The Evolution of Classroom Physics Knowledge in Relation to Certainty and Uncertainty

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Abstract: This paper deals with the joint construction of knowledge by the teacher and the students in a physics classroom. It is focused on the status of epistemic certainty/uncertainty of knowledge. The same element of knowledge can be introduced as possible and thus uncertain and then evolve towards a status of epistemic certainty; the status of other elements can do the reverse. The evolution of a certainty/uncertainty status reflects the evolution of the shared knowledge in the classroom. The study of this evolution is based on a previous analysis of the evolution of knowledge in a classroom during a teaching sequence of mechanics at grade 10. From this analysis two notions were selected and the evolution of the elements of knowledge associated was analyzed in terms of epistemic certainty/uncertainty. The results show how the emergence of new epistemic questions depends on the nature and status of student’s prior knowledge; in other terms, new epistemic uncertainty emerges from epistemic certainty.

Keywords: teaching; learning; classroom; epistemic certainty; shared knowledge

The teaching–learning process in a classroom is recognized as complex (Lemke & Sabelli, 2008; Schwarz, Dreyfus, & Hershkowitz, 2009). Among others, Mercer (2008) advocates the necessity of understanding temporal processes in order to help teachers, for whom one of the main preoccupations is time. He states that we should develop methodology to study the ways “[how] the joint construction of knowledge is achieved over time” (p. 55).

This paper aims at better understanding the temporal evolution of knowledge involved in the teaching–learning process by focusing on an epistemic aspect of knowledge, the evolution of
the status of certainty/uncertainty of elements of knowledge involved in the classroom. The uncertainty of knowledge is a way of questioning elements of knowledge; it is an important part of scientific practice. An example from our research practice is the necessity of research questions to develop new knowledge and to publish it and then to go beyond. These questions are the explicit sign of knowledge uncertainty, they are based on previous research results, and a theoretical framework. The knowledge that has already been acquired allows the researchers to raise new questions because there is uncertainty; a given study aims to decrease this uncertainty and then new questions emerge, again pointing out new uncertainty. This dynamics of uncertainty based on knowledge is a way of developing knowledge. We also consider that, in the students’ processes of construction of knowledge, uncertainty can drive the learning process of knowledge.

Our study was carried out in a classroom working on a mechanics teaching sequence in physics at grade 10. Let us note that mechanics involves a rather formal theoretical part to the extent that it includes principles and vector representations, alongside experiments. The relationships between theory and experiments are particularly difficult for students as shown in all the studies on alternative conceptions. Thus the question of certainty/uncertainty of knowledge can be studied in relation with the importance of the students’ recognition of theoretical and experimental elements of knowledge.

Theoretical Framework

Our theoretical framework is based on the Joint Action Theory in Didactics\textsuperscript{1}—JATD (Sensevy, 2011). This theory is itself based on a paradigm of joint action in social sciences: human action is thought of as a joint action. In the case of education and more specifically didactics, teaching and learning are necessarily associated joint actions. Moreover, this framework involves our positioning on certainty/uncertainty of knowledge. In the following, we first present some features of the JATD and our epistemological position on certainty/uncertainty, then we outline the main characteristics of the teaching sequence on which this study was carried out.

Joint Action Theory in Didactics

In the Joint Action Theory in Didactics, the main object of study is the teaching–learning process. The classroom is seen as a collective thought (Fleck, 1979) shaped by the didactic joint action (Sensevy, 2007, 2011; Sensevy, Mercier, Schubauer-Leoni, Ligozat, & Perrot, 2005). Stemming from French Didactics (Brousseau, 1997; Chevallard, 2007) the Joint Action Theory in Didactics (JATD) aims at linking teaching and learning by postulating that one cannot understand learning practices without understanding the related teaching practices. In that way, the JATD can be seen from a transactional perspective, which attempts to link learning practices and instructional practices (Koschmann, 2011).

From the Joint Action Theory in Didactics (JATD), the teaching–learning process is considered mainly as a communicative process of a certain kind. In fact, due to the \textit{instructional goal} given by society to the school, knowledge is at the core of this communicative process.

Two Main Concepts: Didactic Contract and Milieu

In order to describe and analyze the didactic activity, the JATD gathers a set of concepts which can be primarily described by relying on two elements.

The first element is the \textit{didactic contract} (Brousseau, 1997), an expectation system between the student and the teacher, which gathers the current habits (rules, norms, capacities) relating to the knowledge at stake, and also which constitutes the current students’ actions. Some of these habits are generic and will be lasting as, for example, the habit of working in small groups, the fact that, during classroom discussion, an idea is taken into consideration if it is supported by an
argument, whether it is correct or not from a physics perspective; others are specific to current elements of knowledge and need to be redefined with the introduction of new elements. For example when students have to construct the notion of objects in physics which differs from the everyday meaning, since in physics a small piece of paper and the planet Earth are objects modeled the same way in basic mechanics (mass and position), the idea of objects has evolved in the classroom. Gradually, it begins to belong to the classroom’s common knowledge and to acquire a status of certainty. When later on, the students work with diverse objects it is no longer necessary to discuss that all objects are modeled the same way; the didactic contract has evolved for this element of knowledge. When the notion of object belongs to the common knowledge of the classroom then it becomes a generic element of the contract whereas during its construction by the students, this knowledge was a part of the contract that evolves; it is specific to a period of time and to some elements of knowledge. Thus the didactic contract can be seen as a system of social and socio-epistemic norms (McClain & Cobb, 2001; Yackel & Cobb, 1996) relating to the didactic institution in which the didactic process unfolds. It can be related to norms of a local community like a class (Crawford, Kelly, & Brown, 2000; Kelly, 2005). As a system of habits of action, the didactic contract includes not only these aspects, but all reciprocal expectations between the teachers and the students.

The second related element is the **didactic milieu**. This **milieu** involves the components of the students’ environment in which knowledge is embedded. This environment includes the material elements, like experimental devices, text, but also the human ones, certain teacher and student actions. This knowledge is partly or entirely embedded in the material and symbolic objects of the students’ environment and not necessarily made verbally explicit.

**A Dynamic View of the Classroom**

Mercer (2008) introduced the perspective of “developing a theory of school-based learning as a temporal, dialogic process” (p. 38), and emphasized the crucial character of studying “how the joint construction of knowledge is achieved by participants over time, because the process of teaching and learning depends on the development of a foundation of common knowledge” (pp. 55–56, our italics). In the same paper, he proposes to “focus on the way that a teacher and learner (or group of learners) can stay attuned to one another’s changing states of knowledge and understanding over the course of an educational activity” (p. 39) to study the development of common knowledge.

His proposal focuses, as does ours, on the idea of a “dynamic maintenance” of shared communicative space between the teacher and the students. In our case, the dynamic aspects of the evolution of knowledge involved in this communicative space are studied with the two concepts of contract and milieu. The **contract** determines the possible students’ actions towards the **milieu** in which knowledge is embedded, and it depends on the teacher’s actions in this milieu. The “dynamic maintenance” can be seen as a didactic contract that allows students to look for and use elements of a relevant milieu (material, communicational, organizational, etc.) to construct a meaning of the taught knowledge. This maintenance corresponds to a type of equilibrium between the contract and the milieu.

These two different approaches share the basic idea of a constant attuning of the teacher’s and students’ expectations in order to develop a common knowledge that is always evolving guided by the goals of education. In more theoretical terms, in joint action theory the common knowledge construction is based on the building of a dynamic equilibrium between contract and milieu. For example, when the classroom activities raise a problem or questions, it is the teaching situations and more precisely the milieu that helps the students and the teacher to construct possible elements of knowledge that are questionable and debatable with rational arguments. This joint construction
is possible only if the didactic contract is such that, at certain moments, the teacher gives the responsibility of knowledge to the students. Thus the classroom is considered to be a system characterized by the dynamics of the taught knowledge construction within a communicative process.

Even if the evolution of a class is oriented by a goal, mainly determined by the official curriculum, the processes to attain this goal are very open. These processes depend on the teacher’s and the students’ actions that are specific to the classroom. Then what is taught is not identical from one classroom to another even if, taking into account the official curriculum and the disciplinary knowledge of reference, there must be a large overlap between them. In other words, knowledge emerges from the interaction between the teacher, the students, and the context.

Temporal Evolution and Continuity

Thus, understanding class life necessitates understanding its temporal evolution not only for the teaching or learning separately but also as far as the joint teaching–learning action is concerned. Relatively recently, the temporal aspect on a rather large scale for a class, that is to say weeks and months, has been emphasized in several theoretical perspectives like discourse analysis (Mercer, 2008) or also in the field of computer supported collaborative learning, in particular because of studies on long-term collaboration longer than a month (Riemann, 2009). Mercer considers that a sociocultural perspective allows one to approach a theory of school-based learning as a temporal development:

Not only does this perspective recognize language as a key psychological and cultural tool, but also, as Lemke (2001) explained, “Sociocultural approaches to learning and development are not just about social interaction . . . They are more significantly about the role of longer time-scale constancies and how they constrain, afford and intrude into moment-by-moment activity” (p. 19).

To characterize classroom evolution we use the notion of continuity; here continuity involves links between various parts of activities and/or discourses (Hamza & Wickman, 2013) so that, as proposed by Dewey (1938), “every experience both takes up something from those which have gone before and modifies in some way the quality of those which come after” (ch. 3).

For example a teacher can introduce the concept of Force by establishing relations with the action of objects introduced previously, so there is a strong continuity with what was experienced by the students; on the other hand, the teacher can introduce this concept from an experiment without giving the students the opportunity to refer to what was taught before and in this case the continuity is weak.

The dynamic construction of the classroom knowledge by the teacher and students leads us to analyze the evolution of the status of certainty/uncertainty of elements of knowledge. The students with the guidance of the teacher can construct a new idea and propose a possible element of knowledge by conducting investigations, for example. This state can evolve with time, several types of arguments can lead students to confirm it, reject it or retain it with a questionable status.

Certainty/Uncertainty of Knowledge

Our choice to analyze the evolution of classroom knowledge mainly through the status of certainty/uncertainty necessitates specifying different kinds of certainties. Some of them are taken for granted by people and do not need justification. According to Wittgenstein (1969) this kind of certainty is not specific to knowledge. On the contrary, the kind of certainty that knowledge provides is grounded on articulate reasons; it is the rational certainty (Brandom, 2003; Moyal-Sharrock, 2007; Wittgenstein, 1969). Thus knowledge entails a specific kind of certainty, different both from everyday life certainty and from the “external” certainty that is lent by an authoritative person.
This perspective about certainty/uncertainty is associated to knowledge and knowledge processes whereas in other studies it is associated to beliefs about knowledge and knowing (Hofer & Pintrich, 1997). The investigation of these beliefs is carried out by interviews or questionnaires asking students to what extent they view knowledge as absolute or certain (Mercan, 2012; Peters-Burton & Baynard, 2013). Our orientation is different; we study certainty/uncertainty as a way of processing knowledge to develop new knowledge. In our framework, uncertainty is an essential component of the growing of knowledge, in the scientist’s activity as well as in the science classroom activity. This is why we refer to other types of studies dealing with the construction of knowledge in the classroom.

These studies also deal with the question of the status of knowledge particularly in relation to truth in scientific communities or in society. Kelly (2005) analyzed the question of truth in scientific communities and in science classrooms; other works on argumentation in the science classroom raise the question of claims and their truth (Jimenez Aleixandre & Erduran, 2008). From an interaction perspective, Mortimer and Scott (2003) approach the status of knowledge by distinguishing between authoritative and dialogic discourses and the necessary tension between them (Scott, Mortimer, & Aguiar, 2006). More recently, Gyberg and Lee (2010) investigated “the mechanisms that govern the processes of inclusion and exclusion of knowledges” (p. 1174) to understand how objects of knowledge are constructed in a school context. Here again the notion of inclusion or exclusion of knowledge in a classroom gives different statuses to elements of knowledge according to whether they are acceptable in the classroom, whatever the reasons, not only those related to the epistemology of science.

Figure 1 illustrates the different types of certainty/uncertainty and thus different types of arguments within the metaphor of various possibilities of finding your way when you are lost. On the right, we have disorientation and taken for granted evidence in which knowledge is not involved whereas on the left, the person tries to use elements of knowledge to find her way. In science learning, certainty/uncertainty of knowledge allows us to construct new knowledge, to question it, to justify it: there is a development of knowledge and thus of its understanding. The four cases show the drastic difference in the arguments used. If students do not understand what is going on in the classroom, they are disoriented and lost. If the teacher states knowledge only under its authority, students can use the arguments of evidence, but without taking responsibility for them (it is true for the teacher says so). In these two cases, there is no development of epistemological uncertainty or certainty. On the other hand, in the two other cases, the students can develop rational arguments and convince themselves of the necessity of questioning elements of knowledge or convince themselves of the certainty of these elements at least for a certain period of time. Here the

Figure 1. Illustration of different kinds of certainty/uncertainty.

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certainty/uncertainty of knowledge is inscribed in a dynamic process of knowledge development in the classroom.

In science learning, being aware of the certainty/uncertainty of knowledge allows the learner to construct new knowledge, to question it, to argue it, and thus to gain a better understanding by giving elements about the way knowledge is built and progresses; we are in the cases of epistemic certainty/uncertainty.

The development of epistemic certainty/uncertainty according to the elements or sets of knowledge is strongly associated with the development of an intellectual autonomy (emancipation) of students. This autonomy is very frequently stated in the introduction of scientific curricula; it is a widely shared educational goal. The students should think for themselves, which means in our perspective that they should be able to rationally question or justify their proposals. In our case, physics teaching in mechanics should aim to help students acquire a rational certainty of the main elements of knowledge of this domain.

This certainty should be differentiated from validity. The teacher can state that an element of knowledge is valid from a physics point of view. However this statement does not imply that students have acquired an epistemological certainty for this element, which means that they have acquired the rational arguments associated with this element to lead to a certainty. Consequently, the meaning of similar elements of knowledge can be profoundly different according to classrooms. It also evolves within a classroom according to their status of certainty/uncertainty and thus according to the moment when they are introduced. This evolution occurs in a joint action between the teacher and the students towards the construction of an epistemological certainty.

Main Characteristics of the Teaching Sequence on Mechanics

The teaching sequence on mechanics involved in the observed classroom was designed in the framework of a design-based research project (Ruthven, Leach, Laborde, & Tiberghien, 2009; Tiberghien, Vince, & Gaidioz, 2009). For this study we consider two main characteristics of the design; the epistemological choice of modeling and the emphasis on first developing new knowledge during small work groups and then, debating and sharing it at the whole class level. Concerning modeling, the emphasis, in the case of this sequence, is to make the material events explicit before introducing the concept of Force. This choice is based not only on epistemological considerations but also on learning hypotheses to propose activities where students can use their initial knowledge even if this knowledge is not used in these material situations in everyday situations (to act in this case). Contrary to other teaching choices which start with the usual meaning of force, we decided to avoid the use of this word before the students are familiarized with the way of “seeing” and describing a material situation in terms of action. We consider that this learning is necessary in order to understand the physics concept of Force and the Inertia Principle. Of course the everyday meaning of force has to be considered to help students distinguish it from physics knowledge; a main difference is that in everyday knowledge force is associated with a person or a thing whereas in physics Force is a concept that characterizes an interaction between systems. Thus the first part of the teaching sequence includes activities aiming to help students describe the material situations from the physics point of view. For example analyzing the situation of a table on which there is a book needs to be reformulated in terms of actions on the table for example, like the book acts on the table, and the Earth acts on the table. More generally, we decide to introduce the notion of action to describe what is going on when two objects are in contact or when there is a gravitational action at distance; this last case is limited to the action of the Earth. This orientation led us to introduce a symbolic representation, the system-interactions diagram, (see Figure 2) in order to help the students to “view” the material situation in
terms of events (to act), and to develop a language facilitating the descriptions, and later on to interpret them in terms of force.

Research Questions

This leads us to our research question which deals with the ways certainty/uncertainty of elements of taught knowledge in a classroom are established in relation with characteristics of the evolution of knowledge during teaching, in the dialectic between contract and milieu. This research question requires the analysis of the evolution of knowledge during the teaching sequence which constitutes a research question in itself. Thus we shall deal first with the evolution of knowledge in the classroom. Then we will focus our study on the emergence and the evolution of knowledge in relation to its status of certainty/uncertainty. An element of knowledge may emerge from tentative research, from a person’s authority (teacher or student) or from scientific authority. How can we differentiate between these statuses? How do they evolve?

Methodological Approach

Our approach has several components presented below.

Collected Data

The data of the study were collected in the context of the research-based design project of teaching sequences in mechanics at grade 10 shortly presented above. Two classrooms were observed during the teaching part on dynamics (6/7 sessions); in this paper only one classroom study is used. The teacher of this class, a woman, was very experienced and during several years

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was a member of the group that designed the sequence; this group included about 10 people, teachers and researchers. The school was in the suburb of a big town with a medium socio-economic level. The teachers of different disciplines considered it is a middle level class.

All the sessions were videotaped with two cameras, one was focused on the teacher and a part of the class, the other one on two students (the same students during the whole teaching sequence), and a part of the class. These two students are two girls M and C. M is a medium-low achiever and C is a medium-high achiever.

The written productions of the two students were collected, and questionnaires before and after the sequences were given in these classrooms. In fact, these questionnaires were given in nine classrooms following the teaching sequence (of which the observed classroom presented here) and 11 classrooms following a sequence decided by the teacher; all classrooms followed the official curriculum (Tiberghien & Malkoun, 2009, 2010). The results showed that the observed class was situated in the highest gain compared to the set of all classes.

Preliminary Analyses and Selection of the Sets of Knowledge

These data were first analyzed from the points of view of the evolution of knowledge in terms of the ideas that are treated during classroom activities and of who takes the responsibility of treating them, and in which milieu. These analyses based on classroom activities were developed; they allowed to partly interpret the students’ outcomes given by the questionnaires (Malkoun, 2007; Tiberghien & Malkoun, 2010). We obtained deep analyses of the students’ activities according to the evolution of their experience in the classroom context in relation to the teacher’s actions which give the evolution of knowledge in the classroom.

These analyses support the point of view of a dynamic status of certainty/uncertainty of knowledge as presented in this study. We first summarize our analysis of the evolution of knowledge in the classroom on which is based our study. In this summary we particularly develop our analysis at different scales of time to the extent that we used it in the present study.

Summary of the Analyses of the Evolution of Classroom Knowledge During the Teaching Sequence

The complexity of the classroom as a system has led us to use several scales or levels of analysis (Lemke, 2000). To reconstruct the evolution of the taught knowledge in relation to the didactic contract and the milieu, we use three time scales: macro, meso, and microscopic and for each scale we have units of analysis. The macro scale concerns the whole object of our study, the teaching sequence, whose duration spans several weeks; the meso scale aims at structuring each session; the micro scale concerns specific events at the timescale of a dozen or so seconds, like a few verbal interactions. In our analysis, each scale gives meaning to the other (Lemke, 2000); in particular the micro-scale analysis necessitates the structuring given by the macro and meso scales to interpret the micro events related to certainty/uncertainty.

Macroscopic Scale. This scale concerns the whole teaching sequence. In our analysis at this scale, we proceeded to a qualitative thematic analysis. The sequence is a macro unit that gives the conceptual structure of the taught knowledge corresponding to the designed sequence. Firstly, objects, actions at contact and at distance are introduced while studying various familiar situations. Then the concept of interaction with the system-interactions diagram is proposed with similar situations (see an example Figure 2). The concept of Force as a vector representation is then introduced as a way of modeling action, and afterwards the Inertia Principle. This macro-analysis gives the conceptual structure of the sequence in a chronological order but without precise duration. It also gives the main generic elements of the didactic contract, in particular the generic norms established in the classroom (Malkoun, 2007).
**Mesoscopic Scale.** At the meso-scale, due to our approach, we have also chosen a thematic analysis to account for the meaning of the classroom discourse from the knowledge perspective. In order to keep the meaning of the “taught knowledge” involved in the classroom according to the teacher’s meaning or more generally the meaning that a person who knows the discipline and the official curriculum would give, we structured each session on the basis of a thematic coherence of the classroom discourse; most of the time there are discourse markers of introduction and conclusion (Cross, Khanfour-Armalé, Badreddine, Malkoun, & Seck, 2009). The themes were constructed by a researcher and refined by another one; when there were disagreements, the two researchers discussed to reach a common decision. The theme is our *mesoscopic unit of analysis*; this unit that structures a teaching session can have durations from a few minutes to more than half an hour. Its delimitation depends on knowledge and communication. The title of a theme represents the theme’s content; its formulation by the researcher should be as close as possible to the effective discourse. The words used in the title should be *effectively* involved in the classroom discourse. The theme plays two roles: decomposing the classroom discourse into units in a chronological order and investigating how elements of knowledge are introduced, by which participants, with which teaching aids (experiment, text, etc.). This unit is particularly relevant in the investigation of the students’ and teacher’s responsibility for knowledge development and display (Malkoun, 2007; Mortimer, Massicame, Tiberghien, & Buty, 2007; Tiberghien & Malkoun, 2009). The succession of themes is a representation of the development of knowledge in the class at meso-scale during the whole teaching sequence. Table 1 presents a part of the series of themes in the class (Malkoun, 2007). The succession of themes covers the whole sequence and then relates meso and macro scales. It gives a different structure of the sequence than the usual succession of teaching sessions. Whereas the session structuring is imposed by the institution, the thematic structure depends on the classroom knowledge development even if it is constrained by the session structuring.

<table>
<thead>
<tr>
<th>Session</th>
<th>Duration (min)</th>
<th>Themes</th>
</tr>
</thead>
<tbody>
<tr>
<td>S 1</td>
<td>19:00</td>
<td>1. Introduction of the notion of action</td>
</tr>
<tr>
<td></td>
<td>6:45</td>
<td>2. Introduction of the model of interactions</td>
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<tr>
<td></td>
<td>12:10</td>
<td>3. First use of the model of interactions</td>
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<td></td>
<td>10:10</td>
<td>4. Study of interactions for various situations</td>
</tr>
<tr>
<td>S 2</td>
<td>6:13</td>
<td>1. Graph representation</td>
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<tr>
<td></td>
<td>13:35</td>
<td>2. Interactions for various situations</td>
</tr>
<tr>
<td></td>
<td>18:00</td>
<td>3. Situations for chosen systems in interactions</td>
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<tr>
<td></td>
<td>1:25</td>
<td>4. Introduction of the general theme of the notion of force</td>
</tr>
<tr>
<td></td>
<td>18:44</td>
<td>5. Determination of phases of motion of an object, direction of action on this object, variation of velocity</td>
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<tr>
<td></td>
<td>10:41</td>
<td>6. Analysis of interactions for different phases of motion of an object (case of a medicine-ball)</td>
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<tr>
<td></td>
<td>4:41</td>
<td>7. Introduction of the force and its vector representation and of the principle of reciprocal actions</td>
</tr>
<tr>
<td></td>
<td>9:23</td>
<td>8. Using (exercising) force and its vector representation from interactions</td>
</tr>
<tr>
<td>S 3</td>
<td>5:14</td>
<td>1. Interactions: relations between a symbolic representation and one or several material situations</td>
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<tr>
<td></td>
<td>10:10</td>
<td>2. Representation of force modeling an interaction (not length of vectors)</td>
</tr>
<tr>
<td></td>
<td>30:31</td>
<td>3. Representation of force modeling a moving object</td>
</tr>
</tbody>
</table>
Microscopic Scale. At the micro scale we have chosen two types of analysis: facets and epistemic tasks. In both cases the duration is a few seconds.

Here, we do not develop the analysis with epistemic tasks that consists of investigating how the classroom discourse involves thought processes used in understanding the material world. To define these processes we have adapted the epistemic tasks proposed by Ohlsson (1996) on the basis of our epistemological approach of modeling in physics teaching so that these tasks are related to understanding the material world (Sensevy, Tiberghien, Santini, Laube, & Griggs, 2008).

The analysis in terms of facets involves the smallest units of utterance (and/or gesture) that still have a meaning (like sentences for written language); it is based on Galili and Hazan (2000), Küçükozer (2005), and Minstrell (1992). Our analysis consists of constructing a list of sentences, the facets, corresponding to elements of knowledge, regardless of whether they are right or not. More specifically, a facet is a simple sentence which denotes a component of a theory, a concept, a procedure, an epistemological statement, a description, a skill, or more generally any component of knowledge whatever: scientific, everyday, scientifically correct or not, etc. The list of facets constitutes the reference for analyzing the classroom discourse at the micro-scale level.

When the researcher considers that an element of classroom/teacher’s/student’s production has the same meaning as a facet, it is coded. The list of facets is constructed with an iterative process involving: an a priori list of facets deduced from knowledge to be taught, students’ conceptions, and students’/teacher’s/class productions themselves. Here is an example of analyzing a classroom discussion with facets. We have selected an extract that will be used later on.

Before the moment of this extract, the students were introduced to a “model” involving a graphic representation associated with the action of an object on another one; an object (the notion of system is introduced later on) is represented by an ellipse and the action of contact between two objects by a full arrow, the action at distance by a dotted arrow. The students worked in small groups on the following activity (here “activity” means “task,” “problem”):

With the help of the model of interactions, draw the system-interactions diagram describing the following situations. The underlined word indicates the object corresponding to the system considered.

1. a) An object on a table. b) A table on which there is an object.

Then there is a discussion and correction at the whole class level. The extract is situated during this discussion.

Just before the beginning of this extract, a student drew his solution on the blackboard (Figure 2, part 2), and the teacher asks the other students to give their opinions on this proposed solution. In the exchange, E and M are for students and T is for Teacher. Let us note that the discussion is in French and that, in this language, the word for “soil” is “terre” which also is used to mean the planet Earth (Terre).

1. T (0:09:37) a table on which there is an object
   [several exchanges between the teacher and several students]
2. T (0:11:02) the ground and the Earth is it the same thing?
3. E no
4. T the action of the Earth on the table how do you imagine it? What does the table tend to do?
5. M (inaud.) a force
6. T it is an action that attracts the table towards where?
7. M mm downward (0:11:25)
   [Turns 8, 9, 10]

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From our analysis, turns of speech 4–7 (Teacher and students) correspond to the facet: “The action of the Earth is always downward”. This facet is involved at the whole class level for the first time. Turns of speech 4 and 6 also involve the facet (Teacher): “The Earth always acts on (attracts) the object,” and turns of speech 11–13, and turn 19 involve the facet (Teacher): “The action exerted by the Earth and the action exerted by the ground are not the same.” This element of knowledge is also introduced for the first time at the whole class level even if it has already emerged during small group work as we shall discuss later on. It appears that the same exchange can correspond to several facets. The duration of the exchange or the utterance corresponding to a facet is a few seconds. We consider it as an instant event; it is the facet time. We analyzed the seven sessions by coding each facet and the time where it happens; for this analysis we used Excel.

This analysis was carried out for the whole sequence at the whole class level. It shows what elements of knowledge are involved in the classroom discourse and when. Figure 3 presents the results for the four facets the most used in the sequence. For example, it shows that the element of knowledge corresponding to the facet: “when object A is in contact with object B it acts on it” is introduced at the very beginning of the teaching sequence at the whole class level during theme 1 “Introduction of the notion of action” (see Table 1). This element is reused in theme 3 “First use of the model of interactions.” In session 2, this element is used in several themes (2, 3, 5, 6) and several times in themes 2 (4) and 3 (2). This facet is involved with others like in theme 2 “Interactions for various situations.” This figure also shows that this facet is used in the last sessions 6 (theme 2: system-interactions diagram, Forces, application of the Inertia Principle, four times) and 7 (theme 1: Nature of motion and application of the Inertia Principle). This basic element of knowledge consisting in recognizing that, when an object is in contact with another one it acts on it, is at play until the end of the sequence.

Representations like that of Figure 3 situate events at the micro-scale (an utterance or a verbal interaction corresponding to a facet that lasts for a few seconds) on the meso level with the themes and macro level of the entire sequence. The facets serve as landmarks or pieces of evidence in the

![Figure 3](image.png)

*Figure 3.* Distribution of the three most frequent facets over the duration of the teaching sequence (whole class work). The fourth facet represents the element of knowledge analyzed in terms of certainty/uncertainty.

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The use of elements of knowledge corresponding to the same facets situated at different times of the teaching sequence also gives indications of the potential of similar meanings in the whole classroom discourse; this is an indication of a continuity since the students can use their experience of similar interpretations or similar arguments for diverse material situations.

Discussion of the Units of Analysis From the Temporality Perspective

The units of analysis, themes at meso level, facets, and epistemic tasks at microscopic level are related to the meaning of acts, what the students and the teacher do and say in classroom interactions. The theme accounts for what is said and done in the classroom as a group during a period of about 10 minutes; it is associated with the classroom not with an individual. At microscopic level, events corresponding to the facets are related to individuals, the teacher or students’ utterances or short interaction with 2 or 3 speech turns as we presented above; when these events happen during whole class work, we consider that they belong to the class life. In a theme, the analysis, in terms of who takes the responsibility of introducing and/or dealing with knowledge, connects the class group and the individuals. Similarly, facets are associated with the teacher or the student(s) who produce the corresponding speech or acts. The classroom dynamics depend on the emergence from events at an individual or small group level to events at the class group level and the reverse.

Whereas the macro and mesoscopic levels of our analysis structure the teaching sequence, the microscopic level analysis gives a succession of micro events. To give meaning to a micro event, it has to be situated in a larger period of time. Moreover, the succession of these micro-events makes sense; it is essential in this analysis of the evolution of knowledge. In particular it indicates the frequency of the use of an element of knowledge or a group of elements, the number of elements used in the same period of time like a theme. It gives a tendency that should be confirmed by an analysis at a larger scale, particularly the mesoscale that allows us to take into account the situation in which an element of knowledge makes sense. This succession of micro-events (facets) is analyzed within the context of each event and its evolution.

In conclusion, the entire analysis of the evolution of classroom knowledge during the teaching sequence, gives us the precise time where each specific element of knowledge (landmark of facet) is used in the classroom discourse and its meaning in the framework of the themes and of the whole sequence. This landmark of the precise time is important for the next analysis.

Analysis From Certainty/Uncertainty Point of View

To capture the evolution of the status of certainty/uncertainty of classroom knowledge, specific notions involved in the classroom discourse should be selected. We chose a notion and not a single facet because the construction of the meaning of a notion involves links between diverse facets. We selected two notions corresponding to two sets of elements of knowledge. The first one is about the difference between the actions of the Earth and of the ground. The second one is epistemological as each set is justified by different types of arguments. The former is mainly experimental; the latter is theoretical. The third reason is that these elements play a significant role in constructing the main concepts of mechanics involved in the sequence. Whereas the Principle of Inertia is at the heart of the sequence and then plays a significant role in constructing the main concepts of mechanics involved in the sequence, it is not straightforward for the first set. The distinction
between the actions of the Earth and of the ground is not anecdotic; it is necessary to understand this for almost all the situations to be interpreted in mechanics at this grade, and thus it is used throughout the teaching sequence. Moreover from an epistemological perspective it helps to recognize that the Earth is an object just as a book is as far as the law of universal gravitation is concerned, unlike in everyday knowledge. Let us note that these two sets of knowledge are still in the framework of classical mechanics which is strongly based on a physics theory, and thus the rational arguments to develop certainty or uncertainty are based on it in relation to experimental situations.

**Determination of the First Set: The Ground and the Earth**

To determine a set, we start from our chronological analysis of facets situated in the themes and the sessions (see an example for four facets Figure 3) during the whole sequence. This allows us to locate when the elements of knowledge are involved in the classroom productions. For this study on certainty/uncertainty of knowledge we do not restrict this analysis to moments where the work is done with the whole class, small group work times are included. At this step, the location of facets is based on the micro scale analysis. Then we come back to the thematic analysis and to the videos themselves to check if a meaning of a part of the notion is effectively involved. Looking at the video allows us to determine episodes that give meaning to the notion or a part of it and that account for the contributions of the teacher and the students. These episodes are clearly longer than a facet time and shorter than a theme time. To reconstruct the meaning, it is necessary to extend the micro time span of a facet, this extension cannot be an *a priori* period of time, it depends on the context. Thus the duration of our episodes is not fixed. We obtain a series of episodes that constitutes a kind of narrative of the evolution of a classroom life where a given notion is involved. This is the reason for which we call it “a history” (a narrative) of what happens to a set of knowledge in the class during several sessions. In this way, such a history keeps the actions and their context together (Bruner, 1996). Each episode is analyzed from the certainty/uncertainty status of the elements of knowledge, not in an isolated way but in the context of the theme and the session, and the whole sequence.

Figure 4 presents the chronology of the episodes for the notion “the action of the ground and the action of the Earth are not the same.” In this time line, time is not represented linearly; session 1 is extended since the notion is constructed; sessions 4 and 5 do not include any episode, but in session 6, this notion is again explicitly involved at the whole classroom level. The first three episodes include the elements of knowledge (numbered 1–3, Table 2) used to construct the notion; in the next three episodes (4 and 5, Figure 4) the notion is introduced, then in episode 6 there is a debate in whole class that leads to its status evolving, going from uncertain to rather certain as we present it below. Then the next episodes (7–10) are situated in sessions 2, 3, and 6. Let us not that the presence of episodes for this notion, late (session 6) in the evolution of the taught knowledge shows how students’ learning time does not follow the teaching time; even if the notion constitutes part of the classroom common knowledge, students do not necessarily mobilize it.

**Narrative 1: “The Ground and the Earth”**

The analysis of this narrative is structured by the successive episodes (Figure 4). To present this narrative, we first introduce the chronology of the elements of knowledge of these episodes, then we analyze deeply some episodes to understand the evolution of the status of certainty/uncertainty of the elements of knowledge.

**Chronology of the Elements of Knowledge.** Table 2 gives the series of elements of knowledge. Some of them are more general than facets whereas most of them are identical to facets. The
elements of knowledge numbered 1–5 in Table 2 belong to the narrative on the ground and the Earth.

The first three elements (Table 2) are constructed in the classroom. Students at grade 10, in France at least, do not know these elements, or do not mobilize them easily. The students know a relation between gravity and falling objects, but not precisely in terms of action between objects. This understanding is a necessary prior knowledge in order to differentiate the distant action of the Earth and the contact action of the ground. In the teaching sequence, the way the activities given to the students are designed leads the students to start first with the action of the Earth and then the differentiation between the distant action of the Earth and the contact action of the ground. Elements 4a and 4b of Table 2 correspond to the notion “the action of the ground and the action of the Earth are not the same” whose evolution in terms of certainty/uncertainty we intend to account for. We include it as an element of knowledge, because at one time in the sequence it appears as “a whole”; however it was not constructed directly, in one go, in the classroom. Another element of knowledge is determinant to differentiate the actions of the ground and of the Earth; it is a symbolic representation of the contact and distant actions between systems (element no. 5, Table 2, see an example Figure 2). This diagram, with a double arrow, dotted or full, respectively embeds the elements nos. 2 and 3, Table 2.

Analysis by Episode. This analysis is done in terms of our theoretical concepts of contract and milieu, and of the status of certainty/uncertainty of the element of knowledge. To emphasize the analysis of this status, we entitle the following episodes with the main characteristics vis-à-vis certainty/uncertainty.

Episode 1: From Epistemic Uncertainty to Certainty. This episode is situated in session 1, theme 1 when the students are working in small groups on an activity including the device of a
motionless stone hanging by a piece of elastic. This simple device is associated with the following statement: “What are the objects that act on the stone?” “On what object does the stone act?”

The teacher goes from one group to another depending on the requests (7 out of 15 groups during this episode). It appears that all of these seven groups rapidly find that the piece of elastic acts on the stone, then they raise the question of other things that act and propose weight, gravity but they recognize that gravity and/or weight are not “objects” (material) and cannot be included in the answer. In all the groups with which the teacher intervenes the question of gravity and weight is raised. All groups recognized that gravity or weight are not objects, one group says that this is a “phenomenon,” but only one recognizes that it corresponds to the action of the Earth; all the other groups wonder how to answer the question because there is an action (justified by a potential event: without the elastic the stone falls down) and no object. The emergence of this question is the reason for calling the teacher in most of the groups; the students are uncertain about two arguments, there is an action, and this action is not associated with a material object which would allow them to answer the question. However, during the teacher’s intervention, all the groups answer the teacher’s question about the object (the Earth) that exerts the action corresponding to gravity fairly rapidly.

For this first episode, we present in Table 3 the analysis of an extract coming from the students’ group recorded during all the sequence (M and C stand for the two students of the group).

This extract is divided into six periods (Table 3). Each period corresponds to a same milieu and contract. In Table 3, each period is analyzed. In period 2, an epistemic uncertainty emerges and is maintained even when the teacher arrives in period 4. During this period, the teacher

Table 2
Elements of knowledge (EoK) involved in the two “histories,” elements of knowledge 1, 2, 3, 4a, 4b, 5 are involved in narrative 1, elements of knowledge 1–10 are involved in narrative 2

<table>
<thead>
<tr>
<th>Nb</th>
<th>Elements of Knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The Earth is an object (material)</td>
</tr>
<tr>
<td>2</td>
<td>The Earth acts on objects at a distance</td>
</tr>
<tr>
<td>3</td>
<td>The ground acts on objects in contact with it</td>
</tr>
<tr>
<td>4a</td>
<td>The action of the ground and the action of the Earth are not the same</td>
</tr>
<tr>
<td>4b</td>
<td>The directions of the action of the ground and the action of the Earth on an object</td>
</tr>
<tr>
<td></td>
<td>put on a support have opposite directions</td>
</tr>
<tr>
<td>5</td>
<td>System-interaction diagram</td>
</tr>
<tr>
<td>6</td>
<td>Forces as modeling action and forces are vectors with direction and length</td>
</tr>
<tr>
<td>7a</td>
<td>When two forces are acting on a motionless object: They have opposite directions</td>
</tr>
<tr>
<td>7b</td>
<td>When two forces are acting on a motionless system (object): These vectors have the</td>
</tr>
<tr>
<td></td>
<td>same length (and the directions are opposite)</td>
</tr>
<tr>
<td>7c</td>
<td>Two forces exerted on a motionless system (object) compensate each other</td>
</tr>
<tr>
<td>7d</td>
<td>Two forces exerted on a moving system (object) do not compensate</td>
</tr>
<tr>
<td>8</td>
<td>Two forces exerted on a motionless system (object) compensate each other and do not</td>
</tr>
<tr>
<td></td>
<td>compensate if the system (object) is moving</td>
</tr>
<tr>
<td>9</td>
<td>There is a relation between the forces exerted on an system (object) and the</td>
</tr>
<tr>
<td></td>
<td>variation of its velocity</td>
</tr>
<tr>
<td>10</td>
<td>Principle of inertia: The forces exerted on an system (object) compensate each other</td>
</tr>
<tr>
<td></td>
<td>if the movement of the system (object) has the same direction and the same velocity</td>
</tr>
<tr>
<td></td>
<td>(and the reverse)</td>
</tr>
</tbody>
</table>
Table 3  
**Analysis of an extract of small group discussion transcript during episode 1 (session 1, theme 1)**

<table>
<thead>
<tr>
<th>Per</th>
<th>Transcript</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>... (0:05:34)</td>
<td>Previous knowledge is used (the students learnt the notions of gravity and weight in previous grades)</td>
</tr>
<tr>
<td>1. C</td>
<td>The objects that act on the stone there is its weight</td>
<td>C and M takes the responsibility of the knowledge</td>
</tr>
<tr>
<td>2. M</td>
<td>Yeah</td>
<td>C and M take the responsibility of the knowledge</td>
</tr>
<tr>
<td>3. C</td>
<td>The weight of the gravity of the Earth</td>
<td>C reads the question that becomes a determinant element of the <em>Milieu</em></td>
</tr>
<tr>
<td>4. C</td>
<td>(she reads the question) what are the objects that act on the stone ah yes but no but we are asked to give objects we are not asked for the weight or the gravity</td>
<td>C and M take the responsibility of the knowledge</td>
</tr>
<tr>
<td>...</td>
<td></td>
<td>C recognizes that weight and gravity are not objects even if nevertheless there is an action on the stone related to them</td>
</tr>
<tr>
<td>5. C</td>
<td>The objects that act on the stone Er the elastic for sure</td>
<td>Epistemic certainty for the contact action of the elastic on the stone, but implicit epistemic uncertainty based on the knowledge that the weight/gravity has a role in the actions on the stone and they are not objects) The <em>Milieu</em> acts as a constraint (looking for objects only)</td>
</tr>
<tr>
<td>... (0:06:40)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 4</td>
<td>Shall we ask the teacher (?) M and C decide they need help. It is a way of recognizing uncertainty with the aim to decrease it</td>
<td>M and C decide they need help. It is a way of recognizing uncertainty with the aim to decrease it</td>
</tr>
<tr>
<td>6. M</td>
<td>Yeah</td>
<td>Decision implying a modification of the <em>Milieu</em></td>
</tr>
<tr>
<td>7. C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(T arrives ... 0:07:23)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 8. M</td>
<td>Is there only the elastic which er</td>
<td>Students interact with T: <em>Milieu</em> is modified The ideas already constructed by M and C are shared with the teacher. The responsibility of knowledge is mainly taken by C and M</td>
</tr>
<tr>
<td>... (0:07:43.5)</td>
<td></td>
<td>In 10, T confirms that the answer should be in terms of “objects,” and in 12 T confirms the question asked by C</td>
</tr>
<tr>
<td>9. M</td>
<td>Is it is only the objects?</td>
<td>In 15 and 16, T and C recognize that weight and gravity are not objects</td>
</tr>
<tr>
<td>10. T</td>
<td>Therefore “question a” it is the objects that act on the stone only</td>
<td>All three confirm the <em>epistemic uncertainty</em></td>
</tr>
<tr>
<td>11. C</td>
<td>Well it’s the elastic only</td>
<td></td>
</tr>
</tbody>
</table>

*(Continued)*
recognized this uncertainty, gravity, and weight are not objects. In the next periods (5 and 6),
there is a strong change; the teacher takes the responsibility of knowledge, she orients it. Then
she asks a closed question, obtains an answer (the Earth) that she explicitly considers as the
right one. Then the students accept that the Earth is an object. In this episode, for the two
students M and C the status of the Earth as an object is passed from uncertain to almost certain.
This evolution is rather fast; this is not surprising since this element of knowledge seems rather
easy for these students. In this example, uncertainty emerges from knowledge, here gravity and

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or weight are related to an action on the stone and are not material objects. Here the students construct rapidly the new element of knowledge, the Earth is an object, which mainly consists of establishing new relationships between Earth and object implying a modification of the idea of material object.

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**Episode 2: Institutionalization of an Epistemic Certainty.** This episode is still situated in theme 1 of the first session; it follows on from the small group work in which episode 1 is situated; the class works together on the answers to the two questions of the activity for about 5 minutes. First the teacher confirms that all students proposed that the elastic acts on the stone (and the reverse): “Here there is no problem, all of you saw that the piece of elastic acts on the stone.” After some exchanges between the teacher and students of the classroom, the teacher states the correct arguments; the knowledge is institutionalized.

T You are asked what the objects that act on the stone are so you reply in terms of objects (0:16:31.9) so of course it is not always easy to imagine the Earth as an object well that is to say then it is not an object for everyday life but we have it under our feet all the time, this is a big object, but we can consider that it is an object. You have all answered correctly or corrected if it was not correct. So there are two objects that act on the stone, the elastic and the Earth (0:16:59.3)

From this time on, these elements of knowledge, like the Earth is an object, are considered as shared in the class and part of a common background. That does not mean that all students know them, but it means that the teacher and the students can consider it as already taught even if all students do not know or use it in a relevant way. This is an important feature of the institutionalization in progress in the classroom.

The whole class work leading to this institutionalization shows that the teacher emphasizes the necessity of giving argument to backup a statement. This type of request explicitly appears twice in a short period of time (about 5 minutes).

1. T (0:14:24.3) some of you said that the elastic is attached to the stand therefore you said that the stand acts on the stone, so what is your reasoning Alexandre about this?
2. Al at the beginning I thought that the stand acted on the stone
3. T yes
4. Al in fact not, the stone is not in contact with the stand (0:14:56.2)
5. T so not being in contact is not sufficient as an argument, yes Nicolas (0:14:56.2)

Later on the teacher asked (M and N are for students):

1. T (0:15:52) is there another object other objects that act on the stone Michael?
2. M er the Earth
3. P er the Earth, indeed what allows us to say that?
4. N er because if you cut the elastic the stone falls (0:16:06.6)

In these extracts, the teacher is not satisfied by a direct answer, she asks for reasons. More generally, the necessity of giving arguments belongs to the generic part of the didactic contract in this classroom and it is regularly recalled.

**Episode 3: Authoritative Certainty.** This episode is situated in whole class work during theme 3 (session 1). The teacher introduces a formal representation of interactions called the “system-interactions diagram” (see an example in Figure 2). This associated knowledge is presented as not questionable. It is written on a sheet given to all students and the teacher reads it.

Here is an extract showing the status of the new knowledge that the teacher introduces:
This knowledge, constructed from interpretations of material situations in terms of reciprocal actions, is valid from the point of view of physics. At this time it has not acquired a status of epistemic certainty for the students to the extent that they do not have arguments other than authoritative ones to convince themselves of its certitude.

Episodes 4 and 5 are situated in theme 4 of session 1 during a small group work that lasts for about 10 minutes until the end of session 1. During this period of time, the students have to draw the system-interactions diagram of various situations, an object on a table and the reverse, the Earth, a kite, a biker speeding on his motorcycle, a motorcycle driven at high speed by a biker. Let us note that at the end of the session they have not completed the activity; they have to finish it at home. The teacher interacted 17 times with groups, and for two or three groups twice, which represents all of the groups. Contrary to the previous small group session from which episode 1 was taken, the interventions are much more varied. The role of the Earth is raised several times; the two following episodes deal with this question.

**Episode 4: Emergence of Epistemic Uncertainty.** Here students M and C who are videotaped during the whole session are working together (small group) on the first situation: draw the system-interactions diagram of a table on which an object is set (see the correct solution Figure 2 part 3). Before the beginning of the extract, the two students had decided on their answer, that is, the object and the earth are acting on the table (Figure 2 part 1). They have just had a short interaction with the teacher and then they started to write their answer.

In turns 1 and 5, M clearly wonders if the Earth and the ground are the same. This question emerges from the students’ discussion in the group work situation where they have to identify what is acting on the table and distinguishing between distant and contact action. This extract shows the emergence of uncertainty on a possible distinction between the Earth and the ground. C in turn 5 introduces a property (it can be hard). This property is an object of our direct environment and not to a planet. Moreover, this extract illustrates that the students are familiar with the notion of action, the type of questions and the diagram to the extent that they do not ask questions about how to draw...
it; they only do it. This extract illustrates two phenomena related to the milieu and the contract, the positive role of writing and the rather negative role of using the previous solution. Firstly, whereas the students have already decided of their answer, when writing, M challenges the decision. Writing changes the milieu and the contract. The written answer becomes an external and fixed representation (it can be read), and also it will be visible to the teacher. Secondly, the way C uses the argument of not going too far shows that, at this moment, the milieu is not relevant to help her to go further, or in other terms not relevant to develop an epistemic uncertainty. Thus the uncertainty introduced by C remains pending.

**Episode 5: Decreasing Epistemic Uncertainty.** This episode corresponds to the work of another small group. This group works on the same question as students C and M in episode 4. This group requests the teacher’s help. When the teacher is close to them, they directly ask the question: “is the table in direct contact with the earth (terre in French) or not? Again, this question emerges from the group and not at the teacher’s initiative. Then the teacher helps them to differentiate between the soil and the Earth and to go from gravity to the action of the Earth. The teacher’s argument is that the table in the classroom is not put on the soil (terre in French, the same as the Earth), and then she asks the students if the table was in a garden. With this argument the role of the soil or the ground in preventing the table from sinking downward is raised. Here the teacher modifies the milieu by introducing a new situation (garden) and the possibility of thinking the direction of the action. This new situation reinforces the questioning about the difference between soil and Earth and helps students to be convinced of this difference. These students are making their way from uncertainty to certainty for this notion.

**Episode 6: Institutionalization of an Epistemic Certainty.** This episode takes place in theme 2 of session 2. It involves a classroom debate that occurs during the correction of a part of the activity on which students worked in the previous session as shown in the previous episodes 4 and 5 (Draw the system-interactions diagram of a table on which there is an object). At the request of the teacher, the whole class works together and a student writes his solution on the blackboard. The teacher asks all the students if they agree with the proposed solution (Figure 2, part 2). A student questions this drawing (in which the table has only two interactions: the object (full double arrow) and the Earth (dotted double arrow) by saying:

1. M between the table and the Earth, we put a contact arrow (0:09:59.6)
2. T ah then
3. M because the earth, well the table is put on

This proposal, still wrong, to modify the dotted arrow that means a distant action by a full arrow (see Figure 2 parts 1 and 2) that means a contact action raises a meaningful debate. Here this proposal gives new elements to all of the students to think the situation. The milieu is modified and the contract remains the same, the discussion is opened. This debate is between two incompatible arguments for the students who draw only two arrows (the object on the table, and the Earth or the soil). The first one is that the table is necessarily put on something (full arrow), and the second one is that the Earth acts on all objects (dotted arrow). The first argument is based on common sense: the table is not flying in the air, it touches the ground (or the soil—terre in French—if it is in a garden like the student proposing a full arrow argues). The second one comes from school science. Both are shared in the classroom. The debate between students does not lead to rejecting one of the two arguments. It reinforces the uncertainty, which, appeared in some small groups and is now shared at the whole class level.

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Until this turn the contract corresponds to an open discussion. However there is a change in the next turn. The teacher strongly orients the discussion.

The teacher asks “and the ground and the Earth, is it the same thing? (0:09:59.6)” and immediately raises the question of the direction of the actions:

1. T how do you imagine the action of the Earth on the table? What does it tend to do to the table? (0:11:18.8)
2. M (inaud.) it is rather a force well it is
3. P it’s an action that attracts the table to where?
4. M er down
5. E towards the centre
6. P towards the centre of the Earth good and the action of the soil on the table?
7. E (inaud.)
8. P what does it tend to do?
9. E it allows it to stop it
10. P yes, it prevents yes
11. C it stops it stops the object well it (inaud.)
12. P it prevents the object from falling, that is it prevents the object from sinking instead eh how does the ground act on my feet here? Here does it attract?
13. E (inaud.)
14. T on the contrary no, it acts upwards, the ground, so what does that mean? There’s a third system here which is? Stéphane, can you write this (0:12:03.5)
15. E the soil

In this extract, the arguments are based on material actions of common objects but the type of actions with which they are associated does not belong to everyday life. They require describing the material situations with particular properties of the objects. Here the table intervenes in the milieu as an object of physics study; it is diverted from its usual function due to the problem raised initially in the activity and reformulated in the debate. Again the generic contract about the necessity of arguments plays a central role and also the specific one about discussing of actions of objects in terms of physics. With her arguments, the teacher aims at giving students the opportunities to develop their rational conviction towards certainty that the actions of the Earth and of the ground are different. She helps students develop a physics way of thinking, by a specific thought style as a background with understandable arguments (Sensevy et al., 2008). The students are asked to see an object from the point of view of the direction of action it exerts. In this episode the teacher institutionalizes the difference between the action of the ground and the Earth; consequently the milieu and the contract are modified vis-à-vis this element of knowledge. Even if the students do not completely understand this difference and the associated argument, this institutionalization belongs to the classroom memory. The teacher and the students can refer to it.

Episode 7: Confirmation of an Epistemic Certainty. This episode is situated in the same theme and the same whole class work as episode 6. It concerns the last situation for which the students had to draw the system-interactions diagram: a biker speeding on his motorcycle. In this episode, we propose a short extract commenting on the solution proposed by a student at the blackboard:

1. T so the biker everybody agrees, the biker is sitting on his bike therefore contact interaction with the ground very good you didn’t forget, it shouldn’t be confused with
2. E the Earth
3. P the Earth, those are two different actions we saw it earlier for the table, and the air since the motorcycle system is running at high speed. Therefore with the Earth is it a contact or distance interaction?
4. E distance

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This episode shows the evolution of the contract vis-à-vis the knowledge on the differentiation of the actions of the Earth and the ground. The teacher considers it as already taught, but congratulates the student who did it and reminds them of the type of argument “there are two different actions” (turn 1). It thus shows a new step in the institutionalization in progress.

The following episodes (8–10) are situated after the institutionalization of the difference between the actions of the ground and of the Earth. Episode 8 is situated in session 3 and episodes 9 and 10 in session 6 (see Figure 4). All three involve some student difficulty in using this difference between the ground and the Earth in different material situations. In these three cases, the teacher not only recognizes the difficulty, but uses the same rational argument; this is an element of the continuity of knowledge in this classroom. We present the case of episode 9.

**Episode 9: Reconstruction of an Epistemic Certainty.** This episode is situated in session 6, theme 2 (representation of the system-interactions diagram, and of Forces, and application of the Principle of Inertia) during a small group work. The activity asked to draw the system-interactions diagram and to draw the Forces exerted on the system. The situation was a parachutist standing still on the runway and awaiting the aircraft. The Inertia Principle was introduced at the beginning of the previous session (5). The teacher is walking around the class and looking at the students’ production. She stops close to a student and the following extract presents the discussion:

1. **P** is that something you erased?
2. **E** um (0:15:17.7)
3. **P** what had you written?
4. **E** there in fact I put the runway
5. **P** and why did you remove the runway?
6. **E** the Earth is more or less the same thing
7. **P** is it more or less or completely the same thing
8. **E** it is the same
9. **P** oh okay
10. **E** no?
11. **P** the Earth is a force which has what direction on the parachutist
12. **E** er a force that
13. **P** yes that
14. **E** which goes towards the centre of the Earth
15. **P** and the runway too?
16. **E** no
17. **E** (inaud.) it’s a bit the opposite
18. **P** and it’s even quite the opposite yes because what does the runway do the ground of the runway
19. **E** yeah it allows to hold up

In this episode again the teacher does not give an answer but asks the students with the same arguments, the direction of the Force (or action). The student gives the arguments and then is convinced to modify his answer. His certitude is based on the rational arguments. Here the same type of argument is used; the student’s past experience enables him to reuse them. There is a strong continuity.

The status of certainty/uncertainty of the elements of knowledge involved for the notion “the action of the ground and the action of the Earth are not the same” for each episode are presented Table 4. In the evolution of knowledge and the status of the elements, several aspects appear. The “passage” of ideas between small groups and the whole class plays a determinant role. New questioning involving uncertainty appears first in small groups and then is made explicit at the whole class level. This passage is possible under certain conditions. The activity, including the text, the material devices and any other resources proposed to the small group work should

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be relevant particularly in order to lead students to raise questions that necessitate new ideas closely linked to the object of study and based on previous knowledge and/or experience. Students’ understanding of the situation and questions are necessary; they must be intellectually autonomous to be able to construct new ideas. In the case studied, the role of the representation of the system-interactions diagram is important; it is a common resource in small group discussions and in whole class. It can serve as a common reference in the development of arguments to the extent that the students understand it. This is an aspect of the continuity. These conditions characterize a relevant evolution of the milieu. Moreover, the students’ work is strongly oriented by what they think the teacher is asking them to produce. Here this aspect of the didactic contract of this class (where the necessity of arguments is required by the teacher and involved in the actual practices) orients the small groups’ method of working towards taking responsibility for their proposal to the extent that they can argument it.

The whole class work allows students not only to propose some of their solutions but to discuss them. In this “history,” the new ideas to emerge from the small groups are closely linked to the object of study; whether they are right or wrong, they allow students to propose arguments during the debate associated with the elements of knowledge to be learnt. There is no gap. Then, when the teacher institutionalizes these elements, she can use the arguments involved in the debate. There is continuity between the work in small groups, the whole class debate, and the institutionalization. This allows students to develop understanding of the elements of knowledge and to go from uncertainty to certainty. More generally, this allows for meaningful learning, however this learning can also involve the reverse, going from certainty to uncertainty depending on the elements of knowledge and the learning level.

Let us note that from a methodological perspective, our analysis of events at micro-level in terms of ideas or facets allows us to account for the passage of ideas over a longer period of time, from small group work to whole class work, and from one session to another several weeks later (session 1, 2, and 6 for example). The differentiation and the linkage between micro, meso and macroscale also allows us to relate short events corresponding to a facet to longer events like a debate or a theme and thus to approach the continuity of knowledge.

Narrative 2: Force With Vector Representations and the Inertia Principle

We shall present this narrative briefly (Supporting Information Table 1 gives the series of episodes). It deals with physics theoretical knowledge, the introduction of the concept of Force with the vector representation and the Inertia Principle. Here with this principle, the functioning of physics knowledge is involved; a principle is not demonstrated but stated and kept until it is rejected or modified by the physics community in particular because experiments contradict it (Valentin, 1983).

Figure 5 presents the chronology of the episodes for the concepts “Force with vector representation and the Inertia Principle.” These episodes are selected from facets and constructed by coming back to video and transcripts like for narrative 1. We obtained 10 episodes from the first session to the seventh session with the application of the Inertia Principle. Force as a vector is introduced in episode 2 session 2 and the Inertia Principle in episode 8 session 5.

More precisely, this narrative is focused on the compensation of Forces in relation to a motionless object, in particular to which material situations and to which characteristics of Force vectors this notion corresponds (and the reverse: for a given system does the Force exerted on it compensate or not?). It involves a network of elements of knowledge that go from the Earth as an object, the action of objects, their direction to the relation between Forces exerted on a system and the variation of its motion (direction and velocity) (EoK 9 Table 2). This network is much more important than the first set of narrative 1 but not independent; it includes all its elements. In the first
five elements, there are close relationships between a material object and conceptual notion whereas the following elements (nos. 6–10) involve relations between concepts: relations between Forces that are themselves in relation to motionless or moving systems, to variation of velocity, and to direction of movement.

In session 1, the notions of action and interaction are introduced and the students work on them during several activities (see themes Table 1). Then, in session 2 the teacher introduces the concept of Force as a modeling action on the basis of physics authority. During the last small group work of session 2, the idea of opposite directions of the two force vectors exerted on a motionless object emerges (EoK 7a, Table 2). In session 3, the relation between a motionless object and the length of the two opposite Force vectors (EoK 7b), and the relation between a motionless object and the compensation of Forces exerted on it (EoK 7c) are debated in the classroom and have several statuses. For some students, the force depends on the size of the object that exerts it, for example in the case of a stone hanging by a piece of elastic, as the Earth is bigger than the elastic, it exerts a larger force on the stone. In this case there is a rational justification even if it is wrong. For other students, this relation is taken for granted, it does not need any justification; finally for another set of students, in particular for EoK 7b involving the vector symbolic representation, they have no idea probably due to the complexity of the relations between the vector representation and the material situation. During the debate, the teacher questions the justification of some students’ proposal of equal length vectors or compensation of Force, stating that at this step of teaching, there is no argument to justify it. She introduced an epistemic uncertainty, a physics way of thinking insofar as physics knowledge should have rational justification. It is only during session 5, after the introduction of the Inertia Principle, that these ideas can be justified, at least from the teacher’s point of view. It appears that, during teaching, this evolution of the status of these elements of knowledge is complex because, even during the seventh session, the students have great difficulty in understanding what these elements mean, including how to implement them in a Force diagram. Thus in this narrative, only elements relating to motionless objects and

Figure 5. Successive episodes of narrative 2: Introduction of the concept of force and of the Inertia Principle.
compensation of Forces or equality of opposite vector lengths emerge from students and are debated; these elements have several statuses that coexist in the classroom and are taken for granted, with a rational justification (wrong or not). The other elements related to Force and characteristics of a motion seem too difficult to be debated, an elementary understanding could be a prerequisite.

In the following we briefly analyze the successive episodes. (see Supporting Information Table 1).

Episode 1 (session 1) presents the importance accorded by the teacher to thinking about the types of knowledge, either everyday or physics knowledge; this is an element of the didactic contract.

In episode 2 (session 2), the teacher introduces the concept of Force as modeling the action as a piece of physics knowledge that is not questionable. Consequently, this knowledge is valid and can have a status of certainty but only based on the authority of the teacher who represents the physics community. The students are supposed to start learning it with this status. This status may evolve with the development of rational justifications like the fruitfulness of the concept in the sense that using Force and its vector representation is easy to solve problems, to interpret situations, etc. (Posner, Strike, Hewson, & Gertzhog, 1982); it is a kind of pragmatic justification. The justifications related to the internal coherence of the theory, its validity or its consistency seem very difficult to develop by students during the rather short time of the teaching sequence and the difficulty of understanding the theory (Kuhn, 1977).

In episode 3 (session 3), the students are still working in small groups with the same device as for the introduction of action (a stone hanging by a piece of elastic fastened to a stand) and they have to draw the Force vectors exerted on the stone. This episode shows a big difficulty students have in drawing a Force vector diagram. However, in spite of this difficulty, it appears that students propose to draw the Forces exerted on the stone (the Earth and the elastic) in opposite directions.

Episode 4 (session 3) corresponds to the correction of the activity done in episode 3; it confirms the students’ difficulty in drawing Force vectors in the direction of the action on the stone. The teacher starts to introduce uncertainty about the length of the respective Force vectors representing the Force exerted on the stone.

Episode 5 (session 3) corresponds to the debate that takes place before the introduction of the Inertia Principle during the correction of the following activity done in small groups (draw the forces that are exerted on a stone suspended by a piece of elastic). This episode and the following particularly illustrate the difference with the first narrative developed above.

At the beginning of this episode a student draws his diagram on the blackboard with two arrows of different lengths for the Force exerted on the motionless stone

A student intervenes:
E shouldn’t the arrows be equal?
The teacher reinforces this question by saying that she intended to ask the same question. Then she asks:
T is there a reason? [that the two vectors are the same length]
E no
T so we do not make them the same length
After several exchanges the teacher asks the same student at the blackboard still modifying the length of the vectors:
T are you sure of what I say
E no
After this exchange, the whole class laughs. Again, after several exchanges, the teacher says about the equality of the vector lengths
T it is a point which we’ll come back to because you see, we hypothesized that the forces are equal because the stone is motionless, have you thought of that E?
This episode shows several positions vis-à-vis the length of Force vectors representing two opposite Forces on a motionless object. As we mention in the presentation of this narrative, for some students, this relation is taken for granted (first student’s intervention), so it does not need any justification. This position can be linked to the students’ conception relating force and motion (Viennot, 2001). Another set of students has the idea that if the Earth is bigger than the elastic for example, it exerts a larger force, which in this last case is a rational justification even if it is wrong, as we have seen. A third set of students has no idea about the respective length (like the student saying that he has no reason to give to justify the length of the vectors he drew); this last case can be explained by the students’ difficulty in managing a vector representation.

During this episode and in particular at the end, the teacher introduces uncertainty in the form of a hypothesis, which will be confirmed later on in the teaching sequence. This introduction involves a physics way of thinking where elements of knowledge must necessarily be rationally justified. However, this uncertainty does not seem to be shared in the classroom. As we discuss below, the students do not have enough knowledge to wonder if the equal length is justified.

In episode 6 (session 3), the students are working in small groups on an activity about the representations of Forces exerted on a medicine ball when it is launched, when it goes up, comes down, and is caught. A group of two students working together seems convinced that if the forces were equal the ball would not move:

E when you push the medicine ball if the forces were constant it means that the Earth presses (pulls) on the medicine ball the same way as when you lift up a thing it stagnates[^3]

They do not look for a justification of this type of proposition which is taken as read.

Episode 7 shows the interweaving of elements of knowledge: some are based on direct interpretation of events, others are taken for granted, still others come from the physics information given by the teacher without being understood. It is not possible to give a global certainty/uncertainty status to this set of elements of knowledge.

In episode 8, the teacher states the Inertia Principle as certain under physics authority.

Episodes 9 and 10 show two faces of the way students approach this interweaving of new and old elements of knowledge. In episode 9, the two students working together play the game of constructing an interpretation on the basis of a physics principle. In episode 10, the students’ difficulties in understanding and in using the Inertia Principle to interpret diverse situations dominate the interactions. The status of the elements of knowledge is not questioned; the students’ aim is to understand and use new physics knowledge, which has a status of certainty based on the authority of the physics community, to describe and interpret the material situation (e.g., recognizing the type of motion, relating it to the Force according to the principle).

These episodes reinforce the analysis of narrative 1, which is to say uncertainty emerges from knowledge. Here too many elements of knowledge are not stable enough, so that the students develop rational uncertainty about some elements. The part of the didactic contract consisting of the habit of action related to the necessity of arguments is insufficient; the other condition of understanding the arguments in relation to the knowledge in question does not seem to be filled for most of the students at this time of the teaching sequence.

In summary, our analysis shows the following main conditions for this emergence of epistemic uncertainty on specific elements of knowledge:

- at the macro level, the generic contract favor students’ strategy which particularly leads the students to construct arguments to support new ideas in the classroom by discussions
in small group and in whole class group. The milieu favors the continuity of knowledge by establishing links between elements of knowledge already taught and the new ones.

- At the meso level, the milieu involves elements of the material world and other types of information that are understandable by the students with their previous knowledge, and gives a specific target that delimits the students’ possibilities of bringing to bear new ideas. In other terms the milieu favors the emergence of some types of knowledge already known or new ideas. For example, in narrative 1, the ideas given Table 2 are strongly constrained by the milieu and favor the creation of new ideas related to them, and also in some cases the teacher plays a major role in helping to make new links between ideas. Moreover the institutionalization modifies the milieu and the contract and strongly contributes to the classroom memory.

- At the micro level, the milieu and the contract favor the possibilities of interactions strongly linked to the target knowledge and in the same time favor ideas without restricting them according that they are in agreement or not with physics knowledge; this is a condition for epistemic uncertainty emergence.

If epistemic uncertainty first emerges at the micro level, the conditions of emergence are at the three levels. These conditions strongly help the continuity of knowledge between small groups work and the whole class work and favor the possibility of debates focused on the target knowledge and thus can develop an epistemic uncertainty at the whole class level. They favor a deep understanding on a limited part of knowledge, the epistemic uncertainty evolves towards epistemic certainty for the part of knowledge in question, but other uncertainty can emerge.

In narrative 2, the conditions at the meso level given above are not fulfilled. The elements of knowledge 6–10 given in Table 2 are rather far away from students’ knowledge. In particular it is the first time that they are confronted to a physics principle. The students struggle to relate the intuitive idea of equality of two forces in intensity and with opposite direction when the object on which the forces are exerted is at rest to a much more difficult idea that “at rest” is equivalent to “no variation of velocity (as a vector)” and then to generalize this idea at any situation. In narrative 2, the epistemic uncertainty comes from the teacher and the students do not really take over this uncertainty. The students are focused on the understanding of the new ideas introduced in the milieu and cannot construct epistemic questions about them. Their questions, like those presented above on the vector representation of the equality of the intensity of the two forces (narrative 2, episode 5) are about the relations between the intuitive ideas of equality of forces and their vector representation which is difficult for the students; these students’ questions are not directly on the target knowledge of the Inertia Principle.

All teaching situations cannot allow the emergence of students’ epistemic uncertainty; the students cannot take it over for some parts of the taught knowledge to the extent that they struggle to understand the new ideas introduced. However, when the students have acquired enough understanding, then, epistemic uncertainty can emerge. This emergence can happen only if the continuity of knowledge over time occurs in the classroom, in particular because of the difference between teaching and learning times.

These findings that appear from our analysis of the case study constitute hypotheses. Other studies can start from them.

Discussion

Comparison between the two narratives shows important similarities related to the didactic contract. The teacher emphasizes the physics way of thinking and makes possible the conditions of emergence of uncertainty of some knowledge elements. In other terms, she introduces the necessity of their rational justification. In the two narratives, uncertainty emerges from
knowledge. In narrative 2, where the students’ knowledge seems insufficient, very new elements of knowledge are not questioned, whereas others are debated. This questioning may emerge because, throughout the teaching sequence, the teacher introduces the necessity of rational justification of students’ proposals; it is an essential part of the didactic contract.

This comparison also shows two main differences regarding the types of knowledge and the duration of the emergent uncertainty.

In narrative 1, these elements are fairly well circumscribed; their distance with the material situations is not so remote that the notion of action and the associated diagram is closed to a description in terms of action verbs relative to material objects. Thus most students manage to learn this in a relatively short time, and enough knowledge is shared in the classroom for students to question this knowledge and debate it.

Narrative 2 deals with much more difficult knowledge involving some elements which are already taken for granted by students and others that are totally unknown before their introduction by the teacher, like the vector representations and the relation between Force and the variation of velocity or the direction of motion. However, in physics, all these elements are involved in the same principle that gives a meaning to them not independently one from another. For the students they have separate meanings with different status, some are taken for granted, others are questionable, yet others are not understood. These elements of knowledge include concepts and a principle that are relevant for a very large variety of material situations. The duration of the evolutions of the status of the elements of knowledge is clearly longer than in narrative 1. The coexistence of different statuses according to the students and probably for the same student according to the situation seems to us important to analyze in order to understand the dynamics of a classroom from the knowledge perspective.

This analysis has been carried out in the framework of the Joint Action Theory in Didactics, which sees the construction of knowledge as resulting of the interaction between the teacher, the student and the context. The choice of looking at the classroom in terms of a contract and milieu allowed us to analyze the conditions of the emergence of uncertainty of elements of knowledge and the evolution towards a reasoned certainty. A relevant milieu allows students to understand a problem adapted to their knowledge and to interact with others, in order to develop new ideas with the stakes being to propose these ideas with rational arguments. Thus, a sufficiently well-structured didactic contract, defined as the system of previously taught knowledge, allows to cope with the milieu. Here again appears the necessity of students’ understanding of most of the elements of the milieu and a contract favoring the development of rational arguments. The maintenance of a coherent relationship between the milieu and the contract when they evolve, that is to say their equilibrium, allows a continuity of knowledge during teaching.

In other words, this study enables the development of a set of hypotheses that we considered as the main findings of our studies, and that future empirical research has to work out. These hypotheses specify the equilibrium process between the didactic contract and the milieu through the joint action. We can express them as follows, by relying on the conception of what we term continuity of knowledge as we have brought it in this paper. (1) In the classroom, the continuity of knowledge, as the students experience it, is a core element of the learning process. (2) In order to have students progressively acquainted with a scientific thought style, one of the main functions of this continuity is to enable them both to acknowledge epistemic uncertainty and to build epistemic certainty which rests on scientific reasons. (3) In order to foster a continuity of knowledge based on the building of an epistemic certainty/uncertainty, the teacher has to favor an equilibrium process in which the didactic contract enables the student’s inquiry into a relevant milieu. (4) The nature of this inquiry process lies in the students’ potentiality to consider elements of the milieu as reasons, as scientific warrants of their believes and behaviors.

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However even if our study contributes to the characterization of the dynamics of the development of knowledge during teaching, our two cases concern basic physics knowledge, and the question of the relevance of this study for other much less formal domains of knowledge is raised. Some conditions could be different; in particular the variety of possible arguments can create difficulties in finding criteria to select or organize them. The idea that the teacher and the students share reasoned arguments leading to conviction of the certainty or uncertainty of knowledge is still relevant. However, in this case, reasoned arguments can convince some students and not others. Thus, even if reasoned arguments are shared, their value of conviction may not be shared. New studies should be done.

More generally, this study puts to the fore a dimension of knowledge that is not usually developed in science education, its status of certainty/uncertainty in relation to the development of students’ understanding. It leads to emphasize the importance of questioning knowledge in physics teaching and to study students learning by looking at the way they develop the meaning of different knowledge elements, their rational arguments to construct the certainty status of these elements. It also advances a contribution to the design-based research in the domain of teaching resources. It shows the necessity and the possibility to design a series of teaching activities favoring the students’ construction of epistemic uncertainty/certainty with a continuity of knowledge in the classroom, which is a type of inquiry relevant even for traditional domains in science education like mechanics. Another perspective is the design of resources for teacher development on the basis of a series of video extracts of well selected episodes. In this perspective, the implicit teacher’s knowledge helping to relate situations and different elements of knowledge, etc. or in other terms helping to develop continuity merits further study and development of resources.

Notes

1 In this theoretical frame, “didactic” has the general meaning of “relating to the teaching/learning process concerning a specific knowledge domain.”


3 The French verb “stagner” is not usually employed in such a situation: “quand tu pousses le medecine-ball *(fuit un geste vers le haut avec sa main)* si les forces elles étaient constantes ça veut dire ça veut dire que la Terre elle appuie sur le medecine-ball de la même manière que toi tu soulèves un truc ça stagne” (0:26:35.0).

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