DAVID CROSS AND CELINE LEPAREUR

4. PCK AT STAKE IN TEACHER–STUDENT INTERACTION IN RELATION TO STUDENTS' DIFFICULTIES

PCK has been a very successful concept in science education for the last 30 years. Many research studies have used this construct to study teachers' development, teacher initial training and teachers' practice. Although PCK has been very fruitful in providing a framework to identify what could be important knowledge for teaching, very little, if anything at all, is known about the link between PCK and student learning. One of the few studies to attempt to examine this link in science education is the one published by Alonzo et al. (2012) who looked at the PCK of two teachers teaching the same topic in relation to the students' outcome: knowledge and interest. This study not only provides empirical evidence of a link between PCK and student achievement but also offers reasoned speculations about how PCK may actually influence student achievement and motivation. We assume that students' learning relies mainly on their action in the classroom; therefore to understand how PCK enacted in the classroom can influence students' learning we need to understand how PCK can influence students' action. One way of characterising students' action in the classroom is to refer to self-regulation theory (Carver & Scheier, 1998). Indeed, self-regulated learning is a central process to many learning theories and many studies show that this process is positively connected to academic achievement. As far as we know, such a question has not yet been addressed.

CONCEPTUAL FRAMEWORK

We are interested in PCK enacted in the classroom. Although PCK was conceptualised as practical knowledge from the very beginning, the relationship between PCK and action in the classroom is not very clear. We will therefore start by presenting what PCK is before discussing a model of PCK in action.

Teachers' Pedagogical Content Knowledge

In his seminal paper from 1986, Shulman states that one category of knowledge is central for teaching – Pedagogical Content Knowledge (PCK). This category of knowledge is defined as "going beyond knowledge of subject matter per se to the dimension of subject matter knowledge for teaching" (Shulman, 1986, p. 9).

M. Grangeat (Ed.), Understanding Science Teachers' Professional Knowledge Growth, 47–61.

This category of knowledge is linked to other categories of knowledge, defining a knowledge base that a teacher needs in order to teach. Grossman (1990) developed Shulman's model to incorporate this category of knowledge amongst three other categories: general pedagogical knowledge, knowledge of educational context and content knowledge.

As shown by the important number of research studies on PCK over the last 30 years, the idea of a category of knowledge that is specific to teachers, and that links content knowledge with pedagogical knowledge, has been very enthusiastically embraced by education researchers. However, what exactly PCK is does not seem to have reached a consensus (van Driel et al., 1998). Nevertheless, in science education, one model of PCK developed by Magnusson et al. (1999) has been used by many researchers (Friedrichsen et al., 2011). Different components of PCK are described in this model (see Figure 1): 1) orientations towards science teaching; 2) knowledge and beliefs about the science curriculum; 3) knowledge and beliefs about student's understanding of specific science topics; 4) knowledge and beliefs about assessment in science; and 5) knowledge and beliefs about instructional strategies for teaching science. The Orientation component is central and shapes the other components.

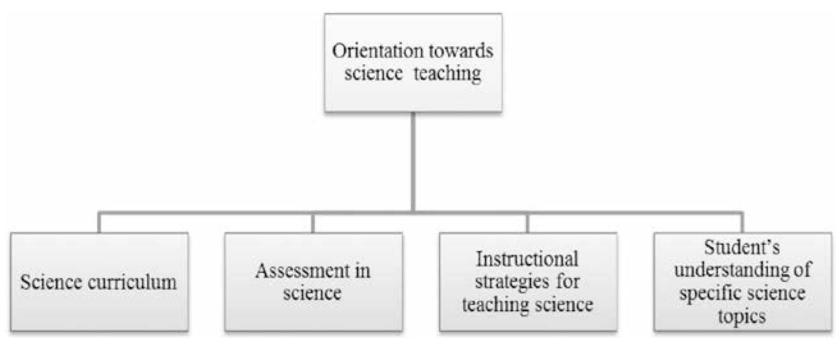

Figure 1. PCK components from the Magnusson et al. model (1999)

In their paper, Magnusson et al. (1999) point out that nine orientations can be defined by providing the goal of teaching science and the characteristics of instruction for each orientation. However, Friedrichsen et al. (2011) have shown that the orientation component lacks empirical and theoretical grounding. Moreover, although the orientation component is described as central in the PCK model, few studies have investigated the ways in which it relates to other components. In the conclusion of their paper, Friedrichsen et al. (2011) argue that the orientation component should be conceptualised as comprising three different elements:

- knowledge and beliefs about the goals and purposes of science teaching;
- knowledge and beliefs about science teaching; and
- knowledge and beliefs about the nature of science.

Another issue about PCK is the way to study it. Based on questionnaires and interviews, the early PCK studies focused on knowledge on action rather than knowledge in action. Since the late 1990s, the research methods show a variety of data and of ways of portraying PCK. For example, the CoRE and Paper method elaborated by Loughran et al. (2004) focus on what teachers are able to say about the teaching of a topic when talking in a group with some colleagues. Another example is given by Park and Oliver (2008) who collected classroom observations, semi-structured interviews, lesson plans, teachers' written reflections, students' work samples, and the researchers' field notes in order to study PCK. These examples show the shift from a knowledge on action towards a knowledge in action point of view that research on PCK has adopted to the extent that some researchers focus mainly on the action of the teacher and the students in the classroom rather than on what the teacher can say about his/her teaching (Cross, 2010; Alonzo et al., 2012).

PCK in Action

We believe that the variety of methods of different models of PCK and action in the classroom for studying PCK is significant. One of the limitations often pointed out when studying PCK from observational data (mainly video data) is that it cannot provide a complete portrayal of PCK (Baxter & Lederman, 1999; Loughran et al., 2004). As video data will show only a small portion of a teacher's activity, Baxter and Lederman (1999) advocate that "When attempting to study a teacher's knowledge of 'best examples', we cannot rely exclusively on observational data as a teacher may use only a small portion of his/her accumulated store of examples during a particular teaching episode. We, as observers, would never see the examples that the teacher decided not to use. In addition, an observation would not reveal why the teacher chose to use some examples while avoiding others" (p. 148). We can see from this quotation that PCK is understood, amongst other things, as teachers' knowledge of "best examples" and the reasons a teacher would decide to use this example rather than another one. Research about PCK should therefore be about having the greatest understanding possible of a teacher's knowledge. Another limitation that is sometimes attributed to observational data is that "[…] myriad factors influence classroom instruction and student understanding. Consequently, the level of consistency between teacher's observed behaviour and their knowledge and beliefs is highly variable" (Baxter & Lederman, 1999, p. 158). In other words, the classroom context might play a role in the action in the classroom, making it difficult to attribute the implementation of a given PCK to a given action.

Concerning the first limitation, we follow Alonzo et al. (2012) when they say that looking at PCK from video data enables us to study PCK when it matters most, that is to say when teachers are interacting with students. Consequently, the aim of the research is not to portray as fully as possible a teacher's PCK, but to understand the role of PCK in the teaching-learning process. It is therefore important to keep in mind that the methods for studying PCK should be consistent with the research questions. Studying PCK from interviews or other self-reported data may be the best way to have a broad understanding and a complete portrayal of a teacher's PCK in order to conceive a teacher training programme. But it would not be sufficient for understanding the role of PCK in teacher-student interactions. We believe that this second limitation is a crucial issue. If the level of consistency between PCK and the action in the classroom is variable, we need to understand what can explain the variability of this level of consistency. One possible assumption is that the context may influence the action, as noted by Baxter & Lederman, but it could also influence PCK itself. Indeed, PCK literature highlights the context-dependant aspect of PCK (Cochran et al., 1993). This assumption is at stake in the model of PCK originating from the PCK summit held in 2012 (see Figure 2).

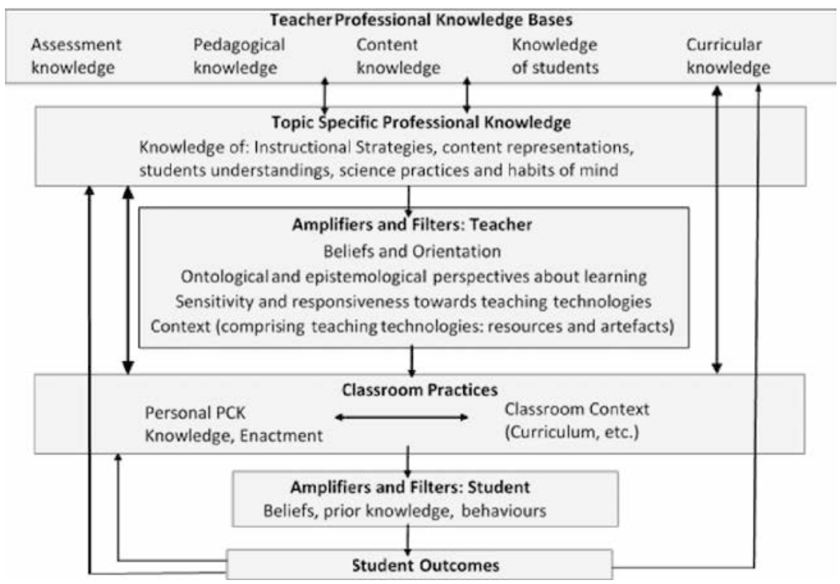

Figure 2. Consensus Model for PCK (after Kind, 2015)

Indeed, in this model the context influences personal PCK, and personal PCK influences the context. The context is also an amplifier and filter of topic-specific professional knowledge. Although we agree with this view about PCK and context, we assume that it is important to clearly distinguish action from knowledge. We would therefore have a different category for enactment rather than having it in the personal PCK category. Another problematic aspect of the PCK summit model is the knowledge category named Personal Professional Knowledge which comprises knowledge of: instructional strategies, content representations, students' understandings, science practices and habits of mind. It is unclear for us how this category is distinct from PCK as many of the components of PCK can be found in the Personal Professional Knowledge category. Thus, we propose a model that takes account of the above discussion and inputs from the PCK summit model:

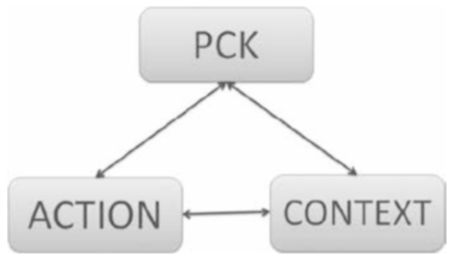

Figure 3. Relationship between PCK, Action and Context

In this model, PCK influences the action in the classroom, but the action also influences the PCK. This is supported by the idea that PCK is practical knowledge, as noted by van Driel et al. (1998, p. 675):

> PCK implies a transformation of subject matter knowledge, so that it can be used effectively and flexibly in the communication process between teachers and learners during classroom practice. Thus, teachers may derive PCK from their own teaching practice (e.g., analysing specific learning difficulties) as well as from schooling activities (e.g., an in-service course on student conceptions). More important, when dealing with subject matter, teachers' actions will be determined to a large extent by their PCK […].

Of course, action will influence context and vice versa. The term "PCK in action" supports the idea that PCK is dependent on a context and is closely related to the action in class.

The Link Between PCK and Students' Outcomes

Alonzo et al. (2012) studied PCK from the interactions between the teacher and students in the classroom. By linking what the students say in relation to what the teacher says, this research opens an important field in PCK research. Indeed, as van Driel et al. (2014) stress, research about the link between PCK and students' achievement is only starting in science education. Most of the research undertaken for the moment uses statistical approaches, and fails to find clear results (Baumert et al., 2010). Maybe this lack of clear results can be explained by considering the model of PCK presented above. Indeed, in this model, students' outcomes are not related directly to PCK but to the teacher's action in the classroom in a given context. Therefore, the question might not be to investigate teachers' PCK as thoroughly as possible by asking questions about a teacher's PCK whatever the context, but to understand how the teacher's action, the context, PCK and students' actions relate to each other. Accordingly, in addition to quantitative approaches that aim to study the impact of PCK on students' learning, a qualitative approach is needed in order to understand how the implementation of PCK can, or cannot, foster students' learning.

Research Questions

Our research questions relate to the above-mentioned model of PCK. We aim to explore the three dimensions of this model: the teacher's action, the context, and PCK. Our research questions rely on two assumptions:

First, that PCK which plays a major role in students' outcomes is PCK enacted in the classroom rather than PCK that a teacher can have but does not enact in the classroom. In other words, we do not focus on PCK as a personal construct (Baxter & Lederman, 1999), but on the teachers' action which will be described as the enactment of a specific type of knowledge, e.g. PCK. We therefore do not attempt to portray all of the PCK that a teacher can have, but only the PCK at stake in a given situation.

Second, to understand in detail how the enactment of PCK in the classroom can play a role in students' outcomes, we need to understand to what extent PCK enacted in the classroom is congruent with the students' action in the classroom, assuming that students' learning relies mainly on their action in the classroom.

Our first question is about the way to describe the action and the context in order to infer PCK. Our second question is about the relations among PCK, the teacher's action, the context and the students' outcomes.

METHODS

Data

Our data consist of a video recording of a physics lesson in grade 8 with an experienced teacher (with more than 15 years of teaching). One camera was pointing to a group of two students, and another one to the teacher, enabling us to grasp the context of the classroom. The teacher was also interviewed after the lesson. The aim of this interview was to clarify the learning objectives and the difficulties encountered. The whole video data and the interview were transcribed.

The aim of the lesson was for the students to make an electric circuit and to do some tension measures of the different components of the circuit. From these measures they had to identify the characteristics of each component. These components are a lamp, a switch, a resistor, a generator and a multimeter. The teacher is used to distributing the equipment needed for the activity in a basin. Not all of the elements in this blue basin are useful for making the circuit. The students make the circuit by using their activity sheet that contains a list of components and their description, but also an electric diagram.

Process

Our analysis consists of several steps:

First Step: Analysing the Students' Activity and Selecting Privileged Moments

Analysing the students' activity. From the field of psychology of learning, the concept of self-regulated learning (SRL) is an important theoretical development which relates the way in which independent learning skills help students to learn (Whitebread & Grau Cárdenas, 2012). As many research studies show that this process is positively connected to academic achievement, we have chosen to analyse the students' activity within this framework. According to the self-regulation theory, highlighting the cybernetic control approach introduced by Carver and Scheier (1998), behaviour is organised around goals and the subjects have expectations regarding the possibility of achieving these goals. According to their expectancies and their perception of where they are according to the goal, subjects will measure (comparator function) the discrepancy between their current state and the goal to be achieved. Subjects will therefore act towards a given goal and implement a set of strategies to reduce this gap. These actions will have effects on the environment. These returns of the environment will constitute the feedback. They are crucial because they provide information on the discrepancy vis-à-vis the goal, the effectiveness of the actions and what remains to be done.

First, the whole video data were coded using keywords corresponding to the students' actions, especially the 'feedback loop' when they implement self-regulated learning strategies. These keywords refer to: (1) the goal and sub-goals to be achieved; (2) the assessment of their current state (related to their progress in the task and their level of understanding); and (3) the set of strategies implemented to reduce the gap. This enabled us to identify when students are engaged in the activity and when they encounter difficulties in progressing in the task. This can be observed when there are little or no solving strategies implemented by students. Second, the teacher's actions are encoded according to the feedback (verbalisation or behaviour) given to the students:

- does it refer to the goal to be achieved?
- does it refer to progress in the task?
- does it refer to the strategies implemented by the students?

Finally, we encode if the provided feedback corresponds to a student's question or if it is initiated by the teacher himself.

Selecting a privileged moment. Since video data have the particularity of presenting a lot of information due to the density and length of this type of data (Tiberghien & Sensevy, 2012), we need to select a moment of the video in order to analyse it deeply. We assume that a possible rich moment of the classroom for implementing PCK would be when students encounter difficulties.

The analysis of the students' activity enabled us to select such a moment, where the students are:

- waiting for feedback from the teacher
- questioning themselves about their understanding
- not implementing solving strategies
- showing signs of demotivation

Second Step: Inferring PCK From the Teacher's Action and the Context

Analysis of the context. The first step in analysing the context is to understand what the difficulty was for the students. For this, we analysed the whole video of the students. It appears that the students plugged in the voltmeter in a series and did not plug a generator into their circuit. From the video, what can be understood is that one of the students believes that the voltmeter is a generator. The following excerpt illustrates this confusion:

> Student 2: I don't know what we are doing wrong, anyway it's written here, look we need a table generator, this, wires. *(Student 2 points to the voltmeter as he says "a table generator")*

How can this confusion be explained, knowing that the students had already used the voltmeters and made this type of circuit? All of the equipment necessary for the activity had been distributed at the beginning of the lesson by the teacher in the basin, except for the generator. The generators the students had to use were 'table generators', which means they are built into the table, and are therefore not directly visible to the students. Besides, the students were used to working with batteries with this teacher, even in previous years. This assumption is evidenced by the students' questions to the teacher while she is handing out the equipment at the start of the session:

Table 1. Excerpt number 1

S3	Miss, but where is the battery?
T	so we're going to use the table generators
S4	and where are the table generators
T	thus if you do a circuit you wait for me to plug it in
S2	there is no battery in the…
S5	and where are the table generators?

Therefore, we believe that the students used the voltmeter as a generator by default as they did not see a battery or a generator in the basin. This confusion of the students can be modelled by the didactical contract (Brousseau, 1997; Caillot, 2007). The didactical contract refers to a system of expectations between the student and the teacher, which gathers the current habits (rules, norms, capacities) relating to the knowledge at stake, and which constitutes the students' current strategies. The strategy implemented here by the students could be formulated as: "Use what's in the basin to make the circuit". This strategy relies on an element of the didactic contract rooted in the teacher's habit of handing out the experimental device in the basin at the beginning of each laboratory work session.

Analysis of the teacher's action. The teacher's action is analysed in relation to the context, based on three moments. The first one corresponds to excerpt 1 (see Table 1), when the teacher is handing out the experimental device to the students. The second one (excerpt 2, see Table 2) is an interaction between the teacher and the group of students which is being filmed. During this episode, the students ask the teacher to validate their circuit. The teacher points out to the students that there is a problem with the voltmeter, and asks them to think about it. The third moment (see Table 3) corresponds to the moment when the teacher comes back to the students. Meanwhile, the students have spent nearly 10 minutes trying to solve the problem.

We point out that the teacher does not explain to the whole class where to find the table generators (excerpt 1). From excerpts 2 and 3 we notice that the teacher focuses on the voltmeter but does not focus on the generator until the problem with the voltmeter is solved. It seems that she only notices the fact that there is no generator in the students' circuit once she has plugged the voltmeter in correctly.

Finally, we can highlight that the teacher asks the students how a voltmeter should be plugged in (theoretically) and then plugs the voltmeter in for the students while thinking out loud (excerpt 3). This last point is important for understanding the task from the point of view of the teacher, which can be understood as:

- (1) students have to make a circuit which has already been made by the students;
- (2) students have to plug a circuit in by applying knowledge about the elements (a voltmeter is plugged in parallel).

Table 2. Excerpt number 2

S2	Miss can we start?
T	are you sure about what you've done?
S1	no
T	come on think about it, first what do you want to do with that?
S1	well we are looking for
T	what do you want to measure?
S2	volts
T	measure volts, how is your device plugged in? Now try to rectify it

Table 3. Excerpt number 3

T	OK your turn
S1	but it's tension so we plug in V and COM
T	yeah it's V and COM theoretically you plug it in?
S1	ah yeah in
S2	series parallel
T	in parallel so here you haven't plugged the device in parallel so it cannot work and if your circuit is to work haven't you forgotten an important element?
S1	the generator
T	OK
S1	see I told you
T	so let's go back to the circuit here I plug there the circuit there you see now we know we're going to plug it in parallel OK and now we're going to see if so there what are you doing go on plug it I'll look where are you going to put it?

Inferring PCK. PCK is inferred on the basis of the analysis of the action, the context and the task and by taking into account Magnusson's categories of the components of PCK (orientations towards science teaching, knowledge and beliefs about science curriculum, knowledge and beliefs about the student's understanding of specific science topics, knowledge and beliefs about assessment in science and knowledge and beliefs about instructional strategies for teaching science). Part of this construction of PCK components is to ask ourselves what the teacher could have done differently, which allows us to take into account the fact that the situation may have guided the teachers' action rather than her PCK. Finally, we look for some evidence of the validity of the construction of the components of PCK in the video data (both the students' and teacher's video). In other words, it is a way to go back to the video data with the lens of the constructed PCK components. This whole process was undertaken jointly by the two authors. Each proposed PCK component was discussed and argued using evidence from the data.

RESULTS

PCK Inferred

From the analysis of the privileged moments two PCK were inferred:

- Students have difficulties plugging in the voltmeter; instead of plugging it in parallel, they plug it in in a series.
- Students do not have problems using a table generator (they know where to find or what a table generator looks like).

These two PCK are from the "knowledge of students' difficulties" category from the Magnuson et al. model.

The first PCK is inferred regarding the teacher's action and the task from the teacher's point of view. Concerning the teacher's action, the fact that the teacher focuses on the voltmeter but does not focus on the generator until the problem with the voltmeter is solved leads us to assume that she does not make a connection between the lack of a generator in the students' circuit and the plugging in of the voltmeter. Moreover, the teacher could have asked the students to explain what they had done, and to describe their circuit. The task that is at stake also contributes to the inference of this PCK. The fact that the teacher asks the students to plug a circuit in that they have already made in a previous lesson by applying knowledge about the elements could be interpreted as an opportunity for addressing a specific difficulty encountered by these students.

The second PCK is inferred based on several aspects; first, on some elements of the context. Students are not used to working with table generators but with batteries. However, the teacher does not first explain to the students what a table generator is or where to find one. She also does not answer the whole class when a student, in a group, asks her where to find the table generator. The teacher could have anticipated the question about the table generators when distributing the experimental device or answered to the whole class about where to find the table generators. These two PCK components are closely linked to each other through the teacher's action. The teacher focuses on the voltmeter and not on the generator as she believes that the main difficulty for the students is to correctly plug the voltmeter in and not to recognise or find a table generator.

Description of the Context

The description of the context is based on the habits of the class, what they had done before, and what these habits enable the students to do; in other words, what are the possible strategies to progress in the task. This description was useful in order to understand the students' actions and their difficulty. We can also include in the context the task from the point of view of the teacher, which was for the students to plug a circuit in by applying knowledge about the elements of the circuit. Thus, the description of the context takes account of the situation from the point of view of the teacher and the students. We think that it is an important feature of our analysis, which we will discuss in the discussion section of this paper.

Description of the Action

Describing the action of an actor of the classroom requires certain decisions from the researcher. Indeed, some choices must be made to select what is relevant in accordance with the research question. We have chosen in this study to focus on the teacher's action in relation to the students' actual difficulty. For this, we concentrated on what the teacher is doing in relation to the voltmeter and the generator. We also focused on what she is doing in relation to the students' strategy to use what is in the basin to make the circuit. In other words, we looked at the teacher's action in relation to the students' action, even though the students' action was not analysed per se but was taken into account in the context by means of the didactic contract.

DISCUSSION

Our results show that 'having' PCK does not mean that the teacher will give effective feedback to the students. In fact, it is a common student mistake to plug a voltmeter in in a series as the ammeter (which must be plugged in a series) is also introduced in the same grade in France. Moreover, the correct use of a voltmeter forms part of the French curriculum. It is therefore an important piece of knowledge for French teachers to know that students have difficulties using a voltmeter. However, in the case we analysed, having this PCK leads the teacher to a false interpretation of the students' difficulty. This result has several implications. First, this means that the relationship between PCK and the students' outcomes is not a linear relationship. Studies trying to relate the amount of PCK a teacher holds to students' outcomes may well never succeed in showing that the more a teacher has PCK the better the students' outcomes. If such a relationship is evidenced, its interpretation should be carefully discussed. Second, in a theoretical point of view, this shows how PCK needs to be understood in its relationship to the context. The situation studied here could be interpreted as if the teacher does not take into account the students' possible strategy to use whatever is in the basin to accomplish the task. This didactic contract aspect of teaching and learning is difficult to account for in the Magnusson et al. model. It could perhaps be included in the orientation towards science teaching category as defined by Friedrichsen et al. (2011) in relation to the sub-category "knowledge and beliefs about science teaching". This brings us to notice that we have only inferred PCK from the "knowledge of students' difficulties" component. We assume that this arises from the fact that we are using a model of PCK that was built more for "PCK on action" than "PCK in action". For example, the category "Knowledge and beliefs on strategies" relates to what the teacher knows about a strategy. But observational data can only inform on what strategy is implemented in a given context. Therefore, this category may not be adapted to study PCK in action. Another reason we did not infer other types of PCK stems from a methodological issue. We have chosen to analyse only one lesson from this teacher. To infer some PCK from the "instructional strategy for teaching science" component, we would need to study this teacher's activity over a longer period in order to spot some regularity in her teaching strategies in relation to the context. We believe that this question of the length of the data is crucial to studying some of a teacher's PCK, especially for the orientations towards science teaching category. In our case, we would need to look at other situations where the teacher does not take into account the effects of the didactic contract to infer that it is part of the orientation component of her PCK.

The use of the didactic contract to understand the situation brings us to include this modelling of the teaching-learning process as part of a teacher's PCK. This point is central to understanding what PCK actually is. As far as we know, the PCK concept is not based on a model of teaching and learning, or at least not on a model that is made explicit or discussed. This may explain why so many definitions of PCK and what exactly comprises PCK can be found in the literature. In our research, we based our analysis on some elements of the Joint Action Theory in Didactics (Sensevy, 2011), which sees the teaching-learning process mainly as a communicative process of a certain kind. In fact, due to the instructional goal given by society to the school, knowledge is at the core of this communicative process. This theory aims to link teaching and learning by postulating that one cannot understand learning practices without understanding the related teaching practices. One of this theory's central features is to consider that the communicational process at the core of the teaching-learning process can be described using the concept of didactic contract. If we postulate that the didactic contract is central in the teaching-learning process, we would need to understand how it can be taken into account in the PCK model. One example of the way a teaching-learning model may influence the conceptualisation of PCK is given in the study by Alonzo et al. (2012). In this paper, the researchers aim to study PCK in action in relation to students' outcomes based on video data. They do not discuss the teaching-learning model they follow to analyse the video data, but the analysis shows they focused on the verbal interactions between the teacher and the students as a describer of the action in the classroom. The researchers came up with three categories of action: flexible use of content, rich use of content and learner-centred use of content. In their discussion, the authors try to relate the description of the action following these three categories to some components of PCK: flexible use of content to knowledge of student learning difficulties, rich use of content to knowledge of instructional representations, and learner-centredness of teachers' use of content to both of the previous components and suggesting that it could be an example of the interplay between these categories. The focus on verbal interaction in the classroom as an important part of teaching and learning in this paper has led the authors to interpret PCK from their categories of description of the action in the classroom. This shows that studying PCK from the action can never be a 'neutral' operation: the theoretical framework used to analyse the teaching-learning process will shape the PCK inferred.

To conclude about the relationship between PCK and student achievement, our research shows that the implementation of PCK can lead, through some filters and amplifiers yet to be studied, the teacher to a wrong understanding of the students' production, entailing feedback that does not allow the students to understand their mistake. We therefore call for some further research about PCK and students' outcomes, especially about which knowledge of a teacher plays a role in the implementation of PCK in a given situation.

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