Chapter 29
Analysis of Teaching and Learning Practices in Physics and Chemistry Education: Theoretical and Methodological Issues

Patrice Venturini, Andrée Tiberghien, Claudia von Aufschnaiter, Gregory Kelly, and Eduardo Mortimer

1 Introduction

Over the past decade, classroom activities have been studied with the aim of describing and modeling teaching and learning practices. Mainly based on the analysis of videotaped teachers' and students' discourses and actions, the corresponding studies relate to particular domains of research in science education. We have chosen to focus on three of them because of their importance in the field: conceptual change, meaning-making, and inquiry-based science education (IBSE). The conceptual change approach considers individual students facing concepts and their difficulties, first from a constructivist perspective and far later paying attention to social interactions and to cultural context in which meaning emerges. Instead, the meaning-making approach emerged as a consequence of the application of a sociocultural perspective to the teaching and learning processes and has a strong root in Vygotsky theory. Lastly, the chosen perspectives of inquiry-based learning environments connect teaching, learning considered from a socioconstructivist perspective and knowledge, referring to the nature of scientific knowledge and scientific practice. In spite of their differences, all of these approaches deal with science learning and

P. Venturini (✉)
University of Toulouse, Toulouse, France
e-mail: patrice.venturini@univ-tlse2.fr

A. Tiberghien
UMR ICAR, CNRS, University of Lyon 2, ENS-Lyon, Lyon Cedex, France
e-mail: andree.tiberghien@univ-lyon2.fr

C. von Aufschnaiter
University of Giessen, Giessen, Germany

G. Kelly
Pennsylvania State University, University Park, PA 16802, USA

E. Mortimer
Federal University of Minas Gerais, Minas Gerais, Belo Horizonte, Brazil

C. Bruguière et al. (eds.), *Topics and Trends in Current Science Education: 9th ESERA Conference Selected Contributions*, Contributions from Science Education Research 1,
DOI 10.1007/978-94-007-7281-6_29,

teaching processes, focusing more or less on one of them or on both. Our purpose is to give an example of studies related to each of these three approaches in order to present some theoretical frameworks and methodologies used in video-based analyses of classroom activities and discuss their interest and their limits. In each case, focusing on physics and chemistry education, we first outline the main research trends in the domain over the last decade to situate the studies on which we report after this overview. A final discussion on this kind of analyses closes the chapter.

2 Analyses of Teaching and Learning Practices Related to Conceptual Change

2.1 Overview of Research Trends

Student thinking and conceptual change have been studied since the 1970s, but studies have changed in emphasis over recent decades (Vosniadou 2008). At first, researchers mainly focused on the characterization of students' thinking (misconceptions, mental models, etc.). From the beginning of the 1990s, some science education researchers considered student thinking as a basis for a learning process leading to scientifically accepted ideas. It is only since the 2000s that research has been influenced by Vygotskian ideas and has focused more on classroom discourse. Thus, the theoretical frameworks supporting these investigations have a strong sociocultural dimension. These analyses are mainly carried out from audio or video recordings of whole-class talks and address three different (but often interrelated) issues. A first set of studies details how students develop an understanding of particular concepts and how their conceptions of these concepts change during learning, in relation with the social discussions in the classroom (e.g., Havu-Nuutinen 2005, about floating and sinking; Rincke 2011, about the concept of force). A second set of studies provides more general information on the conceptual change process. For example, Eschach (2010) reveals "conceptual flow patterns" or structures of whole-class discussions occurring within physics lessons; von Aufschnaiter and Rogge (2010) present conceptual development as "a process that develops from explorations to intuitive rule-based and then to explicit rule-based understanding." A third group of studies deals with the links between teaching practices and conceptual change. Thus, particular learning environments including teaching strategies designed to persuade children of the usefulness and validity of the target scientific concept (Loxley 2009) or chosen sets of learning goals (Beeth and Hewson 1999) influence and shape conceptual changes and student thinking. Fruitful learning environments can also encompass computer simulations (Suzuki 2005, about the concept of force) or other material artifacts (like ambiguous objects used in a sorting activity linked to the concept of matter, Varelas et al. 2008). The former (environment including computers) leads to a dialog among students who have different perspective and to a process of mutual changes in thinking, whereas the latter (environment including ambiguous objects) induces discursive spaces where there is no specific answer or way of thinking.

2.2 Analysis of Learning Practices from a Conceptual Change Perspective

Conceptual change research carried out *during* instruction, focusing on the processes by which "change" comes about, is a relatively young discipline which seems to have its roots in interviews or teaching experiments (e.g., Riemeier and Gropengießer 2008). Researchers who address conceptual change in science classrooms typically have begun to focus their attention toward classroom discourse (e.g., work done by Eshach 2010, or Rincke 2011) in which all students are talking to or with a teacher. "Conceptual change" can then have two meanings: (1) changes in how the entire class conceptualizes different science concepts, thus learning among the *community* of students, or (2) how an *individual student* develops his/her own conceptual understanding while participating in the community. For (1) a focus on entire class discussions is a useful means to investigate how different and/or new meanings of a concept evolve. Video-based research in this focus typically uses one camera to follow the teacher, whereas another camera is used to document the entire class (e.g., Seidel et al. 2005). However, the discourse of a community does not give information about individual progress. Thus, students may participate without understanding the meaning of the discussion. In order to distinguish between the community and the individual, Eshach (2010, pp. 470f.) introduces the idea of an "individual space" and a "collective space." Basing on this idea, we therefore use video in a slightly different way than it is normally employed. Within a classroom setting, we focus on student groups of three to four students. We use two to four cameras, each of which documents one group. This approach makes it possible to follow individual contribution to classroom discourse, which can be assessed completely through group cameras, but also to investigate how students make use of outcomes of this discourse for their own progress in conceptual understanding. Following Eshach's views of interactional spaces, this approach makes it possible to connect the collective space, the social and material learning opportunities, with the individual space. Importantly, it is not only an individual student's participation in classroom discourse that matters but also how he/she works on, for instance, experiments that are carried out during group work or worksheets which have to be completed and so on. These activities which occur outside whole-class discussions are a good indicator of conceptual understanding. Here, a student is typically much more active than during class discussions, which in turn makes it easier to reconstruct conceptions from verbal and nonverbal activities.

In all our research projects, we focus on student groups which are composed of two to four students, either in classroom settings or in laboratory settings in which only one group is present at a time. We do not have a camera which is directed toward the teacher but can hear the teacher on at least one group camera clearly; the same is true for all student participation in classroom discourse even if a particular student is not assessed by a group camera. Videos are coded by trained raters especially to identify the social settings (e.g., teacher talk, classroom talk, single student work, work in pairs or group work) and individual student activity (e.g., verbal content-specific activity, nonverbal content-specific activity, reading/writing, organizational activity, raise hand, observation/listen, emotional utterance, or off-task activity). In order to investigate conceptual change processes, all sequences are transcribed in which we applied codes associated with content-specific individual activity, either verbal or nonverbal. These transcripts are then investigated utterance by utterance or activity by activity to assess conceptual understanding and the progress of it. When analyzing transcripts, we focus, for instance, on whether ideas are “correct,” which level of conceptualization these ideas have (e.g., v. Aufschnaiter and Rogge 2010), how many content elements are interrelated, and how long coherent activities take. We also assess how students experience their current activities and their learning.

As an example, Table 29.1 shows the discussion of three students (grade 11, about 16 years old) about how warm different objects feel. In the right column, our analysis of the students’ utterances is presented with reference to the different categories we typically employ (underlined). In the excerpt, the students seem to realize for the first time that even though different materials (here: the metal blades of the scissors and the plastic handle) feel differently warm, they can have the same temperature. Overall, it takes them about 10 min with repeated own activity to realize the difference between sensory experience and measured temperature. This experience helps them to establish a conceptual understanding of the zeroth law of thermodynamics in the further course of the instruction.

Results of our work can inform science education in different ways:

(a) From differences and similarities in different students’ conceptual change processes, we can generalize patterns which describe how concepts are formed and stabilized through individual activities. Especially, our results indicate that own experiences play a crucial role in concept formation and that conceptual change processes seem to be spiral rather than linear; establishing new conceptual understanding thus requires “back-and-forth movement” (e.g. v. Aufschnaiter and Rogge 2010).
(b) From relating social and material learning opportunities on the “collective space” to individual conceptual change processes, we can conclude which kind of learning opportunities promote conceptual change processes or may hinder them. Previous research has revealed that it seems to be very important for “information” – for instance, a teacher explanation or an explanation given by another student – to match what the individual student already knows (e.g., v. Aufschnaiter 2003). Even though this result sounds trivial taking into account Vygotsky’s (1978) idea of the zone of proximal development, it is harmed repeatedly in everyday teaching by teachers asking questions which students cannot answer, giving explanations which are far away from students’ current experiences and understanding, and so on.
(c) The methodological approach taken broadens current video-based classroom research as it moves away from videoing whole-class settings toward documenting individual student activity while taking part in instruction. The benefit of this

Table 29.1 Analysis of students' discussions about how warm objects feel

Transcript	Analysis (references to categories used are underlined)
Scene 1 [7:00–7:35]	Students explore phenomena
(*The scissors plastic handle is measured*)	
S2:24. Oh [surprised]	Students are astonished about the result of their exploration
S1:We do not know the room's temperature	Students start to cross-connect content, but it is not clear what this cross-connection is about to mean
(*The scissors metal blades are measured*)	Exploration
S1:I reckon 16. What does the thermometer say?	Students have an intuition about the phenomenon. This intuition is not correct
S3: (Looks at thermometer) 23	Exploration
S2: Point 8	Exploration
(Students giggle)	Indicates students' experiences (astonishment/irritation)
S2: Point 7.	Exploration
That cannot be true. I'll have a look on the other side (turns scissors around). 23.7. It is freezing cold [ironically]	Intuition about the outcomes which is not correct. Further exploration. [Turning around the scissors doesn't make sense here and indicates how strong the intuition is and how demanding the physics concept is for the students]
(Students giggle)	Indicates students' experiences (astonishment/irritation)
S1: Strange	
Scene 2 [8:35-8:40]	Exploration
S2: (Touches blades and handle).	Intuition about the outcomes which is not correct
That is so differently warm, that cannot be true	
S1: (Touches blades)	Exploration
Scene 3 [18:18-18:32]	Exploration
S3: (Measures temperature of the air) 22.7	
S1: Oh [surprised]	Experiences
S2: Well, all objects…	Elaboration indicates an intuitive understanding of a certain concept (but is not yet expressed conceptually)
S3:are warmer…	
S2: All are warmer than the air. Including those we thought of as cold	
S3: Yes. Awesome, really	Experiences

approach is information on what constitutes "optimal" teaching. The indicator for teaching which is "in situ" optimal is how it promotes content-specific individual activity in the class, for as many students as possible. A camera which focuses on the entire class cannot give enough information on individuals as these appear as small "spots" on the video for which we can often not say in detail what the students are doing or discussing.

3 Analyses of Teaching and Learning Practices Related to Students' Meaning-Making in a Sociocultural Context

3.1 Overview of Research Trends

Two research trends based on a sociocultural perspective directly address the question of students' meaning-making in socially shared practices. The first one, rooted in Swedish research, is also inspired by pragmatism and the late works of Wittgenstein. Its focus is "to use a formal theory of meaning-making in illuminating the connection between how people produce meaning and what meaning is produced in a specific practice" (Wickman 2004). It considers learning as a dynamic process where relationships are constructed in encounters between individuals and between individuals and the world (Wickman and Östman 2002). Learning proceeds when people notice gaps and fill them with relations they build to what stands fast in these encounters (i.e., is not questioned in talks or acts). This theoretical mechanism for learning provides a methodological approach for analyzing video-recorded students' talk and action, for noting the details of how discourses change and how students become participants in new practices, and thus for describing people's ways of making meaning in action in a particular sociocultural context (e.g., Lidar et al. 2010a, b, about gravity and the shape of the Earth; Wickman 2004, about practical work in inorganic chemistry). The students' "practical epistemology analysis" is completed by an "epistemological moves analysis" to categorize the actions that a teacher takes with the aim of helping students to learn. Using both analyses allows the researcher to investigate the relation between the epistemological moves that teachers make in teaching and the practical epistemology that the students use in their learning process (Lidar et al. 2010a, b), shedding light on the interplay between these intertwined activities (Lidar et al. 2006).

The second trend (Mortimer and Scott 2003) is mainly focused on the teacher as its concern is to characterize "the various ways in which the teacher acts to orchestrate the talk of science lessons in order to support student learning" (p. 24). To reach this aim, Mortimer and Scott have developed a discursive analytic framework based on five linked aspects (e.g., the communicative approach, interactive vs. noninteractive, authoritative vs. dialogic). Their methodology involves the video recording of a set of lessons. Videos are transcribed, and data are mapped into episodes characterized by a specific function in the flow of discourse and then analyzed. The analytic framework empowers the authors to examine, for example, the movements between authoritative and dialogic discourse in the set of lessons and argue that shifts between communicative approaches are necessary to support meaningful learning in science (Scott et al. 2006). Other scholars have borrowed this framework or some of its elements for a discursive analysis regarding science meaning-making in particular cases (e.g., Chin 2006, to analyze teacher questioning and feedback, or Yeo and Chee Tan 2010, to analyze the use of authoritative sources).

3.2 Analysis of Particular Events Related to Students' Meaning-Making: The Turning Points

An inevitable consequence of classroom discourse being characterized as an alternation of dialogic and authoritative discourse is that transitions between the two types of discourse will be critical for planning teaching sequences. If transition is the rule, one of the most important events in the classroom should be the *turning points*, which first and foremost are identified in terms of a change in communicative approach – from dialogic to authoritative or vice versa – during the staging of a teaching intervention.

In terms of methodology of research, we are going to discuss how we could characterize what we are calling the turning point entries and exits. We assume that turning points can be planned by the teacher, even if he/she has never heard about the expression "turning points," or can be spontaneous, in the sense that shifts between authoritative and dialogic discourse (or vice versa) happen independently of the teacher's will. For example, a student's question may restart a dialogic sequence when the teacher decides to answer it. In this article we are going to discuss only the planned turning points, trying to find out which are the cues that we can look for in the ongoing classroom talk to determine a turning point entry or exit.

The data analysis involved examining the videotapes using Videograph® and Transana® to identify all instances of turning points. A typography of turning points was then developed based on the structure and functions of those points. A key part of this development involves identifying unambiguous classes of types of turning points and then being able to allocate examples of turning points to the appropriate classes.

The teacher whom we are going to analyze to exemplify what is a turning point develops a teaching sequence (about 5 h) focusing on the topic of forces, with grade 7 students in a secondary school in a rural area of the North of England.

The turning point is part of this sequence and focuses on teaching and learning about the normal force: that a table exerts an upward force on a cup which is placed on it. The starting point here is that children of this age typically find it difficult to believe that inanimate objects such as a table can exert a force on a cup. Jonathan the teacher in this case started by organizing his class into pairs and giving each pair of students a concept cartoon showing four possibilities for the forces acting on a bottle on a shelf: (a) the bottle is not moving, there are no forces on it; (b) the only force on the bottle is the force of gravity pulling it downwards; (c) there are two forces on the bottle – the force of gravity and the push of the shelf upwards, which balances it; and (d) a shelf cannot push. It is just in the way of the bottle and stops it falling. The students talk in pairs about each of these statements indicating whether they "agree" or "disagree" or are "not sure" about each one. Each pair then works with another pair to compare views and to reach a consensus within the group of four. Finally, Jonathan calls the class around the table at the front of the room.

Jonathan has opened up a *dialogic space* (Wegerif 2007), where students are able to express their ideas. The concept cartoon prompts the students to talk through the various possible models, and it is clear that differences in point of view have been created. In fact, as Jonathan comments, the students *really didn't agree at all*. Josie expresses clearly the view that "a table can't push up," which is in disagreement with the likes of Ryan who thinks that there are two forces on the bottle. Jonathan summarizes this situation using a noninteractive/dialogic approach. There is clear evidence here that the concept cartoon exercise has been effective, in engaging at least some students in thinking about whether or not tables can push. Having opened up these differences in student thinking, the question is: What might be the next step?

We return to the class for the next lesson, which was taught 2 days later. Jonathan starts the lesson and refers back to the debate from the previous lesson: "I'd like to get you to think about one of the ideas that you really *argued* about on Monday." At this point Jonathan has gone as far as is possible in terms of opening up the different ways of modeling the bottle on the shelf. He and the class have reached the *turning point* for this particular intervention. Jonathan now states quite clearly what is to come next:

Teacher: What I want to do… I want to leave you this morning… with a picture of something that might help you to believe that *that* [*knocking on the table*] can push up. Now this is a very logical little argument, so you're going have to follow it through.

With the help of one of the students, Sam, Jonathan presents an argument in favor of the table pushing, using a balloon. He gets Sam to put his hands on either side of this balloon and gently squeeze it together, changing the shape of the balloon. After this, he gets Sam to push the balloon over the table and asked Sam what happens with the shape of the balloon. Sam answered that with his action, the balloon flattened. Jonathan then asked the whole class to answer the question, "Where on Earth is the other force that's changing the *shape*?" Different students answer that the table was pushing.

In this way Jonathan enlists the help of one of the students, Sam, and presents an argument to suggest that the table can push up, focusing attention on the forces acting on a balloon. He achieves this by taking an interactive/authoritative communicative approach, played out through I-R-E patterns of three (initiation-response-evaluation, Mehan 1979). This pattern of interaction continues up to the point when Holly provides the correct response that the other force is "from the table." Jonathan then conducts rapid confirmatory exchanges (Edwards and Mercer 1987) with Levi and Penny prior to concluding the episode with an authoritative statement. In this way Jonathan exits the turning point by "presenting" a logical argument centered on the analogous case of the balloon.

One key characteristic of this turning point is that here the impetus for learning comes from the differences in the students' views about the *models* presented in the concept cartoon, whereas in some case the impetus for learning came from observing a *phenomenon*. Here there is no phenomenon which is open to dispute. There is no arguing about whether or not bottles stand on tables. The point at issue lies with how that situation is modeled in terms of forces. In this case, therefore, the impetus for learning is generated by the students engaging in the modeling task with the concept cartoon. Here, creating differences involves setting up differences in students' views about possible models.

A well-elaborated transition from dialogic to authoritative discourse (and vice versa) becomes an extremely sensitive point in the planning of a teacher. We sought to demonstrate that the transition between dialogic and authoritative discourses can occur anywhere in a teaching sequence, not only at the beginning, when students are still imbued with their everyday ideas. In advanced stages, when students have mastered the scientific tools that allow them to risk a hypothesis to solve a problem, different points of view may again appear in this process, but most of these points of view are well grounded in scientific discourse.

That this dialectic between authoritative and dialogic discourses can occur in classrooms seems to be fundamental for students to progress in their understanding of science. The stronger in articulating authoritative discourse the students become, the greater the chance that they take the risk of offering different points of view in solving problems, reinstalling the dialogic discourse.

4 Analyses of Teaching and Learning Practices Related to IBSE

4.1 Overview of Research Trends

Inquiry was a major focus for the reform efforts of the 1960s in the United States (Yager 1997) and of the 1970s in Europe, and it has been studied for a long time in science education. Among the studies in the last 10 years involving classroom observations with video data, several perspectives have emerged. Some studies mainly focus on the nature of inquiry, such as its authenticity (Chinn and Malhotra 2002; Schwartz et al. 2004); tackle the nature of science dimension (Sandoval 2005); concern socioscientific issues (Walker and Zeidler 2007); or give room to links between inquiry and argumentation (Sampson et al. 2011). Other studies deal with collaborative aspects during inquiry activities (Watson et al. 2004), including with the support of software (computer-supported collaborative learning, Makitalo-Siegl et al. 2011). The way in which teachers implement inquiry in their classroom practices after that inquiry has been added to the official curriculum constitutes another research theme (Blanchard et al. 2010; Smithenry 2010), as do the teacher's role and the characteristics of interactions between the teacher and the students when doing inquiry activities.

In this brief review, we now give an overview of the studies that have the same focus as our own to the extent that they carry out an analysis of teachers' actions when classroom activities concern inquiry. Several analyses related to this trend concern particular types of actions like the teacher's questioning and answering and the students' expectations, whereas others deal with both the teacher's and the students' related actions, either as being specifically linked to inquiry, like developing hypotheses (Shimoda et al. 2002), or as being more general, like assessment (Ruiz-Primo and Furtak 2007). Lastly, investigations approach scientific inquiries dealing with the "social structures that constitute a classroom community" (Enyedy and Goldberg 2004) or with the need for the teacher to withhold the answers and be reticent (van Zee 2000; Furtak 2006). More generally, they show the importance of studying together the teacher's actions and the way in which the classroom situation is designed and enacted to interpret students' actions and vice versa.

4.2 Analysis of IBSE Teaching Practices with the Joint Action Theory in Didactics

This study deals with the analysis of teaching practices in grade 8 related to the voltage law in a series circuit. Our aim was to provide information on how a young male physics teacher coped with inquiry-based physics teaching. Our analysis was supported by the Joint Action Theory in Didactics where the didactic action is considered as a joint action by teacher and students (JATD – Sensevy 2009, 2011). Its use is in line with the previous conclusion according to which it is important to analyze at the same time both the teacher's and the students' action.

JATD regards the situations that make up teaching and learning practices as a set of collaborative didactic games. This allows us, for each game, to consider what is at stake (related to knowledge), what are the definitory rules (to play), what are the strategic rules (to win), the players' investment, etc. To analyze the classroom situations in terms of games, two concepts are used: (1) the milieu which is made up of all the conceptual and material elements in the environment that act on the students and on the teacher and on which the students and the teacher act and (2) the didactic contract which consists of a set of perennial and local knowledge-related rules governing the teacher's and the students' actions, defining their rights and duties, and sharing and limiting their respective responsibilities. Three dimensions thus account for the dynamics of each game: (1) the evolution of knowledge as it unfolds throughout the game; (2) the evolution of the milieu, which is its continuous reorganization due to the students' and the teacher's interventions; and (3) the evolution of the teacher's and the students' respective responsibilities for the progress of knowledge in the class. The teacher intervenes during the didactic game in different ways. He/she can first define the game. He/she can also devolve the game, acting in such a way that the students agree to play the game properly and on their own. Usually the teacher regulates the game, intervening in order that the students modify their actions to become more relevant regarding the stakes of the game. Lastly, the teacher can institutionalize the knowledge at stake, pointing out to the students that their activity has reached a part or the totality of that knowledge.

The grain size of the games can be related to the temporal span of the analysis. Thus, we consider that the modeling of classroom practices necessitates choosing levels of analysis related to different timescales (Lemke 2001): macroscopic (teaching sequence: several weeks, months), mesoscopic (less than a session:

about 10 min), and microscopic (couple of seconds to a couple of minutes). The emergence of one phenomenon at a particular level depends on what unfolds in both the lower and higher levels.

Our analysis was based on a particular methodology. The video of the lesson constituted our main data. The teacher was also interviewed about what he/she intended to do and what he/she actually did during this lesson and why. These talks, the worksheets distributed during the lesson, and the curriculum formed our second set of data. These data were analyzed in three consecutive steps but also by going back and forth between them.

We first made an a priori analysis of the given tasks in relation with the curriculum from an epistemological point of view in order to identify possible variants of the lesson development. We also synthesized the teacher's comments and characterized the students' worksheet according to the curriculum requirements. Lastly, using Transana software (Woods and Fassnacht 2010), we transcribed the classroom interactions.

Second, analyzing the lesson at a mesoscopic level, we divided it according to the social classroom organization, the thematic content of classroom discourse, and the evolution of the milieu, the responsibility for the progress of knowledge, and the meaning of the knowledge involved in the discourse, that is to say according to different didactic games. Each of these parts was indexed in Transana with the corresponding keywords. From an analysis at microscopic level, we characterized sub-games with keywords related to JATD concepts and knowledge at stake using categories of facets. Facets are little components of knowledge whatever it may be (Minstrel 1992) and are defined on the basis of "knowledge to be taught" (curriculum, textbook), students' misconceptions, and classroom productions. This qualitative analysis at micro- and mesolevels provided us, on the one hand, with a static, global view of the lesson with the amount of time linked to the different keywords allowing quantitative calculations and, on the other hand, with a dynamic view of the lesson development given by the succession of keywords over time.

Finally, getting back to the detailed interactions and their meaning regarding the knowledge at stake and supported by Transana outputs, we analyzed the successive didactic games to precisely map out the dynamics of the lesson, including in particular the characterization of knowledge development (continuity or discontinuity in the chronogenesis). Moreover, we inferred some of the determinants of these dynamics. The uncertainty of these inferences was reduced by cross-checking our interpretations with what happened in other games and with information coming from the second set of data.

Both theoretical and methodological frameworks led us to findings, of which we give only some very limited excerpts now to illustrate their nature.

The stake of the first game of the observed lesson was to recall knowledge from the previous lesson orally about nominal voltage and voltage measurement. The stake of the second game was to understand the problem presented by the teacher. This presentation was the first step of the inquiry process, as specified in the French curriculum. The first part of the game [min 3:22] sounded like a story: "A child afraid of the dark wants to light his hut and for this, he uses five bulbs with bases indicating 0.1 A and 3.5 V, 5 bulbs with bases indicating 0.2 A and 6 V, and a 12 V battery in a series circuit. The bulbs light up badly or not at all"; the teacher then asked the students to help the child. In the second part of the game, the teacher asked the students to summarize the problem [min. 5:32]. In short game 3, the students were asked "to propose a solution" [min 6:21], then "an explanation" [min 6:53]. The devolution process (by which the teacher acts in such a way that the students accept the responsibility of constructing knowledge) mainly took place on the practical aspects and the students suggested adding a battery or removing some lamps. One of them hypothesized that the sum of the whole nominal voltage of the bulbs was higher than the battery voltage [min 7:12], but the teacher's epistemological point of view about the knowledge construction prevented him from using this student's hypothesis. As he said in the interview, "knowledge must come from practical experiments [and not from preconceived opinions]."

Then, he asked the students (game 4) to work in pairs and write a question summarizing the problem [min 7:34]. To obtain the scientific question he was looking for, the teacher made many regulations, taking more and more space in the interactions and giving more and more prompts on the content. For example, less than one minute after the students started working in pairs, the teacher spoke to the whole class and strongly guided the students toward proposing a question concerning the bulb voltage in the circuit that would not be appropriate because it was different from the nominal voltage. The facets in the following part of the game (belonging to the category "relations between the functioning and the characteristics of an element") confirmed that the students did that. We consider the teacher's intervention as a breakdown, a discontinuity in the didactic contract: Before the intervention, the students had the responsibility for knowledge; after it, they had only to follow the teacher's request. After the students stopped working in pairs and orally gave their proposals, in agreement with the teacher's proposal, he introduced a new proposal:

1. T: (*Teacher*) Why is the voltage across the lamps not the right one, and what other question might we ask? If it is not the right one, there must be another one. [*min 12*:*53*]
2. S: (*Student*) Yes.
3. T: What could you try to do with your own knowledge? (*student*'*s murmurs*) Yann, what could you try to do with your knowledge? If the voltage is not the right one, then in reality there is another one!
4. S: Check with a voltmeter.
5. T: Here it is, we could try to make the measurement. Do all of you agree with me?
6. S: Yes.
7. P: So, we want to know how the… (*T writes on the blackboard and waits for an answer*)
8. S: The voltage
9. T: Here it is, the voltage is shared out in the circuit. [*min 13*:*15*]

In this excerpt, the teacher modifies the knowledge on which the question is focused. Whereas turn 1 deals with the comparison between nominal and actual voltage across bulbs and thus with the local characteristics of one component of the circuit, turn 9 deals with the way the voltage is shared in the circuit and thus necessitates thinking about this circuit as a whole, as a system. In fact, many studies have shown that it is very difficult for students to take this viewpoint. They rather interpret a circuit in terms of a causal relationship between the generator and the receivers involving the dipoles in a sequential reasoning (Closset 1983). Thus, we consider that there is a significant discontinuity of knowledge between the beginning and the end of this exchange. Moreover, as students could not build meaningful relations with the milieu regarding the knowledge at stake, in turn 3, we see that their sole resource was a usual school practice according to which the knowledge of the previous lesson (voltage measurement) must be useful in the following one, that is to say, a perennial rule of the didactic contract.

These short excerpts of our findings indicate that the JATD framework enables us to account for didactic phenomena occurring in a physics lesson. Moreover, as shown here with the use of facets, patterns in the interactions, and timescales, this theory can work with other frameworks produced in science education or in neighboring fields. To go further and obtain a more integrated view on teaching and learning practices, we think it would be interesting to combine the use of JATD with the analyses of students' practical epistemologies (Wickman and Östman 2002). We also consider that software like Transana is very valuable for analyzing such lessons. It gives the researcher some quantitative information linked to qualitative analysis, helping him/her to objectivize his/her conclusions. But it requires keywords to be associated with video episodes. At a mesoscopic level, we used several ways of structuring the session, according to the social organization, the theme at stake, and the game played. Whereas the first two are mainly associated with one aspect and are rather easy to determine, the last one implies taking the milieu, the contract, and the knowledge at stake into account and considering the rules of the game. It therefore needs much more interpretation from the researcher. Lastly, the study shows that the continuity of knowledge can be analyzed using JATD at a mesoscopic level (e.g., how responsibility for knowledge is shared or relations between themes) as well as microscopic level (e.g., construction of the meaning of interactions, in particular from a student's perspective).

5 Final Discussion

The three cases presented offer the field of science education ways of examining theories and methods for researching pedagogical approaches in science education. Whether looking at conceptual change, meaning-making, or inquiry in science, a set of common methodological themes emerges from the theoretical commitments of the research teams presenting each of the three cases. We discuss three of these common themes.

First, the cases show how everyday life in schools is interactionally accomplished. By opening up the processes of conceptual change, the first case focused on student conceptual change evinces the relationship of the commonly constructed knowledge of the group and the variation among the individual knowledge among the students and teacher constituting the group. Conceptual change among students occurs through the opening of a collective space where students can engage and make sense of the concepts in question. Changes in understanding are accomplished in and through discourse, as meanings are constructed, modified, corrected, and taken up among students (Kelly et al. 2012). In the second case, focused on meaning-making, a turning point was constructed through the shared knowledge and joint recognition between the teacher and students that this significant discourse event occurred and that a shift in the conversation is needed to accomplish the next emerging goal. Thus, a turning point becomes recognized among participants through interaction. The third case examined an inquiry event in which the discursive moves by the teacher led to discontinuity of knowledge among students. The case shows how a brief interactional episode can change the dynamics of the classroom conversation and the meanings made available to students.

Second, communicative approaches and interactive spaces are constructed intertextually through dialog, each offering different opportunities for learning. Across the three cases, the different interactive spaces for communication – individual and collective space in case 1, dialogic space in case 2, and reorganization of the milieu in case 3 – are constructed through discourse and make use of previous knowledge evoked to stimulate student discussion. By making intertextual references to previous knowledge, that is, ways of talking in the particular milieu evoking previous discourse, the teachers in each case use various communicative approaches to engage students in substantive talk about science ideas. By opening up the conversation for meaning-making, the teachers make choices about how to situate students in dialog about science. These choices have consequences for student learning. Thus, analysis of classroom discourse needs to examine both the use of previously established meanings of the conceptual knowledge of science and the reevoking of common ways of being in the collective action. This shows the connection across conceptual understanding, common discourse, and social practices.

Third, classroom norms and practices are established over time. In each of the cases, examples of micro-moment interactions occur within broader social contexts where local norms for such interaction frame events as they are interactionally enacted among participants. For example, in the third case focused on inquiry, the learning game of the classroom is framed within a set of perennial and local knowledge-related rules governing the teacher's and the students' actions. Such local rules are continuously constructed, evoked, enacted, and renegotiated through the everyday discourse processes of this, or any, classroom. Understanding the nature of inquiry, student conceptual change, or key turning points in instructional conversations requires methodological approaches that move across timescales and interactional spaces to examine how what counts as science in a milieu is constructed over time (Kelly 2008). To understand the consequences of different pedagogical approaches, research methods need to examine both the moment-to-moment interactions where meanings are constructed and the overtime practices that stabilize meaning through conversation within a collective.

References

Beeth, M.-E., & Hewson, P. W. (1999). Learning goals in an exemplary science teacher's practice: Cognitive and social factors in teaching for conceptual change. *Science Edition, 83*, 738–760. doi:10.1002/(SICI)1098-237X(199911)83:6<797::AID-SCE9>3.0.CO;2-Y.

Blanchard, M. R., Southerland, S. A., Osborne, J. W., Sampson, V. D., Annetta, L. A., & Granger, E. M. (2010). Is inquiry possible in light of accountability? A quantitative comparison of the relative effectiveness of guided inquiry and verification laboratory instruction. *Science Edition, 94*, 577–616. doi:10.1002/sce.20390.

Chin, C. (2006). Classroom interaction in science: Teacher questioning and feedback to students' responses. *International Journal of Science Edition, 28*, 1315–1346. doi:10.1080/09500690600621100.

Chinn, C. A., & Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Edition, 86*, 175–218. doi:10.1002/sce.10001.

Closset, J. L. (1983). Sequential reasoning in electricity. In Research on Physics Education. Proceedings of the First International Workshop. La londe des maures, pp. 313–319.

Edwards, D., & Mercer, N. (1987). *Common knowledge: The development of understanding the classroom*. London: Routledge.

Enyedy, N., & Goldberg, J. (2004). Inquiry in interaction: How local adaptations of curricula shape classroom communities. *Journal of Research in Science Teaching, 41*, 905–935. doi:10.1002/tea.20031.

Eshach, H. (2010). An analysis of conceptual flow patterns and structures in the physics classroom. *International Journal of Science Edition, 32*, 451–477. doi:10.1080/09500690802635247.

Furtak, E. M. (2006). The problem with answers: An exploration of guided scientific inquiry teaching. *Science Edition, 90*, 453–467. doi:10.1002/sce.20130.

Havu-Nuutinen, S. (2005). Examining young children's conceptual change process in floating and sinking from a social constructivist perspective. *International Journal of Science Edition, 27*, 259–279. doi:10.1080/0950069042000243736.

Kelly, G. J. (2008). Inquiry, activity and epistemic practice. In R. Duschl & R. Grandy (Eds.), *Teaching scientific inquiry: Recommendations for research and implementation* (pp. 99–117). Rotterdam: Sense Publishers. 288–291.

Kelly, G. J., McDonald, S., & Wickman, P. O. (2012). Science learning and epistemology. In K. Tobin, B. Fraser, & C. McRobbie (Eds.), *Second international handbook of science education* (pp. 281–291). Dordrecht: Springer.

Lemke, J. L. (2001). The long and the short of it: Comments on multiple timescales studies of human activities. *Journal Science of Learning, 10*, 29–43.

Lidar, M., Lundqvist, E., & Ostman, L. (2006). Teaching and learning in the science classroom: The interplay between teachers' epistemological moves and students' practical epistemology. *Science Edition, 90*, 148–163. doi:10.1002/sce.20092.

Lidar, M., Almqvist, J., & Ostman, L. (2010a). A pragmatist approach to meaning-making in children's discussions about gravity and the shape of the earth. *Science Edition, 94*, 689–709. doi:10.1002/sce.20384.

Lidar, M., Lundqvist, E., & Ostman, L. (2010). Comparative studies of manners of teaching. Communication presented at ECER 2010 *Education and Cultural Change*. University of Helsinki, 25–27 August 2010.

Loxley, P. M. (2009). Evaluation of three primary teachers' approaches to teaching scientific concepts in persuasive ways. *International Journal of Science Edition, 31*, 1607–1629. doi:10.1080/09500690802150114.

Makitalo-Siegl, K., Kohnle, C., & Fischer, F. (2011). Computer-supported collaborative inquiry learning and classroom scripts: Effects on help-seeking processes and learning outcomes. *Learning & Instruction, 21*, 257–266. doi:10.1016/j.learninstruc.2010.07.001.

Mehan, H. (1979). *Learning lessons: Social organization in the classroom*. Cambridge, MA: Harvard University Press.

Minstrell, J. (1992). Facets of students' knowledge and relevant instruction. In R. Duit, F. Goldberg, & H. Niedderer (Eds.), *Research in physics learning: Theoretical issues and empirical studies* (pp. 110–128). Kiel: IPN.

Mortimer, E., & Scott, P. (2003). *Meaning-making in secondary science classrooms*. Maidenhead: Open University Press.

Riemeier, T., & Gropengießer, H. (2008). On the roots of difficulties in learning about cell division: process-based analysis of students' conceptual development in teaching experiments. *International Journal of Science Edition, 30*, 923–939. doi:10.1080/09500690701294716.

Rincke, K. (2011). It's rather like learning a language: Development of talk and conceptual understanding in mechanics lessons. *International Journal of Science Edition, 33*, 229–258. doi:10.1080/09500691003615343.

Ruiz-Primo, M. A., & Furtak, E. M. (2007). Exploring teachers' informal formative assessment practices and students' understanding in the context of scientific inquiry. *Journal of Research in Science Teaching, 44*, 57–84. doi:10.1002/tea.20163.

Sampson, V., Grooms, J., & Walker, J. P. (2011). Argument-driven inquiry as a way to help students learn how to participate in scientific argumentation and craft written arguments: An exploratory study. *Science Edition, 95*, 217–257. doi:10.1002/sce.20421.

Sandoval, W. A. (2005). Understanding students' practical epistemologies and their influence on learning through inquiry. *Science Edition, 89*, 634–656. doi:10.1002/sce.20065.

Schwartz, R. S., Lederman, N. G., & Crawford, B. A. (2004). Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry. *Science Edition, 88*, 610–645. doi:10.1002/sce.10128.

Scott, P., Mortimer, E., & Aguiar, O. (2006). The tension between authoritative/dialogic discourses: A fundamental characteristic of meaning-making interactions in high-school science lessons. *Science Edition, 90*, 605–631. doi:10.1002/sce.20131.

Seidel, T., Prenzel, M., & Kobarg, M. (2005). *How to run a video study*. Muenster: Waxmann. Technical Report of the IPN Video Study.

Sensevy, G. (2009). Outline of a joint action theory in didactics. In Proceedings of the Sixth Conference of European Research in Mathematics Education, Lyon. http://ife.ens-lyon.fr/publications/edition-electronique/cerme6/wg9-12-sensevy.pdf. Retrieved on 5 Jan 2012.

Sensevy, G. (2011). *Le sens du savoir. Éléments pour une théorie de l'action conjointe en didactique (The meaning of knowledge. elements for a joint action theory in didactics)*. Brussels: De Boeck.

Shimoda, T. A., White, B. Y., & Frederiksen, J. R. (2002). Student goal orientation in learning inquiry skills with modifiable software advisors. *Science Edition, 86*, 244–263. doi:10.1002/sce.10003.

Smithenry, D. W. (2010). Integrating guided inquiry into a traditional chemistry curricular framework. *International Journal of Science Edition, 32*, 1689–1714. doi:10.1080/09500690903150617.

Suzuki, M. (2005). Social metaphorical mapping of the concept of force "CHI-KA-RA" in Japanese. *International Journal of Science Edition, 27*, 1773–1804. doi:10.1080/09500690500206507.

van Zee, E. (2000). Analysis of a student-generated inquiry discussion. *International Journal of Science Edition, 22*, 115–142. doi:10.1080/095006900289912.

Varelas, M., Pappas, C. C., Kane, J. M., Arsenault, A., Hankes, J., & Marmotes Cowan, B. (2008). Urban primary-grade children think and talk science: Curricular and instructional practices that nurture participation and argumentation. *Science Edition, 92*, 65–95. doi:10.1002/sce.

von Aufschnaiter, C. (2003). Interactive processes between university students: Structures of interactions and related cognitive development. *Research in Science Edition, 33*, 341–374. doi:10.1023/A:1025452430958.

von Aufschnaiter, C., & Rogge, C. (2010). Misconceptions or missing conceptions? *Eurasia Journal of Mathematics, Science & Technology Edition, 6*, 3–18.

Vosniadou, S. (2008). *Handbook of research on conceptual change*. Hillsdale: Erlbaum.

Vygotsky, L. S. (1978). *Mind in society. The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

Walker, K. A., & Zeidler, D. L. (2007). Promoting discourse about socio-scientific issues through scaffolded inquiry. *International Journal of Science Edition, 29*, 1387–1410. doi:10.1080/09500690601068095.

Watson, R. J., Swain, J. R. L., & McRobbie, C. (2004). Students' discussions in practical scientific inquiries. *International Journal of Science Edition, 26*, 25–45. doi:10.1080/0950069032000072764.

Wegerif, R. (2007). *Dialogic education and technology: Expanding the space of learning*. New York: Springer.

Wickman, P. O. (2004). The practical epistemologies of the classroom: A study of laboratory work. *Science Edition, 88*, 325–344. doi:10.1002/sce.10129.

Wickman, P. O., & Östman, L. (2002). Learning as discourse change: A sociocultural mechanism. *Science Edition, 86*, 601–623. doi:10.1002/sce.10036.

Woods, D., & Fassnacht, C. (2010). *Transana v2.42*. Madison: The board of regents of the university of Wisconsin system. http://www.transana.org.

Yager, R. (1997). Science education a science? *Electronic Journal of Science Education, 2*, 1–4. Retrieved 2 April 2012, from http://wolfweb.unr.edu/homepage/jcannon/ejse/yager.html.

Yeo, J., & Chee Tan, S. (2010). Constructive use of authoritative sources in science meaning-making. *International Journal of Science Edition, 32*, 1739–1754. doi:10.1080/09500690903199564.