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6. STUDYING THE ACTIVITY OF TWO FRENCH CHEMISTRY TEACHERS TO INFER THEIR PEDAGOGICAL CONTENT KNOWLEDGE AND THEIR PEDAGOGICAL KNOWLEDGE

Documenting teacher professional knowledge is the subject of numerous studies because teacher professional knowledge is assumed to have an effect on teaching (Crahay, Wanlin, Issaieva, & Laduron, 2011; Magnusson, Krajcik, & Borko, 1999). The analysis of teachers' discourse about their practice gives insights into their knowledge (Fernández-Balboa & Stiehl, 1995; Padilla & Van Driel, 2011) but sometimes does not always match their actions in the classroom (Farré & Lorenzo, 2009; Simmons et al., 1999). Some researchers infer teacher professional knowledge from analysis of their actions (Alonzo, Kobarg, & Seidel, 2012; Cross, 2010). Others use mixed methods combining analyses of teachers' statements or reflections and of classroom observations (e.g., Friedrichsen & Dana, 2005; Loughran, Milroy, Berry, Gunstone, & Mulhall, 2001; Park & Oliver, 2008). This study addresses the activity of two teachers working on the same subject, the spontaneous evolution of chemical systems in 12th grade, and aims to infer part of their professional knowledge from an analysis of their actions and statements.

FRAMEWORK

The analysis of classroom activity follows the methodological framework of the double didactic and ergonomic approach (Robert & Rogalski, 2002; Vandebrouck, 2013), and teachers' professional knowledge according to Shulman's typology (Shulman, 1987).

The Double Didactic and Ergonomic Approach

The double didactic and ergonomic approach falls within the activity theory. A subject's activity is constituted by what the subject does to achieve a task in context (Rogalski, 2003, 2013). The real activity is not accessible because it includes everything that the subject thinks, says or does not, does or does not (Robert, 2008). Only indications of the subject's activity, "operations on the objects of action", are observable (Rogalski, 2013). This unifying point of view enables us to consider both the teacher's and the students' activity in the classroom (Robert & Vivier, 2013).

M. Grangeat (Ed.), Understanding Science Teachers' Professional Knowledge Growth, 89–115.

The teacher's activity in the classroom denotes part of the teacher's practices which include everything a teacher does in and out of the classroom over a long period of time. It constitutes what he/she implements to achieve his/her tasks: promoting the students' learning of a given topic in a given teaching session and designing the learning environment for this.

Examining what can be perceived of students' potential activities in the classroom enables a reconstruction of the cognitive pathway the teacher proposes to the students, the working modes and the students' scaffolding implemented (Robert & Rogalski, 2002). This kind of analysis, a didactic one, was insufficient to understand what was at stake in mathematics teachers' choices (Robert & Rogalski, 2002). To explain and describe the regularity and variability of practices between teachers, it was necessary to deal with factors that are not part of the classroom context like the syllabus instructions, the teacher's personal beliefs, his/her colleagues and professional habits (Robert & Rogalski, 2002). These factors also impact the teaching session and are thus considered determinants of the teacher's practices. This point of view corresponds to an analysis of the teacher's work that takes the constraints he/she faces and the specificity of the learning session into account. Combining a didactic point of view (the cognitive aspect and the mediative aspect of the practices) with an ergonomic approach (categorising the determinants of the practices as institutional, social and personal) leads to analysing the teacher's activity according to five dimensions.

The five dimensions structuring the analysis of the activity are the following:

- the cognitive dimension concerns the design of the tasks given to the students, the lesson plan and the chemical content involved;
- the mediative dimension concerns implementation of the lesson plan, paying particular attention to the choices of classroom organisation and of students' scaffolding;
- the institutional dimension examines how the teacher takes the syllabus and the resources into account;
- the social dimension deals with the relationships between the teacher and students, people working in the school, parents and the way the teacher takes account of the students' social background; and
- the personal dimension revolves around the teacher's knowledge, conceptions of chemistry, chemistry teaching and the impact of his/her personal experience on his/her beliefs.

The constraints that determine the activity are gathered in the last three dimensions that therefore influence the two others. Splitting the activity analysis into five dimensions aims to reduce the activity's complexity, but allows approaching the coherent system that a teacher's practices constitute from different points of view (Robert & Rogalski, 2002). Combining these five dimensions then enables a teacher's acting principles to be addressed. Robert and Rogalski (2002) state that the regularities of teaching practices are the translation of a teacher's determining choices.

Attaining these dimensions is made possible by analysing the tasks proposed to the students and the lesson plan on one hand, and implementation of the lesson plan on the other. The latter analysis pinpoints the work organisation in the classroom, the relationships between the teacher and the students, the kind of help and the feedback the teacher gives the students. Interviews with the teachers are needed to complete the previous analyses.

Teachers' Knowledge

Teachers' professional knowledge is "action-oriented, person-bound and tacit" (van Driel, Beijaard, & Verloop, 2001). During the course of action, tacit knowledge is mobilised (Rix-Lièvre & Lièvre, 2012; Schön, 1996). Thus, choosing to approach teachers' professional knowledge from the analysis of action implies that most of the inferences made in this study will concern knowledge which is neither articulated nor mentally expressed.

To describe the teacher's knowledge, two models are used: Morine-Dershimer and Kent's model for pedagogical knowledge (PK) (Morine-Dershimer & Kent, 1999), and Magnusson, Krajcik and Borko's model for pedagogical content knowledge (PCK) (Magnusson et al., 1999). Among PK three facets (or components) are considered: instructional models and strategies (PK-strategy), classroom management and organisation (PK-management), and classroom discourse and communication (PK-discourse) that should be mastered by beginning teachers to attain higher professional development stages (Corrigan, 2009). The PCK model (Magnusson et al., 1999) includes five components. The first one, orientation to science teaching, shapes the others, knowledge of curriculum (PCK-programme), knowledge of assessment (PCK-assessment), knowledge of students' understanding of the chemistry topic under consideration (PCK-student), knowledge of instructional strategies (PCK-strategy), that enable the students to understand the topic at hand or overcome their difficulties. Content knowledge (CK, here knowledge of the topic "evolution of chemical systems") constitutes a separate domain of knowledge apart from PK and PCK but influences the PCK domain.

According to a literature review, PCK-strategy and PCK-student on one hand (van Driel, Verloop, & de Vos, 1998) and PK-strategy and PK-management on the other hand (König, Blömeke, Paine, Schmidt, & Hsieh, 2011) are the core components of PCK and PK, respectively.

Clearly differentiating PK-strategy and PCK-strategy is crucial to categorising knowledge. PK-strategy concerns the design of tasks, their structure and diversity without taking the content into account, and the teacher's goals. If these goals and tasks can be expressed in the same manner for another chemistry or physics course, then they will be ascribed to PK-strategy. PCK-strategy denotes a strategy devoted to overcome a topic-specific learning difficulty. PK-management includes time management (time left for thinking, for achieving tasks), the distribution of tasks among students, establishing routines.

The Link between the Double Approach and Teacher Professional Knowledge

The teacher's activity in the classroom results from decisions taken during both the planning and implementation (Wanlin & Crahay, 2012). These decisions depend on the teacher's knowledge, the constraints he/she faces and on the results of his/her actions. Focusing on the knowledge supporting the decision-making enables one to specify what type of knowledge is involved. The tasks and lesson plan design (cognitive dimension) entails choosing a global pedagogical strategy (PK-strategy) and relies on chemistry content knowledge (CK), curriculum knowledge (PCK-programme), knowledge of the students' understanding of the topic (PCK-student) and knowledge of specific methods suiting the cognitive goals to be achieved (PCK-strategy). The enactment of the course project (mediative dimension) includes the classroom organisation and the students' scaffolding which rely on knowledge of instructional strategies (PK-strategy) and of topic-specific strategies (PCK-strategy), of the students' understanding (PCK-student), of how to communicate with the students (PK-discourse) and of classroom and time management (PK-management).

Giving a broader sense to PCK "defined as a personal attribute of a teacher and … considered both a knowledge base and an action" (Gess-Newsome, 2013), Gess-Newsome legitimises the point of view adopted in this research, namely that PCK is intimately bound to a teacher's actions and can be inferred from their analyses.

CONTEXT OF THE STUDY AND RESEARCH QUESTIONS

Teacher Training Session

A three-day teacher training session was organised to develop the teachers' professional knowledge on the topic "teaching the evolution of chemical systems" during the 2010–11 academic year. The goals of the session were to enhance the CK and PCK of the trainees, support the appropriateness of and enactment of new knowledge and encourage reflection and discussion in order to reveal their teaching habits and to eventually slightly modify them. The first day was devoted to a presentation of an epistemological analysis of the syllabus of 12th grade, highlighting the three models that could be used in the syllabus and of the students' reasoning and difficulties (Kermen & Méheut, 2011). It was hypothesised that this reflection in terms of three different models was new to the teachers and that some of the students' difficulties or reasoning were unknown. The 12th grade teachers were asked to design a lesson plan about the introduction of the spontaneous change criterion and to set it out during the second day of the training session two months later. They were also told that they would have to implement the lesson plan in their classroom thereafter and that the implementation would be video recorded and discussed on the third day of the training session. On the second day, two 12th grade teachers, an experienced woman and a beginning man, set out their lesson plan and their objectives. On the last day (three months later), some extracts of each videoed teaching session were shown and both volunteers explained their specific choices and goals.

The session was preferably intended for teachers working in 12th grade, but most of the trainees were not doing so. Given the low number of 12th grade teachers involved and their different teaching experience, it appeared interesting to determine whether this difference could be noticed in their activity in the classroom, and if so how.

Chemical Content Involved

The students had hitherto only dealt with systems that comprised reactants (chemical species about to react) in the initial state and no products (species about to be formed). They had been introduced to incomplete chemical changes, which means reactants and products are present in the final state. These changes are modelled by a pair of opposing chemical reactions being symbolised by a chemical equation to which are associated the equilibrium constant K and another quantity, the reaction quotient Qr, a function of the concentrations of the solutes appearing in the chemical equation. At that point, the students knew that, when the change is over, the reaction quotient is equal to the equilibrium constant, but was different in the initial state. They also encountered chemical changes occurring in the forward direction of the chemical equation or in the reverse one. The goal of the new lesson was to establish a law: depending on the initial reaction quotient value Q_{ri}, a system will proceed in the forward direction (Q_{ri}<K) or in the reverse one (Q_{ri}>K) to reach an equilibrium state (Q_r=K). To induce this law, the so-called change criterion, the syllabus authors suggested studying systems initially comprising all the chemical species involved in the chemical equation. Relying on the chemical equation thus does not enable a prediction of what will happen, and a new reasoning based on the acquired knowledge is to be built.

Research Questions

Analysing teachers' activity within the framework of the double didactic and ergonomic approach intends to shed light upon the choices they make before and during the teaching session. As outlined above, these choices rely upon the various constraints they face, the local features of the teaching session (in particular, how the students behave in response to the prescribed tasks) and upon the teachers' knowledge. In this paper, the focus is on the knowledge (PK and PCK) underlying some of these choices and which can be inferred from the analysis of actions.

Examining the choices the teachers made, which components among CK, PK and PCK can be identified?

How can any difference between both teachers be specified in terms of actions and, finally, PK, PCK and CK?

METHODOLOGY

Collecting the Data

Two teachers were observed. Both were volunteers. Let us call the experienced teacher Dora (33 years old, 10 years' teaching experience and 4 years' in grade 12) and the beginning teacher Bud (26 years old, 2 years' teaching experience and none in grade 12). Both have the same qualification, a degree in physics and chemistry – a compulsory requirement to become a qualified teacher in France – and both had passed the required competitive examination. They were working in a high school in a middle-sized town in northern France. Bud is a supply teacher (like many of the new physics and chemistry teachers) and started to work in that position in mid-October. The teaching sessions took place in March.

Three types of data were collected. The first set includes some discussions between the trainees during the teacher training session. The trainees' reactions to the presentation of the lesson plan (second day) were audio recorded. In the following, for the sake of simplicity, the second day of the training session is called 'day 2'.

The second set is composed of the video-recorded sessions in the classrooms and the third one of the interviews taking place with the teachers. The teachers were briefly interviewed before and after their teaching session and told to comment on their classroom video some weeks later. All interviews were audio recorded. The third interview, a self-confrontation, is a kind of stimulated recall because each teacher watching his/her classroom video was told to comment ad lib on his/her actions and the students' behaviours. The researcher did not ask questions before the teacher addressed the topic being discussed or the extract being watched. Indeed, the teacher was considered a professional commenting on his/her work and not being judged or told what he/she should have done. Therefore, the researcher paid attention to the wording of the questions in order not to place the teacher in such a position. This had its own limitations: some topics or actions might not have been commented on by a teacher although the researcher would have liked to hear some explanation of such a choice or action. This is a methodological aspect that may change in the future.

The teaching sessions and the interviews were transcribed. The teachers' gestures and movements were also written down in case they could inform what was at stake.

Analysing the Data

The lesson plans were analysed in terms of the proposed chemical content, tasks given to the students and predictable classroom management. This analysis was carried out slightly differently for each teacher. Both teachers set out their lesson plan on the second day of the training session and, moreover, Bud gave all of the participants the labwork sheet he would give out to the students, with answers to the questions he intended to ask. The analysis of Bud's lesson plan relies on this labwork sheet and on the talk he gave during the training session. Dora did not prepare a labwork sheet. Thus, her course project is reconstructed by the researcher after watching the classroom video, looking for the nature and succession of the tasks and without noticing the students' reactions. For Dora, the analysis relies on what she said during the training session and on the reconstructed course project.

The second analysis deals with the teaching session transcriptions which were split into episodes delimited by the completion of a task. In each episode, the classroom organisation is categorised, specifying the role of the teacher and of the students in an attempt to reveal the work organisation enabling the pedagogical strategies involved to be determined. The interactions between the teacher and the students were studied to set out the verbal exchanges, the kind of help and the feedback given by the teacher.

The last analysis addresses the interviews which were read thoroughly to note the comments on the implemented strategy, the classroom management and the students' difficulties, reasoning or actions. It aimed to bring to the fore the teacher's reflective ability.

Each type of analysis reveals some components of the teacher's knowledge; the knowledge inference takes place in three complementary stages.

ANALYSIS OF THE LESSON PLANS: NATURE AND ORGANISATION OF THE TASKS

The *a priori* analysis focuses on the content of the tasks given to the students, the knowledge they need to achieve them, and the possible classroom management of the teacher.

Structure of the Lesson Plans

Bud's lesson project. When Bud set out his lesson plan on day 2, he exposed the global objective of the session, enabling the students to calculate some reaction quotients to finally deduce that a chemical system tends to reach equilibrium.

Bud prepared a labwork sheet with all the instructions needed to perform the experiments, the chemical equation involved and the questions to be answered with blank spaces to fill in. It is entitled "the spontaneous evolution of a chemical system". The sheet has two main parts. In the first part, four experiments are carried out in test tubes and are set out in the same way: mention of a chemical equation, detailed instructions to achieve the experiment, observation and interpretation. The second part is composed of an experiment with pH measurements and a list of detailed questions involving calculations, whereas in the first part there was none.

Just before the teaching session, Bud was questioned about his objectives. He stated that he wanted:

> to prompt [the students] to be attentive by showing them visual experiments … which simply show that ... a change is possible in the forward or in the reverse direction.

He then added that the second part of the lesson would be more "quantitative" and shares a similar goal regarding the direction of change by means of pH measurements, this time before "addressing the calculations".

Bud expressed his conception of the teaching of chemistry in the lab. Experiments should include visible clues of chemical change. Is this belief due to the fact that he had only taught classes in lower secondary school so far? Regarding the pH experiments, he clearly distinguished two stages, achieving the experiment should be done before "the calculations".

It would be too long to describe each experiment and which skills and knowledge the students are expected to mobilise. Thus, only a brief overview[1] to see what is at stake in the following sections is proposed here.

In the first part, section 1 deals with two experiments involving solutions of cobalt ions of different colours. In the first experiment, the colour change can be associated with a chemical change occurring in the reverse direction of the written chemical equation, which is quite unusual. Has Bud a special intention? Does he want to stress that possibility?

In the second experiment, the expected interpretation is limited to identification of the (forward) direction of the chemical change regarding the chemical equation.

Section 2 of this first part is devoted to some experiments involving the formation of a precipitate of benzoic acid as a visual indicator and is divided into two sub-sections. In the first one, the interpretation should be a forward direction of change and a reverse one in the second sub-section.

The second part of the labwork sheet begins with the chemical equation and its equilibrium constant. Two different mixtures have to be made. Both include the same four solutions, an ethanoic acid solution, a sodium ethanoate solution, a methanoic acid solution and a sodium methanoate solution, with all having the same concentration. The first mixture is made with equal volumes (10 mL) of each solution whereas the second one is realised with different volumes. The students are asked to measure the pH of each mixture and to do this they first have to calibrate the pHmeter, which is not mentioned on the paper. Finally, they have to answer a list of eleven detailed questions, nine of which are to be solved twice (for both mixtures) and most of which are calculations. Except in the second question where the students are not told to express the initial concentrations of the solutes to calculate the initial value of the reaction quotient, they have to mobilise knowledge and concepts that are mentioned in the questions, all the reasoning is set out, and it is a succession of simple tasks. It looks like an exercise where each answer leads to the following one.

Dora's lesson plan. On day 2 when Dora set out her lesson plan, she said she had conceived for the first time a lesson where the evolution criterion had to be induced from experimental situations and not applied to them. She added that the students had the conceptual tools (reaction quotient, equilibrium state) to understand such an approach. Just before the teaching session, when expressing her objectives Dora said she would prompt the students to put forward hypotheses about the direction of change, if any, of the acid-base mixtures without giving them any clue at the outset. Her main objective seemed to make the students reflect and wonder about the different factors that may affect an experimental situation.

First, she presented the solutions (two acids and two bases) that compose both mixtures the students would have to realise. These mixtures are exactly the same as those in Bud's lesson. The students are asked to write a chemical equation that can represent what could happen in the mixtures. They have to decide what acid and what base to write on the left of the chemical equation. Expressing the initial concentrations of chemical species in the mixture constitutes the next task and is more usual than the previous one: nevertheless, the students should not forget the dilution, which is a common mistake. In the following task, they have to realise the mixtures. The next step begins with a question: what is relevant to foresee the direction of a prospective chemical change in each mixture? It is still uncertain whether and in what mixture a change may occur. The students ought to think and propose reasons. Then they are asked to establish the literal expression of the ratio of the concentrations of the ethanoate ion and the ethanoic acid in the initial state of each system. Before realising the pH measurement, the students have to think about the usefulness of that measure, what it is possible to do with the pH value. In the last step, the students seek how to link the pH value and the ratio of the concentrations in the final state to obtain this ratio value and, finally, to compare to the ratio in the initial state.

Comparison of the Two Lesson Projects

Both teachers were pursuing the same final goal – inducing the evolution criterion from the study of acid-base mixtures. The acid-base experiments common to both lessons and their interpretations come from the accompanying booklet made by the syllabus authors. Bud slightly adapted it adding some detailed questions, whereas Dora imagined new tasks for the students: seeking the chemical equation, predicting a chemical change and looking for reasons of such a change, if any, and reflecting on the role of the measurement.

To introduce the topic, Bud proposes qualitative experiments which draw attention to the possible change in the forward or reverse direction of the chemical equation; moreover, he always provides the chemical equation involved in the experiments before their description whereas Dora's students have to find it. Knowing that a change can proceed in the forward or reverse direction of the chemical equation is not new to the students. Twice achieving this kind of experiment does not help the students grasp the central idea of that lesson, namely, how to determine the direction of change if all the species about to react are initially present? Bud seems to have misunderstood the issue of that specific lesson.

Obviously, both teachers did not make the same choices for their lesson plans, and these choices are now analysed to infer some of their pedagogical knowledge and beliefs.

Pedagogical strategies. No prediction is asked in Bud's labwork sheet, although it is possible. Bud's pedagogical strategy is classical and inductive: performing the experiment leads to observation and the interpretation or the answer to the questions then follows. The students are only performers of the different tasks in the sense they do not have to imagine what to do, almost everything is written down. On day 2, he simply described the succession of the tasks he intended to set for the students without mentioning the cognitive goals, and said he would gain time because the last part constituted an exercise which was closely related to certain examination topics. This is indicative of his lack of perspective as he did not have a clear vision of the sequence of the different concepts and of their relative importance (lacking in PCK-programme). The preparation for the examination is a more powerful factor of choice than the learning of concepts. The institutional dimension of his activity prevails over the cognitive one.

Dora's pedagogical strategy is more student-centred than Bud's. On day 2, Dora set out her session exposing all the questions she wanted the students to ask, stressing the knowledge they would have to mobilise in the reasoning she intended to conduct. Just before the session, she stated the students would not conduct many experiments but would have "to mobilise the knowledge they just acquired this year ... to put forward hypotheses, to discuss the way the system is about to change". So she intended to prompt them to reflect before conducting an experiment. Dora's students are engaged in a hypothetical-deductive approach.

Both strategies are different and thus not underpinned by the same tacit pedagogical knowledge. Nevertheless, the syllabus instructions recommend adopting pedagogical strategies that involve the students and enable them to ask questions, propose solutions, and debate. Bud read the programme and obviously chose to teach the prescribed content but not according to a student-centred strategy.

Possible classroom management. Just before the session, Bud stated that he had prepared the labwork sheet to allow the students to work in an autonomous way regarding the practical instructions and that he would "have an interaction with them" once the experiment is over. For the second part of the session, he said "the students should manage with their measurements" to answer the questions but immediately added that he was teaching this lesson for the first time and that they would "resolve the questions together even if this is not pedagogical". On day 2, after listening to Dora's lesson plan, Bud declared "my session will be more directive than yours". Bud intended to manage the classroom in a classical way: the students are to follow the instructions to perform the experiments all by themselves, and Bud would guide them to answer the questions, probably by asking a student to answer. He said another type of management in accordance with the institutional instructions is possible but he might not feel confident enough to do it. There is a tension between what he feels able to do and what he should do, that is between the personal and the institutional dimensions of his activity.

On day 2, Dora expressed her doubts because she wondered whether the students could write a chemical equation (two are possible). She was aware it could be ambitious to base the beginning of her session on an uncertainty, but she said "we'll see". She declared that the presence of a pH meter constitutes a clue for the students to imagine a solution to the problem. Dora's classroom management relies on the students' propositions and it is unclear how she would take the different propositions into account, but implicitly it does not seem to be a matter of concern.

Anticipating the Students' Lines of Reasoning and Difficulties

One of the core components of PCK is knowledge of the students' understanding of a given topic, of the kind of reasoning they may engage in regarding the different concepts that compose that topic, and of the difficulties they encounter when learning this topic. And this kind of knowledge influences the design of the lesson plan which is a result of the cognitive dimension of the teacher's activity. This explains why during the interview preceding the teaching session both teachers were asked what kind of students' reasoning and difficulties they were expecting.

Bud thought the students would have forgotten what they knew about the reaction quotient because they have been studying electricity for six weeks. For him, this is a reason not to let them work autonomously to resolve the questions of the fifth experiment. But he did not evoke any of the reasoning the students might have.

First, Dora said she expects the students would refer to the value of the constant of the acid-base couple (K_a) to predict what could happen in the mixture and later they would use the available tools such as the relationship between pH and pK_a. Then she described two errors she thought the students might make. First of all, she expected they would make a wrong prediction, the mixture made with equal volumes of acid and base solutions would not undergo any change. She then declared that the students often confuse the equivalent point (the end point of a titration) and the equilibrium state of a system and that this confusion might lead them to look for a limiting reagent whereas there is none in the equilibrium state. Finally, she emphasised they should realise that the measured pH is that of the final state of the system when the chemical change is over and they have to mobilise their knowledge in a new situation.

Dora was aware of the different concepts and type of knowledge the students would have to utilise. Moreover, she pointed to an error – no change if the same amounts (Stavridou & Solomonidou, 2000; Tyson, Treagust, & Bucat, 1999) – quoted during the training session to predict that her students might have this incorrect reasoning too. She also mentioned the widespread confusion (equivalence and equilibrium) among French students and the error it could provoke. This is sound evidence of PCK-student: quoting a difficulty and the error it may cause.

Bud could not imagine his students' difficulties and reasoning and just evoked a memory problem. The contrast between both teachers is obvious and was expected due to the nature of the PCK that mostly develops while teaching.

THE UNFOLDING TEACHING SESSION

Work Organisation

Introducing the teaching session. At the beginning of the teaching session, both teachers set out the goals of the session to their students.

Bud starts by saying they are beginning a new part in which they will use the reaction quotient. Commenting on the handout he gives out, Bud introduces his first goal: enabling the students "to see" the direction of the evolution of a chemical system while performing qualitative experiments in the first part of the session. He mentions his second goal: letting them carry out the experiments autonomously in order to prepare for the final examination. He immediately limits the scope of his talk, adding that the students should themselves note the observations but they will make the interpretations of the experiments together. Does this mean they will construct the knowledge to be learned together or that he will guide their reasoning?

Dora begins by telling her students they are going to study a new part she does not name because they have to discover it as the session progresses. She says they will have to mix a given volume of four different solutions, each containing either an acid or a base the name of which she writes down on the blackboard, and have to discuss what is going on in that mixture. Half the students will make the first mixture and the others will make the second one. She tells them "before realising a mixture and making any obscure measurements we are going to think it over" and asks them to write down a chemical equation on their paper. Dora expresses her main goal, making the students think. Indeed, this is the first task she assigns to them. Moreover, although they are in a labwork room she does not stress the practical work they will do and even more talks about "obscure measurements" as if these were not a goal of the session. Thus, measurements are presented as a tool to answer the questions that are asked.

Bud's session organisation. In the following table, to provide an overview of the way Bud organises his session, the different episodes and the different working modes are gathered. An episode corresponds to the achievement of a given task. Indeed, performing the experiment, noting the observation and interpreting it are considered as three sub-tasks of a global task, and thus correspond to a single episode, for the sake of simplicity. Different sub-tasks may correspond to different working modes: for example, students working in pairs, collective dialogue. Then an episode corresponding to a global task includes several work modes.

Bud's session is in two parts, like the lab sheet he gave out. In the first part, for each experiment described on the lab sheet, he lets the students perform the experiment, corrects their gestures, specifies some instructions and, when all the students have finished, stops the manipulation and asks them what they observed. During the collective dialogue stages, he strongly guides the interpretation, giving the students few chances to answer and then dictates a conclusion.

Although the first experiment led to an unusual conclusion so far – an evolution of the chemical system in the reverse direction of the chemical equation – he did not

Table 1. Description of Bud's unfolding session

Episode (duration)	*Working modes*	*Teacher's main actions*	*Students' main actions*
Introduction (6 min)	Teacher's talk	Sets out his goals and instructions	Listening
First experiment (15 min): colour changing from pink to blue, reverse direction	Students working in pairs, then collective dialogue	Moves between the benches, specifies instructions, strongly guides the interpretation, dictates	Perform experiments, ask questions about practical work, answer, write from dictation
Second experiment (10 min) colour changing from blue to pink, precipitate, forward direction	idem	idem	idem
Third experiment (13 min 30 s) precipitate, forward direction	idem	idem	idem
Fourth experiment (9 min 30 s) less precipitate, reverse direction	idem	idem	idem
Fifth experiment (41 min), performing mixtures and pH measurements	Students working in pairs	Moves between the benches, corrects students' gestures. At 26 min unexpected pH values. At 37 min asks students to interpret if measurements done	Perform experiments, ask questions about practical work
Responses to questions (12 min)	Collective dialogue	Writes on the blackboard, asks some students	Write, respond

stress that point. At the end of the second experiment, he did not mention that the evolution in the forward direction was the opposite of the previous conclusion. He also does not link the conclusions of the third and fourth experiments. To conclude the first part, he only says that “the test tube experiments are over” and the students may clean the equipment and then calibrate the pHmeter. He does not link what was done and what is supposed to be noticed (that a chemical system may evolve in the forward or reverse direction of the written chemical equation depending on its initial composition) with the following experiment (the fifth one).

During the fifth experiment, some students obtain much lower pH values than expected. He tells them to take another pHmeter but the pH values do not change and he does not propose to make the mixture again. Nevertheless, he could have suspected an error because two different ethanoic acid solutions were used during the session. A pH calculation shows that using the most concentrated solution instead of the less concentrated one leads to a value close to that measured. This incident reveals that Bud is restricted by time, he could have asked them to realise the mixture once again, and that he is not confident enough in his content knowledge.

At the end of the fifth experiment, a student asks Bud: “why doesn’t the colour change?”.

Bud answers: “because this wasn’t the fun part of the practical work”.

This answer is very revealing: for Bud, the experiments have to catch the students’ attention to entertain them and the cognitive reflection comes next. This answer could also have been a joke if he had then added an explanation, but he did not.

The choice of visual experiments could have been motivated to prompt the students to ask questions, to let them make a prediction which could be easily checked or rejected. On day 2, after listening to his proposal Dora suggested he did so. Bud did not lead his students down this path and had no intention of doing so according to his previous declarations.

Dora’s session organisation. The different episodes and working modes in Dora’s session are gathered in Table 2.

Dora gives information orally and instructions step by step. Dora alternates different working modes while the students have to achieve various tasks. They have to think twice in silence to resolve a question set by Dora. During these episodes, Dora moves from bench to bench and discovers some unexpected answers. She asks the student to explain his/her line of reasoning, and their conversation takes place in hushed voices. During the collective dialogue stages, Dora makes some brief talks to recall the objective of her question or of the reasoning and the result they just obtained. When the students are working in pairs, she tries to get explanations from each pair she debriefs.

During the first student research stage, as she said later, she is very surprised by the chemical equation proposed by Chloé. Chloé wrote four species on the left of the chemical equation (the four chemicals were present in the initial state of the system) and was then wondering about the species she could write on the right. For

Table 2. Description of Dora's unfolding session

Episode (duration)	*Working modes*	*Teacher's main actions*	*Students' main actions*
Ep 1: Introduction (6 min 30 s)	Teacher's talk	Sets out the solutions and the mixtures to realise, asks for a chemical equation	Listen, take notes
Ep 2: Seeking a chemical equation (6 min 45 s):	Student's individual reflection	Moves between the benches, spends 4 min with Chloé and Lucile	Think
Ep 3: Sharing answers and problem enunciation (9 min 15 s)	Collective dialogue	Writes on the blackboard; sets out the problem, asks for the literal expression of the initial concentrations	Justine dictates the chemical equation, students listen, take notes, respond
Ep 4: initial concentrations (8 min 30 s)	Student's individual reflection	Moves between the benches, realises students cannot succeed and decides to change the task	Seek
Ep 5: Realisation of the mixture (14 min)	Students working in pairs and reflecting	Moves, helps some pairs	Perform experiments, try to write the expression of concentrations
Ep 6: Looking for reasons and predictions (25 min)	Collective dialogue	Writes on the blackboard, asks for predictions, tries to elicit their arguments	Listen, write, respond
Ep 7: pH measurement and calculations (28 min)	Students working in pairs and reflecting	Moves, helps some pairs, to all, focus on logarithm function, focus on the goal of the measurement	Perform measurement, write, seek

the second student research stage (episode 4), Dora realises that the students cannot write the literal expression of the solutes concentrations in the mixture they are about to make. She decides to stop this task and asks the students to make the mixture, hoping it will help them later express the solutes concentrations. This is clearly a decision she took after seeing that the students were not succeeding.

In the following collective dialogue stage, she asks them whether and how the composition of the mixtures would change. She prompts them to put forward hypotheses to support their predictions, she excludes Lucile's proposition which relied on the chemical equation and interacts with her to explain why, and requires a justification for the second proposition which is about the volumes of the different solutions, as she anticipated before the teaching session. Then she claims that pH measurements are needed to come to a decision.

Dora's pedagogical strategy was fruitful because the students dared to express their ideas, some inadequate (or unexpected) ideas arose and one of them supported a prediction so that the teaching session could continue.

Comparison of the two performed teaching sessions. Both sessions have some common features: the teachers did not come to the end of their project; they addressed the same topic of acid-base mixtures; the students worked in pairs, the teacher moved between the benches, collecting information on the achievement of the task and making some adjustments, giving precise instruction or help.

Both teachers alternated between different stages: teacher speaking without questioning the students, collective dialogue stages when they questioned different students, students working in pair stages.

The difference lies in the work organisation, the place given to the students' reasoning and the practical tasks. Dora dedicates moments in the session to the students' autonomous reflection, lets the students express their ideas and tests their plausibility during the collective dialogue stage, and sums up the questions and the statements periodically to specify the objectives they are trying to achieve together. Bud does not. Bud's students spent 1 hour on practical tasks versus 20 minutes for Dora's students (both sessions lasted 1 h 40 min). Although Dora lets her students take notes, Bud dictates everything that he wants them to write down.

Bud does not pay the same attention to the calculation of solutes concentrations as Dora. She spent time (4th episode, 22 minutes) to be sure that nearly all the students achieved the calculation. In the last episode (2 minutes), Bud questions a student who gives a wrong answer, corrects him by telling how to write the expression, writes it on the blackboard, and finally asks the other students the result of the calculation. The roles ascribed to the students are different: often performers of detailed tasks in Bud's session, they just have to give an answer, whereas in Dora's they are also prompted to suggest solutions or ideas that are not in writing.

Both teachers share some PK-management, but not all of their PK-strategy as the *a priori* analysis foresaw.

Interactions between the Students and the Teacher: Scaffolding the Students

There are several ways to support the students' activity. The focus will be on three aspects: help to achieve the manipulations, help to provide answers, and landmarks to follow realisation of the tasks.

Practical aids. During the students-working-in-pairs stages, Bud gives new instructions to all the students when some instructions are lacking or not precise enough in the lab sheet, he repeatedly corrects the students' practical gestures when they are manipulating. At about this point during the self-confrontation, he wonders why the students always ask "why", for example asking why the beaker has to be tilted 45 degrees when dispensing a liquid inside with a volumetric pipette. He says that he answers "because of the user manual" and seems quite disconcerted by the frequency of these questions. Explaining why to the students could allow them to better understand the reason for the gesture and how to better achieve it. He notices the students' difficulty but does not provide a means to overcome it (lacking in PCK-strategy).

During Dora's session, the students only have two occasions to manipulate; first, they prepare a mixture and then measure its pH. She does not correct their gestures as they transfer volumes of liquids with pipettes but repeats twice that they have to rinse the pH probe.

Aid to providing answers. To help his students answer questions Bud asks numerous simple questions. He splits the original task into several micro-tasks (PK-strategy). The students generally answer briefly. During the self-confrontation, Bud said that the students understood because they answered the questions he had asked. Nevertheless, they did not create the line of reasoning. At the end of the 4th episode, Bud wants the students to link a visible cue (the observation of a white precipitate formation) with a chemical change in the forward direction of the chemical equation. He has used this kind of reasoning twice before with them. But when he asks them to look at the chemical equation to conclude, the students fail to provide a relevant answer. Then Bud again splits the reasoning into smaller pieces and obtains answers to his successive questions. This incident reveals that, although Bud showed the students how to interpret the previous experiments, in a new situation they cannot. Without help, they are unable to link the tiny tasks Bud proposed. The collective dialogue thus looks like a teacher's talk with some holes that the students fill in (Kermen & Barroso, 2013; Venturini, Calmettes, Amade-Escot, & Terrisse, 2007).

Dora also asks her students numerous questions. But, unlike Bud, she mostly gives them time to answer. Dora tries to help her students express their idea and not just answer to the questions she asked. For instance, when she asks them in episode 6 to put forward a hypothesis to justify whether the composition of mixture 1 or of mixture 2 should change or not, Lucile suggests that it depends on "the volume put in the solution", Dora reformulates by saying it depends on the initial state and asks why. Lucile answers "the volumes are not the same" and Dora carries on specifying her response and asking a new question "the initial amounts of the species are different so what are you going to predict?". Lucile suggests a direction of change, and Dora keeps questioning her until she gives the reasons for her choice, the amount of one species is lower than the other (PCK-strategy). Dora holds detailed discussions, taking each argument into account (PK-strategy).

Landmarks. Bud's session is strongly structured, he ends the interpretation of each experiment with a conclusion he dictates. During the self-confrontation, he says he periodically concluded for the students' progress at the same rhythm but recognises he dictated too much. However, he did not link the different conclusions whereas he could have helped the students better understand the final goal of the session and how to reach it. So the experiments appear disconnected and their goals are not obvious.

Dora frequently sums up what they are seeking and why, what they know and what the problem is. She also formulates these ideas and questions in several and successive ways. Thus, she talks a lot and her students ought to be attentive. During the self-confrontation, she noticed that and justified it by saying she wants them to understand the objective before achieving the task.

To summarise, it appears that Bud tends to foster the acquisition of practical skills and the production of answers without trying to elicit the students' thinking and reasoning, whereas Dora tries to promote the acquisition of knowledge and the expression of students' ideas but pays little attention to the students' practical skills.

COMMENTING ON THE UNFOLDING TEACHING SESSIONS AND THE CLASSROOM VIDEOS

In this section, the comments made by the teachers on their pedagogical strategy, classroom management and the students' understanding are reported and linked to the domains of teachers' professional knowledge if possible and to the dimensions of their activity.

Bud's Comments

Watching his classroom video does not enable Bud to acknowledge that his students had encountered conceptual difficulties. Before the session, Bud could not foresee the students' difficulties and does not notice them in the video (lacking in PCK-student) whereas his students encountered the same difficulties in expressing the solutes concentrations as Dora's students. He simply expected the students to have forgotten what the reaction quotient is. However, a student supposed to be a low-achiever[2] gives the correct expression of this quotient in answer to Bud's question and Bud makes no comment (lacking in PCK-student).

Although Bud says he struggles to make comments at his session, he considers several modifications regarding the mediative dimension of his activity. Watching a student pair who did not mix the right solutions (3rd experiment), he says that instead of mentioning what was wrong he could have asked the other students to correct that pair (PK-strategy). Regarding the last experiment, he recognises that he should have split the students into two groups, with each group making a single pH measurement to gain time (PK-management). He reconsiders the choice he made when designing the lesson plan to let the students perform many experiments. He says that during the teaching session he became aware of the time needed to realise the interpretation of the final experiment and of the interest of this task which is closely related to what can be required at the examination. He concludes by saying he would have only a single introductive experiment achieved by a student at the teacher's desk (another distribution of tasks) and revises the role of the students who would not be compelled to write under dictation (PK-management). The cognitive dimension of his activity is influenced by two other interwoven dimensions, mediative and institutional.

As a beginning teacher, Bud mentions several times that he has no prospective vision and no point of comparison. He notices that he often reads his notes during the session, and justifies that because he does not want to blunder, which is a sign that he lacks self-confidence and may not master CK. He usually asks colleagues in the high school for advice (social dimension) but cannot for this topic because unfortunately the other teachers do not organise practical work session on it and being left behind (relative to them) worries him.

Dora's Comments

During the self-confrontation, Dora makes a lot of remarks regarding the mediative dimension of her activity. She realises that the lack of a labsheet provoked a communication problem because the students did not know the names of the chemical species and this prevented them from discussing the difference between both mixtures, and wasted time (PK-management). She could actually have anticipated this student difficulty (lacking in PCK-student). The choice of classroom management, giving a paper or not, combined with a lack of knowledge of students' difficulty has a consequence for the progress of the session.

Dora states she encountered dilemmas: i) letting each student reflect on his/her own production and then supporting the students one by one or choosing a particular student's response as a starting point and guiding all of them together to reach the goal (PK-strategy); ii) guiding the students to give rhythm to the session or giving them time to reflect, but she ignores what proportion of guidance should be chosen for keeping enough rhythm (PK-management).

Watching the video, she explains the students' errors enabled her to discover incorrect lines of reasoning she did not suspect (new PCK-student). For instance, she describes Chloé's mistake and explains that writing all species formulas on the same side of the chemical equation means not imagining that some of them will be consumed and others will be produced.

She stresses the students cannot calculate the solutes concentrations in a mixture. During the session, seeing this difficulty she interrupted the students' reflection and asked them to perform the experiment (PK-strategy). She says this change responds to a need, helps the students imagine what is at stake and boosts the rhythm of the session (PK-management). Dora reminds us of the particular goal she has pursued from the beginning of the academic year – to obtain the literal expression of a species concentration – this difficult task for her students is reinforced here by the impossibility to imagine the initial state of the system. She admits she did not expect this other difficulty (new PCK-student) and wonders about a more efficient strategy: Making the mixture and then expressing the concentration or expressing them before achieving the mixture (PCK-strategy)? According to Dora, the result was unsatisfactory for two reasons; first, the phenomenon is too fast so the students cannot visualise the initial state and, second, it is an abstract state and thus not visible, contrary to the initial state of a mechanical system.

She wonders about the relevance of the order of tasks she prescribed to the students (PK-strategy). She admits that making them reflect on the whole approach before they achieve the concentration calculation and the mixtures was too early. Although they did not construct the whole reasoning, she nevertheless thinks they understood what she proposed.

SUMMING UP THE RESULTS

Bud's activity seems to be mostly oriented to the following objectives: the students have to successfully and autonomously achieve the prescribed hands-on tasks, they must have correct written notes of the results and interpretations. He therefore specifies the instructions to achieve the hands-on tasks and strongly guides the students to interpret the experiments towards the right answer, but he does not necessarily try to discover how they reason.

Dora's activity appears principally oriented to questioning the students so that they reflect on the prescribed tasks and achieve them. She promotes individual interactions with the students while she examines the students' reasoning and tries to modify it. To maintain the students' engagement, she frequently sums up the ongoing approach and stresses the key issues. The experiment is a means to achieve the goal of the lesson and its technical achievement comes next.

The different analyses are convergent, Dora exhibits different PK than Bud (Table 3) and more PCK than him (Table 4). They reveal that Bud is subjected to tensions between the personal and institutional dimensions of his activity like other beginning teachers (Brickhouse & Bodner, 1992; Sweeney, Bula, & Cornett, 2001) and Dora expresses dilemmas about the best way to engage the students' reflection, which is a sign of her reflective ability and probably of a tension between the mediative and cognitive dimensions of her activity.

DISCUSSION AND IMPLICATIONS

The pedagogical strategy enacted by Dora enabled her to interact quite deeply with the students. She recognised the students' difficulties and reasoning and helped them use adequate elements of chemical content knowledge (Alonzo et al., 2012). Conversely Bud, who nevertheless possesses content knowledge, did not provide explanations using chemical content in response to the students' difficulties (about pH) or questions (about pipette). Using the content knowledge in interactions with students is one aspect of PCK that has an effect on students' knowledge (Alonzo et al., 2012). Alonzo and colleagues observed two German physics teachers with

Table 3 (part 1). Examples of the teachers' PK

		Description of action corresponding to reconstructed knowledge	*before or during the unfolding session*		*during the self-confrontation*	
			Bud	*Dora*	*Bud*	*Dora*
PK-strategy	global strategy	strongly teacher-guided inductive approach	x			
		hypothetical-deductive approach and students' proposals taken into account		x		
	specific strategy	holding detailed discussions with the students to elicit their reasoning		x		
		dilemma: following each student's reasoning or imposing a student's reasoning on all?				x
		interrupting a task completion to begin another task in order to revive the students' reflection		x		
		making the student think about the whole approach before thinking about a specific task				x
	nature and diversity of tasks	students perform experiments in pairs	x	x		
		students think alone		x		
		students propose reasoning, argument or hypothesis		x		
		splitting a task into separate micro-tasks	x			
		students correct other students			x	
PK-management	time available	to perform experiments	x	x		
		to think		x		
		to propose an answer		x		
		dilemma: giving time for students' reflection or strongly guiding students?				x
	tasks distribution	all students conduct the same experiment	x			
		half the students conduct one experiment		x		
		a student conducts an experiment at the teacher's desk			x	
	landmarks	notes taken by students		x	x	
		conclusions dictated by teacher	x			
		frequent summing up by the teacher		x		

Table 3 (part 2). Examples of the teachers' PK

		Description of action corresponding to reconstructed knowledge	*before or during the unfolding session*		*during the self-confrontation*	
			Bud	*Dora*	*Bud*	*Dora*
PK-discourse	communication	students express their ideas		x		
		students fill in holes in teacher's talk	x			
		instructions are written	x			x
		instructions are told orally step by step		x		

Table 4. Examples of the teachers' PCK

	Description of actions corresponding to reconstructed knowledge	*before or during the unfolding session*		*during the self-confrontation*	
		Bud	*Dora*	*Bud*	*Dora*
PCK-student	anticipating students' reasoning e.g. relying upon pK_a value to predict a chemical change		x		
	predicting some students' errors, e.g. no chemical change if species amounts are equal		x		
	explaining students' unexpected answers, e.g. Chloé's chemical equation				x
	identifying students' errors or difficulties, e.g. Nicolas' idea who thought a base could not exist in an acid solution		x		
	practical aids, e.g. correcting gestures to transfer liquid with a pipette	x			
PCK-strategy	correcting students' errors (without discussion)	x			
	eliciting students' reasoning, e.g. Lucile's proposal about the different volumes and the direction of chemical change		x		x
	time left for reflection and calculation		x		
	Dilemma: expressing the solutes concentrations then making the mixture, or conversely?				x

strong content knowledge and proved that the students who had deeper knowledge belonged to the class of teacher whose aspect of PCK was more developed (Alonzo et al., 2012). Students' knowledge was not assessed in this study, but the nature of the interactions with Dora and her students proved that her students had grasped some important points, contrary to Bud's students. Our results therefore partially agree with the findings of Alonzo and colleagues.

Bud favoured a procedural approach (answering questions) to a conceptual understanding (which Dora seemed to promote). Rollnick, Bennett, Rhemtula, Dharsey and Ndlovu (2008) attribute this behaviour in the case of two South African teachers they observed to their limited understanding of the chemical concepts. Indeed, Bud showed some limitations in his understanding of the lesson goals. When confronted with his classroom video to reflect on his practice, he revised the role of the introductory experiment and thus partially readjusted his understanding of the topic. Rollnick and her colleagues (2008) consider such a change as a sign of an approach promoting conceptual understanding in the classroom practice. Our study does not support this claim. Evidence of a future change in Bud's pedagogical strategy towards a more student-centred approach is unclear. When he proposed some modifications, he still did not consider eliciting the students' reasoning nor prompting them to ask questions whereas it is a means to stimulate constructive learning (Chin & Osborne, 2008).

The first reason to carry out the comparison between the teachers' activities was their different teaching experience. "Does the teaching experience matter?", asked Friedrichsen and her colleagues (2009). Indeed, they studied the impact of teaching experience on lesson planning in biology secondary education among beginning teachers and members of an alternative certification programme without any teaching experience, where neither had previously taught the topic "heritable variation". They found that all participants of their study relied on PK rather than PCK to plan their lesson, that they "viewed 'teaching as telling'" and that this orientation was perceptible in their lesson plan (Friedrichsen et al., 2009). The difference in both groups of participants was in PK whose components were more integrated among the beginning teachers (Friedrichsen et al., 2009). They concluded that the teachers had not gained topic-specific PCK about the topic "heritable variation" (Friedrichsen et al., 2009), which is not surprising because they had not taught it before and PCK is rooted in classroom practice (Loughran et al., 2001; van Driel et al., 1998). Moreover, they claimed that

> teaching experience, in the absence of teacher education, supported the development and initial integration of PK components, but did not lead to PCK development. (Friedrichsen et al., 2009, p. 376)

Although both methodologies vary, our findings confirm their results (Bud's case) and supplement them regarding PCK development (Dora's case). Dora integrated the students' conceptions about the direction of change (Stavridou & Solomonidou, 2000; Tyson et al., 1999) that had been presented on the first day of the teacher training session, to change the nature of the tasks the students had to achieve (predicting a direction of change instead of applying a law). There is evidence that this strategy enabled her to discover some new alternative ideas. Further, Dora did not content herself with giving rise to incorrect ideas but examined the students' reasoning that underpinned their answer, which allowed her to enhance her PCK-strategy. Examining the students' difficulties during the training session acted as a valid intervention for the development of Dora's knowledge and supports Gess-Newsome's claim (2013) as well. On the contrary, the training session had a limited impact on Bud's knowledge who needed to enact his project before considering modifying it. Having not taught that topic before, Bud could not reflect on his previous teaching experience and did not increase his topic-specific PCK during his teaching session.

Bud seemed reluctant to engage a student-centred strategy, which has been reported in other studies also involving experienced teachers (Barak & Shakhman, 2008; Laius, Kask, & Rannikmäe, 2009). A long-term study (three years) involving sciences and mathematics beginning teachers showed that the majority "espoused and enacted a teacher-centred teaching style" (Simmons et al., 1999). As Magnusson, Krajcik and Borko (1999, p. 111) stated:

> The transformation of general knowledge into pedagogical content knowledge is not a straightforward matter of having knowledge; it is also an intentional act in which teachers choose to reconstruct their understanding to fit a situation.

Dora's willingness to revise her understanding was salient when she said on day 2 that she had made a lot of errors before and, as a consequence, changed the nature of the tasks and her pedagogical strategy. Indeed, Bud knew that a strategy other than his teacher-centred pedagogy is desirable according to the syllabus instructions but he did not change it and had no intention to. Does this kind of strategy contradict his beliefs about teaching? Or does Bud consider that enacting both a new lesson content and a new strategy would exceed his capacities? Gess-Newsome (2013) states the teacher's beliefs "extinguish student-centred instructional practices" and act as a filter.

To summarise the findings of this case study, the increase in PCK especially PCK-student and PCK-strategy during and after a session about a specific topic is allowed by a student-centred pedagogical strategy and depends on the teacher's reflective ability, among others. Moreover, this case study suggests that the teacher should feel able to conduct such strategy and thus another issue arises: does the teacher's belief he/she has to be able to achieve this strategy play a significant role in such a change in strategy?

Some limitations should be taken into account. The observation of the teaching session does not give information on what the students effectively learn, but only indications of their activity. Nevertheless, in Dora's class some students' reactions lead to thinking they understood what was at stake. The training session intended to enhance teachers' knowledge in two domains, CK and PCK, and was destined for experienced teachers. Given the brevity of the session, the choice was made not to address pedagogical strategies and thus PK. Indeed, the participation of a beginning teacher was not expected because usually grade 12 classes are entrusted to experienced teachers. However, it appears that the training session should have included a third dimension encompassing pedagogical strategies and students' learning.

Teacher training sessions that address all these dimensions should continue and associate researchers and teachers of a same school in a medium-term project (Venturini & Tiberghien, 2013). Examples of such sessions could be designed according to projects like Nilsson's learning study (Nilsson, 2014) or the AeDeP (Associated educational Design-experiment Places), a research network being implemented by the French Institute of Education (IFE) in which an educational project binds teachers of an educational institution and researchers with the support of the institution.

NOTES

1 All tasks are listed, but only those of the second part are detailed because they share some commonalities with the task Dora assigned to her students.

2 According to Bud's appraisal.

REFERENCES

Alonzo, A. C., Kobarg, M., & Seidel, T. (2012). Pedagogical content knowledge as reflected in teacher-student interactions: Analysis of two video cases. *Journal of Research in Science Teaching*, *49*(10), 1211–1239.

Barak, M., & Shakhman, L. (2008). Reform-based science teaching: Teachers' instructional practices and conceptions. *Eurasia Journal of Mathematics, Science & Technology Education*, *4*(1), 11–20.

Brickhouse, N., & Bodner, G. M. (1992). The beginning science teacher: Classroom narratives of convictions and constraints. *Journal of Research in Science Teaching*, *29*(5), 471–485.

Chin, C., & Osborne, J. (2008). Students' questions: A potential resource for teaching and learning science. *Studies in Science Education*, *44*(1), 1–39.

Corrigan, D. (2009). Chemistry teacher education to promote understanding of learning through effective reflective practice. *Chemistry Education Research and Practice*, *10*(2), 121–131.

Crahay, M., Wanlin, P., Issaieva, É., & Laduron, I. (2011). Fonctions, structuration et évolution des croyances (et connaissances) des enseignants. *Revue française de pédagogie*, *172*(3), 85–129.

Cross, D. (2010). Action conjointe et connaissances professionnelles de l'enseignant. *Éducation et didactique*, *4*(3), 39–60.

Farré, A. S., & Lorenzo, M. G. (2009). Another piece of the puzzle: The relationship between beliefs and practice in higher education organic chemistry. *Chemistry Education Research and Practice*, *10*(2), 176–184.

Fernández-Balboa, J.-M., & Stiehl, J. (1995). The generic nature of pedagogical content knowledge among college professors. *Teaching and Teacher Education*, *11*(3), 293–306.

Friedrichsen, P., Abell, S. K., Pareja, E. M., Brown, P. L., Lankford, D. M., & Volkmann, M. J. (2009). Does teaching experience matter? Examining biology teachers' prior knowledge for teaching in an alternative certification program. *Journal of Research in Science Teaching*, *46*(4), 357–383.

Friedrichsen, P., & Dana, T. M. (2005). Substantive-level theory of highly regarded secondary biology teachers' science teaching orientations. *Journal of Research in Science Teaching*, *42*(2), 218–244.

Gess-Newsome, J. (2013). *The PCK summit consensus model and definition of pedagogical content knowledge*. Paper presented at ESERA2013 conference, Nicosia, Cyprus, Europe.

Kermen, I., & Barroso, M. T. (2013). Activité ordinaire d'une enseignante de chimie en classe de terminale. *Recherches en didactique des sciences et des technologies*, *8*, 91–114.

Kermen, I., & Méheut, M. (2011). Grade 12 French students' use of a thermodynamic model for predicting the direction of incomplete chemical changes. *International Journal of Science Education*, *33*(13), 1745–1773.

König, J., Blömeke, S., Paine, L., Schmidt, W. H., & Hsieh, F. J. (2011). General pedagogical knowledge of future middle school teachers: On the complex ecology of teacher education in the United States, Germany, and Taiwan. *Journal of Teacher Education*, *62*(2), 188–201.

Laius, A., Kask, K., & Rannikmäe, M. (2009). Comparing outcomes from two case studies on chemistry teachers' readiness to change. *Chemistry Education Research and Practice*, *10*(2), 142–153.

Loughran, J., Milroy, P., Berry, A., Gunstone, R., & Mulhall, P. (2001). Documenting science teachers' pedagogical content knowledge through PaP-eRs. *Research in Science Education*, *31*(2), 289–307.

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome & N. G. Lederman (Éds.), *Examining pedagogical content knowledge* (pp. 95–132). The Netherlands: Springer.

Morine-Dershimer, G., & Kent, T. (1999). The complex nature and sources of teachers' pedagogical knowledge. In J. Gess-Newsome & N. G. Lederman (Éds.), *Examining pedagogical content knowledge* (pp. 21–50). The Netherlands: Springer.

Nilsson, P. (2014). When teaching makes a difference: Developing science teachers' pedagogical content knowledge through learning study. *International Journal of Science Education*, *36*(11), 1794–1814.

Padilla, K., & van Driel, J. (2011). The relationships between PCK components: The case of quantum chemistry professors. *Chemistry Education Research and Practice*, *12*(3), 367–378.

Park, S., & Oliver, J. S. (2008). Revisiting the conceptualisation of pedagogical content knowledge (PCK): PCK as a conceptual tool to understand teachers as professionals. *Research in Science Education*, *38*(3), 261–284.

Rix-Lièvre, G., & Lièvre, P. (2012). La dimension «tacite» des connaissances expérientielles individuelles: une mise en perspective théorique et méthodologique. *Management International*, *16*, 21–28.

Robert, A. (2008). La double approche didactique et ergonomique pour l'analyse des pratiques d'enseignants de mathématiques. In F. Vandebrouck (Éd.), *La classe de mathématiques: activités des élèves et pratiques des enseignants* (pp. 59–68). Toulouse, France: Octarès Editions.

Robert, A., & Rogalski, J. (2002). Le système complexe et cohérent des pratiques des enseignants de mathématiques: Une double approche. *Canadian Journal of Science, Mathematics and Technology Education*, *2*(4), 505–528.

Robert, A., & Vivier, L. (2013). Analyser des vidéos sur les pratiques des enseignants du second degré en mathématiques: des utilisations contrastées en recherche en didactique et en formation de formateurs-quelle transposition? *Éducation et didactique*, *7*(2), 115–144.

Rogalski, J. (2003). Y a-t-il un pilote dans la classe? Une analyse de l'activité de l'enseignant comme gestion d'un environnement dynamique ouvert. *Recherches en didactique des mathématiques*, *23*(3), 343–388.

Rogalski, J. (2013). Theory of activity and developmental frameworks for an analysis of teachers' practices and students' learning. In F. Vandebrouck (Éd.), *Mathematics classrooms: Students' activities and teachers' practices* (pp. 3–22). Rotterdam, The Netherlands: Sense Publishers.

Rollnick, M., Bennett, J., Rhemtula, M., Dharsey, N., & Ndlovu, T. (2008). The place of subject matter knowledge in pedagogical content knowledge: A case study of South African teachers teaching the amount of substance and chemical equilibrium. *International Journal of Science Education*, *30*(10), 1365–1387.

Schön, D. A. (1996). A la recherche d'une nouvelle épistémologie de la pratique et de ce qu'elle implique pour les adultes. In J. M. Barbier (Éd.), *Savoirs théoriques et savoirs d'action* (pp. 201–222). Paris, France: Presses Universitaires de France.

Shulman, L. S. (1987). Knowledge and teaching foundations of the new reform. *Harvard Educational Review*, *57*(1), 1–23.
Simmons, P. E., Emory, A., Carter, T., Coker, T., Finnegan, B., Crockett, D., … Labuda, K. (1999). Beginning teachers: Beliefs and classroom actions. *Journal of Research in Science Teaching*, *36*(8), 930–954.
Stavridou, H., & Solomonidou, C. (2000). Représentations et conceptions des élèves grecs par rapport au concept d'équilibre chimique. *Didaskalia*, *16*, 107–134.
Sweeney, A. E., Bula, O. A., & Cornett, J. W. (2001). The role of personal practice theories in the professional development of a beginning high school chemistry teacher. *Journal of Research in Science Teaching*, *38*(4), 408–441.
Tyson, L., Treagust, D. F., & Bucat, R. B. (1999). The complexity of teaching and learning chemical equilibrium. *Journal of Chemical Education*, *76*(4), 554.
Vandebrouck, F. (Ed.). (2013). *Mathematics classrooms*. Rotterdam, The Netherlands: Sense Publishers.
van Driel, J. H., Verloop, N., & de Vos, W. (1998). Developing science teachers' pedagogical content knowledge. *Journal of Research in Science Teaching*, *35*(6), 673–695.
van Driel, J. H., Beijaard, D., & Verloop, N. (2001). Professional development and reform in science education: The role of teachers' practical knowledge. *Journal of Research in Science Teaching*, *38*(2), 137–158.
Venturini, P., & Tiberghien, A. (2013). La démarche d'investigation dans le cadre des nouveaux programmes de sciences physiques et chimiques: étude de cas au collège. *Revue française de pédagogie*, *180*(3), 95–120.
Venturini, P., Calmettes, B., Amade-Escot, C., & Terrisse, A. (2007). Analyse didactique des pratiques d'enseignement de la physique d'une professeure expérimentée. *Aster*, *45*, 211–234.
Wanlin, P., & Crahay, M. (2012). La pensée des enseignants pendant l'interaction en classe. Une revue de la littérature anglophone. *Education & Didactique*, *6*(1), 9–46.

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