed in theory, enabling a significant connection between theory and practice, as mentioned in previous research (Larssen *et al.*, 2018; Ponte, 2017), minimising a major problem pointed out with regard to ITE (Cochran-Smith and Villegas, 2015).

It must be understood that the LS does not solve all the problems of ITE, since not all teacher knowledge can be addressed in the LS process (Ponte, 2017). However, it seems to be a formative process that enables the development of prospective teachers' PCK, involving them in planning, teaching and reflecting on a real lesson and deepening several ITE goals

(Ponte *et al.*, 2017). Since the experiences that prospective teachers have in their ITE have great relevance to their practice (Leavy and Hourigan, 2016), the opportunity to use LS in which so many aspects of PCK are discussed, may be beneficial for their preparation for teaching.

7. Conclusion

This research aims to understand how LS can promote the development of prospective teachers' PCK. As they were in the last semester of the ITE programme, the prospective teachers involved already had some knowledge and ideas about mathematics teaching. However, through the initial interview and during the first sessions of LS, it was observed that several aspects of PCK were not clear for them and these were therefore addressed in the LS. The results suggest that prospective teachers (1) develop knowledge about lesson planning when setting the lesson aim, analysing curriculum documents, discussing lesson planning and reflecting on the research lesson; (2) develop knowledge about task design, when selecting and solving tasks, analysing the wording and discussing adaptations, both at the planning and reflection phase; (3) develop knowledge of students' difficulties and solving strategies when searching about the tasks, solving the tasks, anticipating possible solving strategies and difficulties and discussing the solutions of the students they observed; (4) develop knowledge about communication in discussion moments, when planning whole-class discussions, reflecting on the difficulties they felt and observed and discussing improvement strategies during the post-lesson reflection; and (5) develop knowledge about observation of student learning when, during planning, discussing what and how to observe, when observing students in the research lesson, and, in the post-lesson reflection, when discussing and reflecting on student learning. Although the prospective teachers had already planned, taught and reflected on other lessons in previous courses, the way they involved themselves in detailed lesson planning in the LS and their subsequent reflection allowed them to develop aspects of PCK that they had not developed so far.

This research arises from the search to overcome some of the challenges faced by ITE, seeking to improve teacher education and, consequently, the teaching and learning of mathematics. It enabled us to investigate the possibility of using LS integrated into ITE and its potential for developing prospective teachers' PCK. It contributes to understanding what activities to carry out at each LS moment to develop specific aspects of PCK. As such, other teacher educators working within similar programmes may identify and carry out similar LS in their institutions, seeking for improvements in ITE and may have a greater understanding of the development of PCK and how it can be learnt more effectively. A limitation of this study is that it was conducted with only one group of prospective teachers and is not a regular part of the ITE program.

This research sought to deepen how the development of prospective teachers' PCK may occur during LS. Further research may be carried out with other groups and address how, in LS, other aspects of teacher knowledge may be developed, such as mathematical knowledge.

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