ALAIN JAMEAU AND JEAN-MARIE BOILEVIN

3. THE DOUBLE LOOP OF SCIENCE TEACHERS' PROFESSIONAL KNOWLEDGE ACQUISITION

The study of teachers' professional knowledge has already been addressed in numerous educational research studies at the international level, both in general and with a focus on science teachers. These research studies often refer to the concept of Pedagogical Content Knowledge or PCK (Shulman, 1986, 1987), which is specific knowledge for teaching that is enriched, in part, by content knowledge (Sensevy & Amade-Escot, 2007). As shown by Abell (2007), most international studies have sought to identify teachers' knowledge based on what they say about their knowledge and their practice. In France, some groups have implemented methodologies that identify PCK based on teachers' actions (Bécu-Robinault, 2007; Kermen & Méheut, 2008; Cross, 2010; Jameau, 2014). Some of these methods emphasise the need to focus on a smaller scale in order to better conceptualise PCK (Cross, 2010; Morge, 2008). In all cases, the original model is rarely discussed because it is either redefined in each study or another theoretical framework is proposed (Abell, 2007).

Further, in recent years a reflection at the international level about the role of experimental activities in science teaching along with an evolution of the purposes of science education have allowed the development of new curricula, accompanied by new teaching practices, such as Inquiry-Based Science Education (IBSE) (Boilevin, 2013a, 2013b; Venturini & Tiberghien, 2012). The different curricula around the world (AAAS, 1989; NRC, 1996; Eurydice, 2006) describe this teaching approach in more or less the same form, but there is no real consensus on the definition of IBSE. The challenge is to renew teaching practices in science and technology (and sometimes in mathematics) by trying to make learning more active and more motivating and by providing more open tasks for the students, which give them greater autonomy (Boilevin, 2013; Calmettes, 2012). Thus, we move from activities focused on laboratory work or on conceptual learning, organised into stereotypical approaches, to education based on open investigations including the elaboration of questions and of hypotheses etc.

In this chapter, we present a model for science teachers' professional knowledge acquisition and compare it with an empirical study based on the implementation of a science course based on an investigation in the French curricula context.[1] IBSE is indeed promising if we assume that its implementation incites teachers to change their practices so as to meet the new requirements. Before we describe the model we

M. Grangeat (Ed.), Understanding Science Teachers' Professional Knowledge Growth, 27–45.

have constructed in detail, and demonstrate its interest, we present the conceptual framework to which we refer.

RESEARCH QUESTION AND THEORETICAL FRAMEWORKS

Our study led us to explore different theoretical frameworks, which we present here. First, we discuss our references on professional didactics for the analysis of the organisation of teacher activity and its accompanying regulation mechanisms. Then, we examine the studies about the PCK concept before presenting the Magnusson, Krajcik and Borko (1999) model, which we used in our analysis. Finally, we present some research concerning the concept of unexpected events.

Teacher Activity/Action

According to Sensevy (2007), the meaning of the word “action” in the phrase “didactic action” refers to acting “whether this is manifest or intellectual, and the general meaning that we give it when talking about philosophy of action” (our translation, p. 5), which Bronckart (2005) calls “any form of oriented intervention from one or more humans in the world” (p. 81). Schubauer-Leoni et al. (2007) emphasised the utility of retaining the elements of articulation between activity and action as they were proposed by Leontiev (1975) and, subsequently, by Bronckart. The latter defined activity as an interpretation of acting at the level of an organised collective and action at the level of a single person. The collective dimension of the activity is driven by *goals*, while the individual dimension of the action is driven by *intentions* and *motivations* that are specific to the reasons for acting. Leontiev (1975) considers realised actions as essential components of human activities. They are subordinate to activities. Activities are carried out through actions and actions respond to conscious goals. These goals are part of the task that he defines as a specific goal in defined conditions (Leontiev, 1975). Actions are realised by operations determined by the conditions of the activity and activities are oriented by a motive, which is a material or conceptual objective satisfying a need (Venturini, 2012).

It is important to differentiate what is related to the task from what is related to the activity in order to study the tasks required of students. The work of Leplat (2004) connects these two elements while showing precisely what differentiates them. He states:

> the task is what there is to do: the goal to be achieved under certain conditions (…), the activity depends on the task and the characteristics of the subject, of the individual, but it can contribute (in return) to the definition of the task and to the transformation of the subject. (p. 14)

Consequently, the activity cannot be studied independently of the task (Vinatier, 2009).

Retroactive Activity Regulation Loops

Leplat (2006) notes that the concept of regulation is often used in texts devoted to the study of activity in work situations. In addition, according to Coulet (2011):

> It is, indeed, difficult to account for activity without insisting on the regulation mechanisms that accompany it. (p. 15)

Consequently, Leplat (2006) proposes a definition and a model that allows him to show how a model of regulation can highlight some aspects of the activity. He mentions a few of the main types of regulations that he classifies as retroactive and proactive regulations: the first type is based on results, the second on anticipation. Coulet (2010) adds that:

> The function of proactive regulations is the adjustment of a scheme with regard to the specificity of the situation through the variability of the actions performed, while retroactive regulations show the reorganization of the activity as a result of the feedback of the action taken into account by the subject. (p. 5)

In the context of his research on the learning of nuclear power plant operations using simulators, Pastré (1999) shows that there are two types of strategies, both qualified as "retroactive and partial". The novice teacher cannot have an overview of the whole operation; his strategy called a short loop is procedural by nature. The result of the simulator training led Pastré to qualify the second strategy as a long loop; it is analytic by nature. In other words, the novice modifies his activity gradually, using a procedure that may be described as trial and error, where each mistake is associated with a rule for action. The short loop represents an "active coordination" regulation (Piaget, 1974), mainly oriented towards success. Concerning the long loop, the operator implements a form of "conceptual coordination" (Piaget, 1974) through a global approach. Moreover, in problem-solving situations, another form of retroactive activity regulation is seen: one that reorients the subject towards other forms of activities, towards other schemes, which would be better adapted to the properties of the situation and the task. According to Coulet (2010), these represent "scheme change" regulations.

Pedagogical Content Knowledge

The Shulman model can be used to understand the specific knowledge involved in the teaching of subject-related knowledge in order to distinguish a teacher from a specialist in a subject. He first defined three types of "content understanding" and studied their impact in the classroom: "Subject Matter Knowledge" (SMK), "Pedagogical Content Knowledge" (PCK) and "Curricular Knowledge" (CK). Later, Grossman (1990) proposed developing the Shulman model by defining four domains: general pedagogical knowledge (PK), disciplinary knowledge (SMK), pedagogical content knowledge (PCK), and knowledge of context (KofC).

Magnusson, Krajcik, and Borko (1999) defined the components of PCK separately (see Figure 1). According to these authors, there are four components: knowledge of teaching strategies, knowledge of programmes, knowledge of assessment, and knowledge of students. These four components of PCK are also divided into subcategories that interact with each other. In addition, a fifth component shapes the others: the "orientation to teaching science" component.

In our study, this model is useful in order to categorise the knowledge involved in teacher practice. It is composed of categories and subcategories that make a fine distinction between knowledge at the level of the teacher, which he uses in relation to the content to be taught (weight and mass in our study), and knowledge at the student level that is specific to the teaching of this content.

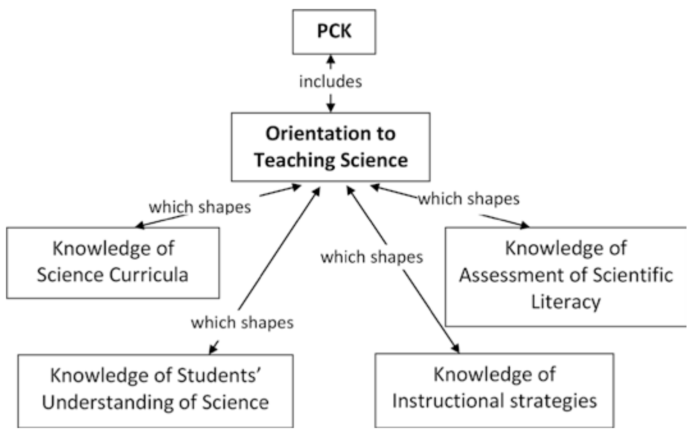

Figure 1. Examining pedagogical content knowledge (Gess-Newsome & Lederman, 1999)

The Concept of Unexpected Events

In some studies, the unexpected is considered as a tool while, in other works, it is seen as an object or as "a structuring object integrated in a method or as a training element" (Jean, 2008, p. 25). Unexpected incidents are sometimes synonymous with disruptive incidents (Woods, 1990) or misunderstandings (Broussal, 2006), linked to teaching described as "vague work" by Tardif and Lessard (1999). Yinger (1986) refers to improvisation to describe the work of expert teachers.

Huber and Chautard (2001) consider the unexpected as a particular type of event defined as disruptive, which leads the teacher to look for "a new balance" either immediately or later. This implies that the unexpected should be considered as a regulation system for learning. We find this relationship between the unexpected and regulation in the work of Broussal (2006). He demonstrates a relationship between the identification of misunderstandings and the expertise of teachers who use the misunderstandings as "pertinent indicators" that have an impact on their interventions. Perrenoud (1999) also uses the concept of event, but adds the qualifier "unexpected". He distinguishes the case of the predictable event whose occurrence is not planned, and the unpredictable event for which only an improvised response is possible.

A THEORETICAL MODEL FOR PROFESSIONAL KNOWLEDGE ACQUISITION

Our study of the gap between the planned and the realised entails identifying unexpected events in the class. Based on the work of Huber and Chautard, as well as that of Perrenoud, we define the unexpected as a disruptive event that occurs in the classroom and is not planned by the teacher. We consider the particular case where the unexpected event is perceived by the teacher and generates a regulation. These unexpected events can lead to the construction of new teacher knowledge.

From a methodological point of view, we identify the unexpected events during self-confrontation interviews (Clot, Faïta, Fernandez, & Scheller, 2001) (see the methodology section). Then, we note the goal changes that are characteristic of retroactive regulations of activity with reference to the work of Leontiev.

We propose a theoretical model (see Figure 2) that expresses the acquisition of new knowledge from the in-class activity and, at the same time, shows the impact of this new knowledge on the organisation of the teacher's activity. This impact can be measured by in-class and out-of-class work. It reflects the fact that the activity has a constructive factor and a productive factor (Samurcay & Rabardel, 2004). We consider that this model allows us to differentiate between the teacher activity

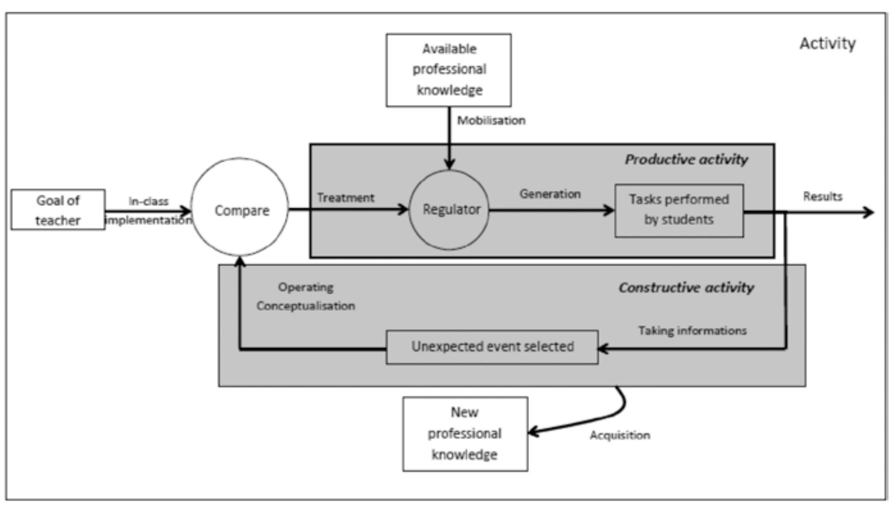

Figure 2. Theoretical model of a short-term loop

constructed during the preparation on one hand, and the evolutions of the activity as a result of the new knowledge gained in the class action on the other hand.

Our model covers two different situations. The first corresponds to an unexpected event that is perceived and selected by the teacher. He operates a short regulation loop that allows him to achieve her/his goal by operating step by step (Pastré, 1997). Then, she/he resumes the planned course of the lesson. During this regulation, new professional knowledge is acquired.

In the model, the circles represent actions of information treatment from several sources. The rectangles represent states. The regulator function aims to represent the fact that the activity of a subject position is never automatic, i.e., without checks and taken information. Here, it is either for the teacher to achieve its goal in relation with what is planned, or it comes to treating a gap between what is planned and what is realised. In the first case, we refer for example to the different modes we can characterise from the abstraction hierarchy of Rasmussen et al. (1994). In the second case, we focus on the treatment by the teacher in the class action that allows her/him to achieve her/his goal by working step by step (Pastre, 1997).

The second situation describes the consequences of the new knowledge acquisition on the result of the short regulation loop, as previously described. This allows the teacher to achieve her/his goal, but not in a way that is always satisfactory. Consequently, she/he performs a long regulation loop at a time scale that exceeds that of the class session. The result is generally more appropriate for the class, i.e., the responses given are more accurate and more efficient from the point of view of student learning (see Figure 3).

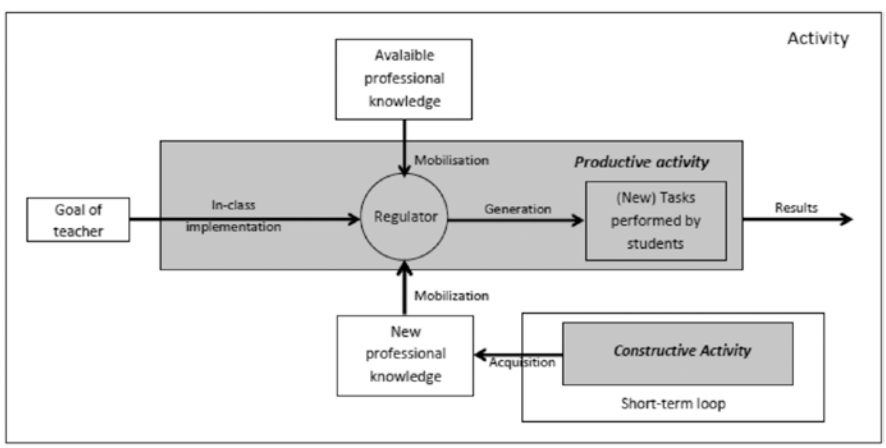

Figure 3. Theoretical model of a long-term loop

We will now compare this model with an empirical study to test its ability to account for the acquisition of professional knowledge by science teachers, as well as its evolutions. We first present our research methodology and then describe our results.

METHODOLOGY

In this paragraph, we describe the data collection and processing tools with respect to the context of the study.

Context of the Study

We implemented this methodology during two consecutive years. It consists of monitoring two experienced teachers in French secondary schools who are specialists in physics-chemistry teaching. We will call them Henri and Florence. The case study we present here involves a mechanics course for 14-year-old students. We chose Henri and Florence because they are neither novice teachers nor expert teachers. Indeed, studying novice teachers and the problems inherent to the early career stage may have obscured the objectives of our study. On the other hand, expert teachers who have been teaching at the same level for years, and among whom we might observe succinct preparations and installed routines, would have made the changes that interest us less obvious.

The chosen topic concerns the concepts of 'weight and mass'. It is treated by each of the teachers in three one-hour sessions. The advancements were coordinated so that this chapter was taught at the same time of the year to allow everyone to discuss teaching situations that had been experienced recently.

Finally, we note that the practice of these two teachers was performed within the French curricular context, where IBSE has been one of the requirements since 2005, following on from elementary school.[2]

Tools for Data Collection

The corpus we collected includes audio and video recordings of class sequences and interviews with each of the teachers, as well as data from a diary filled in by the two teachers for the duration of the study. The latter provides a trace of their class preparation and their analysis of the previous session. It allows us to address their out-of-class work. It is an essential tool in the reflexive investigation methodology in the sense that it encourages reflexivity on the activities (Power, 2008; Gueudet & Trouche, 2010).

The total duration of the video recording was approximately 38 hours. Two cameras were installed: one at the back of the class, which was focused on the blackboard, and a second mobile one, filming the interactions between the teacher and the students. The teacher was equipped with a lavalier microphone and two 'ambiance' microphones were placed in the class. The video recording was then digitised.

We conducted different types of interviews with the teachers: interviews at the beginning and at the end of the sequence, as well as self-confrontation interviews (Clot & Faïta, 2000; Clot, Faïta, Fernandez, & Scheller, 2001). The topic studied during the sequence was decided in advance by the teachers and the researcher together. It was the basis for the two interviews, in which the teachers performed a self-analysis of their action, watching the video recordings of the sessions, according to methods that are similar to simple and cross self-confrontation. Self-analysis is envisaged here as a method for collecting empirical data and analysing verbal protocols in relation to the action. Simple self-analysis consists of an interview between the researcher and each teacher. They are asked to describe and then analyse their actions, verbalising what they did, thought or took into account, and avoiding any interpretations or generalities. The cross self-analysis involved the two teachers and the researcher in a common analysis of the same video recording. It was used to analyse the unexpected events identified in the simple self-analysis. Therefore, we chose to monitor the two teachers simultaneously in order to organise these talks.

Tools for Data Processing

Our analysis was sometimes done at a very fine scale, at the statement level, to allow us to perceive the adjustments made by the teachers in the class action, which led us to proceed according to the methodology of the case study, with two levels of analysis.

At the first level, we produced a synopsis (Sensevy & Mercier, 2007) of the sessions, based on an initial video analysis. From a methodological point of view, the session synopsis corresponds to a reduction of the corpus, allowing an overview of the complete session studied. In order to prepare the simple self-analysis interview, we provided each teacher with the videos of their own practice in class, together with the synopsis. Then, we asked them to indicate all the situations that they would like to discuss with their colleague, in particular noting all the unexpected events that occurred during the class. During this interview, the unexpected events identified by the teacher were compared to those identified by the researcher, and then discussed. Those that were judged relevant to our study were kept for discussion in the cross interview. We then provided each teacher with the videos of their colleague's courses, as well as the session synopses. They had to do an initial analysis of the courses and note the subjects for discussion with their colleague. This could be related to the progress, the planning, a situation etc. This corpus represented the basis for the cross self-analysis interview. At the second level, we made transcripts of the situations that were discussed in the interviews. They concerned notably the unexpected events that were defined. We also made transcripts of the interviews related to these situations. We inferred the knowledge of the teachers by triangulating all of the data from the videos and transcripts.[3]

RESULTS

We now present some results of our research. We focus on one teacher and choose excerpts that we consider as representative. We analyse a topic taught by Florence during two consecutive years and present the unexpected events that gave rise to retroactive regulations of activity. We analyse a short loop and a long loop. Then, we discuss our results.

Analysis of an Entry Situation Implemented by Florence

Year 1: A short-term loop. In the first year, Florence starts the sequence by asking the students the following question: "So if I just say weight or mass what does that make you think of?". She explains that they will then classify their propositions in a table with respect to weight or with respect to mass. The students respond by mentioning "kilogram", "gram", which they put in the mass column or in the weight column. She validates these responses as she punctuates each proposition from a student with "ok" or "yes". Then, we observe a rupture in the planned lesson when a student (S_1) proposes to classify "volume" in the weight column. In fact, Florence nods for a few seconds. She seems surprised! The proposition "heavy, light" is made by student S_2, and is repeated by Florence. Then, she decides to respond to the "volume" proposition. Consequently, at this moment in the session, her goal is no longer to collect propositions from the students concerning weight and mass in order to classify them, but to 'correct the error' of student S_1 (see Table 1).

Table 1. Translation of session transcript: Confusion between mass and volume. The case of Florence

Speakers	*Verbal productions*
S_1	Volume
F (Florence)	Volume? ((the teacher nods her head))
S_2	Heavy, light
F	Heavy, light! So volume there is a small distinction between mass and volume ok? So volume, then this is more the capacity so heavy light no? Can you think of anything else?

We note that Florence's intervention is brief and hesitant because it is punctuated by pauses of at least 2 seconds each. We observe the teacher mobilising the class on this confusion, by formulating the first element of her response that she finishes with "ok", looking at the entire class, followed by a pause of about 4 seconds. Then, she says that volume is related to a capacity, before returning to the planned course of the lesson by asking the question: "can you think of anything else?". Florence says in the interview that she "eliminated" this proposition because density is not in the secondary school programme and "it can quickly become very complicated". We note this unexpected 'confusion between mass and volume'. In our opinion, she performed a regulation that we model with a short loop during which she made a correction to the confusion between mass and volume to avoid letting wrong ideas pass which could constitute "an obstacle later".

We observe that the teacher activity is organised around three goals during the short regulation loop. Her first goal is to mobilise the class on the proposition of student S_1. The second is to correct the confusion by saying that volume is associated with capacity. The teacher's third goal is to return to the initial goal, which was to find out the students' initial conceptions of weight and mass. Indeed, the teacher tells us her objective: "is precisely to classify everything related to weight on one side, and everything related to mass on the other, but already to try to clean up their knowledge a little before starting". According to her, it is by classifying the propositions in the table that the students express their initial conceptions on the subject. She expects certain answers: "kilogram I thought that was pretty sure I knew that kilogram would be in weight, it's classic! Light heavy I had had it in a class in sm[4] but not in the other one for some words. I knew they were going to come out but not in the right place not in the right class after". In contrast, Florence is not expecting "volume" as a characteristic of mass.

During this regulation, the teacher mobilises professional knowledge. We identify PK of class management, SMK of the concepts of weight, mass, volume and density. We also find PCK of the programmes that we note "density is not in the secondary school programme" and two PCK of the students "I need to eliminate the 'volume' proposition because I know that it can become very complicated"[5] and "I need to distinguish between volume and mass". The first belongs to the subcategory "Specific knowledge of the programme" and the other two to the subcategory "Knowledge of domains where students have difficulties".

Year 2: A long regulation loop. In the following school year, Florence is in class, in the same situation as described previously, but we observe her giving a different answer. She refers to the eighth grade programme where volume and mass are defined: "the volume is the space occupied by an object and it is measured in litres or dm^3". In the interviews, Florence justifies this change by the fact that she had expected this response, which she had already heard the previous year. The unexpected event of the first year actually turned into a predictable event in the second year. However, her preparation remained identical. For us, this change is characteristic of a long retroactive regulation loop.

The new PCK about the students, "Volume can be associated with mass", is the basis for this regulation that we model with a long loop. It was constructed during the first year by the teacher. We observe that the response provided by Florence in the second year is more structured and clearer than the one she formulated in the first year. To do this, she mobilised the PCK of the students "volume is defined in

8th grade" and knowledge that we could not situate in the model of Magnusson et al. We called it "Knowledge of what students learned in previous years" because, according to us, it goes beyond knowledge of students' prerequisites and of science curricula. It concerns the content of the response given by the teacher, which is precisely what she asked students to learn two years earlier. According to her, this ensures a better understanding on the part of the students of the difference between mass and volume. This teacher knowledge is constructed from the common history she has with the students because she is the only teacher of physics and chemistry in the school. We observe that this type of knowledge can influence her practice. In our opinion, it is PCK of the students because it is linked to specific content.

We observe that the teacher has learned merely by acting in a situation. She acquires the PCK of the students who make her plan a more appropriate response to this confusion, which she constructs in another context. Indeed, it is by giving the course on the measurement of volume in eighth grade, a month later, that Florence tells us that she elaborated it.

DISCUSSION

We now discuss the elements of the analysis presented in this study. We develop our proposals further based on the case of Henri. We start with the professional knowledge mobilised by the teachers. We compare our results with the model of Magnusson et al. (1999) and mention certain limits. Then, we present the evolution of professional knowledge through mechanisms of new knowledge acquisition. We analyse the consequences of the reorganisation of teacher activity. Finally, we discuss our model for professional knowledge acquisition by science teachers.

The Professional Knowledge of the Teachers

The model of Magnusson et al. allows us to identify the professional knowledge mobilised by the teachers during the implementation of a course based on investigation. Let us return to the two moments we analysed in the previous part: the introductory situation of the sequence and the experimental investigation constructed by the two teachers.

We previously showed that Florence has two goals: on one hand, she wants the students to propose characteristics of weight and mass and to classify them in a table and, on the other, she wants to find out their conceptions of these two quantities. In order to build and implement this introductory situation, the teacher mobilises not only CK, but also PCK. This includes CK of the concepts of weight, mass and gravity applied to the Earth. We observe different categories of PCK: of the students, the programmes and the strategies (see Table 2).

The question posed at the start concerning "what do you know about…" seems fairly common to us when it comes to understanding the students' conceptions. It is not specific to the teaching of weight and mass. It is a strategic approach as there

Table 2. Categories of PCK mobilised by Florence in the entry situation

PCK categories	*Subcategories*	*Formulation*
PCK of the students	Knowledge of the domains where students have difficulties	I know that kilogram will be in weight. I know that the word scale will not necessarily go with mass. I know that the students mix up weight and mass.
PCK of the programmes	Knowledge of the goals and objectives in the official instruction	I know that I have to find out the students' initial conceptions at the start of the sequence in order to construct the subsequent learning
PCK of the strategies	More general knowledge of strategies (for multiple topics)	Start the sequence by asking the whole class a question in order to identify the confusion between weight and mass

is a question and the answers are put in a table. We classify this PCK as "general knowledge of strategy". It is linked, in our opinion, to the fact that the teacher already understands a certain number of conceptions that we have classified in the sub-category "domains for which students have difficulties". She knows that the students' conceptions will emerge when the propositions are classified in the table.

Florence refers to the programmes and, more specifically, to the investigation approach when she says "find out the students' initial conceptions at the start of the sequence in order to construct the subsequent learning". Indeed, this moment of the session corresponds to the problem that aims, notably, at "identifying the conceptions or representations of the students, as well as the persistent difficulties (analysis of cognitive obstacles and errors)".[6] This approach allows the students to carry out investigations where "the search for explanations or justifications leads to acquisition of knowledge, of methodological skills and the development of technical know-how" (ibid.). We classify this knowledge as belonging to the sub-category of the goals and objectives in the official instructions.

We observed Henri starting the sequence on "weight and mass" with the study of a comic strip of the adventures of Tintin from the album "Explorers on the moon". This strip shows one of the heroes, Dupont, on the moon, jumping over a crevasse and falling much further than expected. The teacher tells us in the interview that he has two goals: to interest the students to ensure their adherence to this new chapter and to give a definition of the weight of an object. He gives us two reasons for choosing a comic as the start situation. The first reason is strategic: "Everyone knows Tintin, so it speaks for itself if you like (…) so we get caught up in it, it's easy". His goal is to attract each student, to gain their interest from the start of the lesson, to ensure they will stick with it as long as possible. The second reason is linked to the programmes that advocate teaching by IBSE for some subjects. According to him, implementation of this kind of teaching requires "asking open questions to break down erroneous representations, to make them evolve". Therefore, it involves choosing a topic that can be associated with a "concrete" problem situation and allows him to pose a problem that is "understandable" by the students. During the discussion, for Florence, the term "concrete" means "referring to the students' daily life". The problem situation constructed from the comic strip, described above, thus appears relevant for the two teachers: "Everyone knows Tintin, so it speaks for itself if you like (…) so we get caught up in it, it's easy".

As in the case of Florence, Henri mobilises knowledge of the CK and PCK types to formulate his objective in line with the level of the class and his answers to questions that are appropriate from the point of view of the concepts and vocabulary used.

Evolution of the Teachers' Professional Knowledge: The Case of Unexpected Events that Do Not Generate Regulation

In the two cases we studied, the acquisition of PCK led to regulations operated by the teachers. It included PCK of the students in the sub-categories "Prerequisites necessary for learning a concept" and "Knowledge of domains where students have difficulties", respectively, and PCK of the strategies in the sub-category "more general knowledge about strategies (for multiple topics)". But unexpected events can be perceived by the teacher and do not necessarily generate a regulation loop. In other words, they are not the subjects of short or long regulation loops. In this case, they represent an event for the teacher but not necessarily for the student. Indeed, the teacher did not always have the answer to an event in action, as with the case of Florence when she saw that the question asked in the introductory situation "aimed at finding out the characteristics of weight and mass to better differentiate between them was not precise enough". But this new knowledge acquired by the teacher is saved in the sense that it can create a system with other new knowledge elements acquired at different moments of the session or the teaching sequence and participate to activity reorganisation.

We observe Florence modifying the organisation of the introductory situation of the first session in the second year. Indeed, she uses part of Henri's student material.[7] She shows an animated film and distributes the cartoon strip associated with the part she wants to study. Hergé's characters are found on the moon, jumping from place to place. The teacher builds on the students' description of the film, by asking: "why do the characters jump so high?".

The teacher says in the interview that she was not satisfied with her introductory situation in the sequence during the first year. She thinks that her questions and the students' answers were not "precise" enough. She says that the articulation with the previous course on gravity did not occur, resulting in difficulties in defining the notion of weight. She observes that she lost a lot of time in discussions. In our opinion at the end of this analysis, the teacher had constructed three new pieces of PCK: "The students do not re-use the concept of gravity to define the weight; the student knowledge is not sufficient at the beginning of the sequence to distinguish between the two concepts; the question asked the previous year aimed at finding out the characteristics of weight and mass to better differentiate between them was not precise enough". The first two items of knowledge are the PCK of the students, in the sub-categories "Prerequisites necessary for learning a concept" and "Knowledge of domains in which students have difficulties", respectively. The third statement corresponds to a piece of PCK of the strategies, in the subcategory "more general knowledge about strategies (for multiple topics)". All of these pieces of PCK lead to the changes we have described above.

In our opinion, Florence can change her introductory situation in the sequence because all pieces of the PCK are related to each other and constructed from elements of her in-class activity. We say that the knowledge elements create a system and participate in this type of regulation performed by the teacher. They are acquired on the time scale of the sequence or the activity. That is what we call "saving new knowledge". Nevertheless, some questions arise: on what time scale is each new piece of knowledge acquired? Is it only the new knowledge formulated by the teachers that creates a system? In the case we analysed, the new PCK is related to the activities carried out in the first session and also concerns the learning achieved in the previous sequence (the gravitational interaction). However, we think that elements from other activities at other, possibly later, moments in the sequence, the assessment results for example, can participate in the acquisition of new pieces of knowledge that create a system with the formulated ones and participate in the teacher's decision to reorganise their activity.

For us, these changes are characteristic of a long retroactive regulation loop. It would appear that the teacher's goal changes, as well as the students' task, at the level of the activity. Indeed, Florence's goal is different from that in the first year. Here, it is to define weight with the students based on their previous knowledge, notably about gravity depending on the planet. The students' task is to explain why Hergé's characters jump so high and so far. The acquisition of the new PCK actually leads to an organisational change in the teacher's activity. It is particularly characterised by a change in the teacher's goal and in the students' tasks. Here, Florence partly rewrites her preparation.

Limits of Our Analysis Framework

Our analysis framework allows us to identify the four types of knowledge in the model of Magnusson et al. (1999). In this study, we show how the CK and PK of class management or of strategy (Florence deciding to dismiss the student S_1's proposition) is mixed with PCK in the organisation of the teacher's activity. However, our results raise several questions concerning the definition and characterisation of PCK.

We now go back to Florence's response to the confusion of a student between mass and volume in the second year of our study. We have shown that she uses knowledge that we could not situate in the model of Magnusson et al. We called it "Knowledge of what students have learned in previous years". This teacher knowledge of the history of these students' learning is specific to the context in which Florence teaches because she is the only teacher of physics-chemistry in this French school. Consequently, not only does she know exactly what the students have learned in previous classes in physics or in chemistry, but she also makes planning choices on the scale of several years. For example, Florence says during the second year interview that she did not ask the students to plot their measurements because she had already insisted on this the year before (in eighth grade). She gives this task based on an exercise in the students' textbook. This category does not appear in the model of Magnusson et al. and is, for us, a new type of knowledge.

Another outcome of our study questions the analysis framework of PCK. It concerns the nature of the teaching approach, which can be described as inductive or deductive depending on what the teacher can anticipate about the students' difficulties. For example, when the two teachers want the students to find the mathematical relationship between weight and mass ($Fg = mg$) they either ask them to find a "mathematical relationship" or a "link" between these two quantities, or they give them the scientific law and ask the students to prove it by measurements. The teachers mobilise a system of the PCK of the students which allows them to better adapt the approach to formulate a law. However, we noticed that the two teachers were not aware that the nature of the educational approach changed between the two years. They thought they were still implementing an inductive approach because "in theory in physics we obtain laws from experiments, so it's not math!". Yet our study shows that the reality is different. We see from this that the epistemology of academic teaching subjects is an important element in the teachers' decision-making, although we do not know if, in this case, the mobilised knowledge is CK or another category of knowledge linked to a 'practical epistemology'.

Our study raises a new question: What is strategic for a teacher? Is it the implementation of a plan such as a lesson experiment, or starting a session with a question, or the choice of a medium such as a comic strip or is it the approach that is associated with it? This question comes as a result of the difficulties we had distinguishing between two subcategories of the PCK of the strategies or distinguishing it from the PCK of the programmes or the students. We can consider the following example: when Florence reformulates the task the students have to complete in order to find the law $Fg = mg$, she changes the instructions during the lesson. Indeed, she rephrases the sentence given at the start "show that there is a link or that there is no link" so as to make the students "find a mathematical relationship". During this regulation, does the teacher mobilise the PCK of the strategies or the PCK of the students? In contrast, when a teacher uses an analogy, we can say that he uses the PCK of the strategies. It is an approach with knowledge involved that aims to help the students understand one or more phenomena or to conceptualise ideas.

If we consider that it is the plan or the type of media that is strategic, we are in the presence of pedagogical knowledge because a plan or a medium is not specific to a topic.

CONCLUSION

The theoretical and methodological approaches used in this research allow us to illustrate our model for science teachers' professional knowledge acquisition. This model gives a macroscopic view of the modes of professional knowledge acquisition. We organise it within the PCK framework, which allows us to specify the type of knowledge acquired. In fact, we believe that our model and the PCK analysis framework are complementary.

Our study shows that the teachers mobilise other types of knowledge in addition to the knowledge of their academic subject: knowledge of students, knowledge of the programmes, and knowledge of the teaching strategies. The knowledge depends on the content to be taught, and corresponds to the PCK categories. It is combined (Shulman, 1986) notably with discipline knowledge (CK) of a level higher than that being taught, and pedagogical knowledge (PK). All these categories are included in the teacher's professional knowledge base. They allow the teacher to make the study topic more understandable for the students. In this study, we raised a theoretical question. In accordance with other research results, we encountered difficulties in identifying the PCK of the strategies. What is strategic in the teacher action? Is it the plan used, regardless of the content or is it everything? What can be used to differentiate the PK of the strategies from PCK? We also asked a question about the discipline epistemology that is involved in the teachers' decision-making, although we do not know if the mobilised knowledge in this case is CK or another category of knowledge linked to a 'practical epistemology'.

We believe that our study results in the identification of some elements concerning the teachers' experience acquisition. Indeed, the unexpected events lead to the construction of new PCK for the students. They sometimes generate retroactive activity regulation loops, which show how this knowledge participates in the teacher's adaptation of the teaching for the class over a more or less long time scale. In fact, the mechanisms that could model, in part, the professional experience acquisition are the acquisition of new PCK and the constitution of predictable events that we identified in the action and which were constructed previously. Nevertheless, this study should be continued, particularly by positioning it with respect to the work on teachers' professional development.

The empirical study presented here shows that the model we have constructed is suitable for representing and explaining the acquisition of professional knowledge by science teachers based on IBSE. But is it predictive? It should be tested in other cases and especially in other science teaching situations because IBSE has specific characteristics. Further, with its specific epistemology is this model suitable for academic subjects other than physics-chemistry? Again, it should be tested in other academic subjects.

In addition, other questions arise concerning our model of professional knowledge acquisition by science teachers. Is it adapted to more general or 'versatile' teachers, such as primary school teachers? Indeed, teachers can mobilise different kinds of PCK and PK, notably concerning the learning of French (syntax, phonology, spelling etc.) at the service of science learning, or about the role of writing in science learning (Jameau, 2015). Is PK not used more often when the PCK and CK are limited?

All of these questions indicate the work we still have to do to better understand teacher activity and its evolutions from the point of view of professional knowledge. We believe a research programme should be elaborated based on our model in order to test its heuristic power and possibly use it as a baseline for research in the context of science teacher training.

NOTES

1 BO N°5, 25 August 2005, Special Edition.
2 BOEN N°1, 14 February 2002, Special Edition.
3 We use "transcript" to refer to the tables of transcripts of verbal productions of classroom situations, and the interviews, together with some brief descriptions from the researcher.
4 sm is the other secondary school where Florence teaches.
5 Our underlining.
6 MEN. Les programmes du collège (Secondary school programmes). BO Special edition N°6, 28 August 2008.
7 Florence considered it more effective to enter into the sequence with the character of Tintin, as Henri did, rather than as she did in the first year. But she adapts the situation to her own objectives. This is a consequence of the self-confrontation interviews methodology. The reflexive collective activity on his own work transforms the participants, and the situation (Clot et al., 2001).

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