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► **To cite this version:**

Jérôme Santini, Gérard Sensevy, Serge Quilio, Dominique Forest, Jean-Noël Blocher. Semiosis and joint student–teacher action. Contract-milieu dialectics in a case study of two subsequent primary school earth science sessions. *International Journal of Science Education*, 2022, 44 (7), pp.1067-1095. 10.1080/09500693.2022.2066732 . hal-03658290

HAL Id: hal-03658290

<https://hal.science/hal-03658290>

Submitted on 7 Dec 2022

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Semiosis and joint student-teacher action. Contract-milieu dialectics in a case study of two subsequent primary school earth science sessions.

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Abstract

This paper addresses the subject of the semiosis process in the transactions between teachers and students about the knowledge at stake in science education. We present a conceptualization of these transactions as a joint action between students and teachers. This conceptualization enables us to understand the semiosis process as it unfolds during teaching–learning situations as the semiosis of both the didactic contract and the didactic milieu. We analyze this semiosis in a case study of earth science education at 5th grade, which comprised two subsequent teaching sessions delivered by the same teacher. Our results give an account of the contract–milieu semiosis under the description of different semiotic modes (speech, gestures, stance, gaze, writings, modelings and proxemics). We also define the generic and specific dimensions of semiosis in relation to the knowledge at stake. Finally, we evaluate the relevance of the teaching practice we observed in terms of its staging of a relationship between the semiosis of didactic contracts and didactic milieus.

Keywords: case study; earth science education; joint action; semiosis

Introduction

Our research program focuses on the processes of teaching and learning in action, or in the making, in science education. This means we aim at understanding teaching and learning practices in context. It may be seen as a “practice turn” (e.g. Bourdieu, 1990; Schatzki, Knorr-Cetina & von Savigny, 2001; Stern, 2003). We have undertaken this practice turn in science education alongside a number of researchers such as Jiménez-Aleixandre and Crujeiras (2017), Kelly (2008) or Östman and Wickman (2014).

It is well established that educational practices rely on language and other semiotic systems (e.g. Lemke, 1998). This leads us to investigate how teaching, learning and semiosis interact in science education. Several studies have investigated how students rely on different semiotic resources to make meaning and engage in conceptual understanding in science education. In

this perspective Roth showed the importance of studying gestures in science education (Roth, 2001; Givry and Roth, 2006) but also of the uses of space (Roth & Hsu, 2013). Singer, Radinsky and Goldman (2008) studied how 6th grade students used hand gestures to understand plate tectonic concepts prior to the use of speech. Hardahl, Wickman and Caiman (2019) have scrutinized how the body is involved in the production of phenomena in science and science education. Shaby & Vedder-Weiss (2021) also described the importance of the body when visiting a science museum. Siry & Gorges (2020) analyzed how a student uses different semiotic resources (gestures, facial expressions and drawings) to make meaning or communicate meaning. Wilmes & Siry (2021) have shown how a student uses a wide range of semiotic resources to engage in scientific practices.

Kelly (2021) emphasizes the need to analyze discourse in practice and in multimodal analyses in science education research. Jewitt, Kress, Ogborn and Tsatsarelis (2001) argued that learning is multimodal and requires different modes of communication. Learning is multimodal and so is teaching (Pozzer & Roth, 2020; Tang, Tan & Mortimer, 2021). Moro, Mortimer & Tiberghien (2020) point out that little research has been done on teacher's performance in terms of multimodality. These authors then show how the teacher's performance can be understood as a multimodal whole. In the same idea Lehesvuori & Ametller (2021) investigate how three teachers make pedagogical links between what has been studied and what is being studied, and how they communicate these connections. These authors suggest that how a teacher orchestrates this communication can be relevant to students' learning. Following the preceding outlines we think there is a strong need for empirical studies investigating multimodal semiosis in teaching practices. In this paper we propose to do so through a case study in earth science education.

1. Theoretical elements

1.1. The joint action theory in didactics (JATD)

Didactics account for teaching and learning as the interplay between three “characters”, three poles of a system: teacher, student and knowledge, i.e. the didactic system (Chevallard, 1999; Hudson & Meyer, 2011; Warfield 2013). It entails apprehending the knowledge as it “lives” in classrooms (Tiberghien, 2016), or as it is “transposed” (Tiberghien & Sensevy 2015) or “recontextualized” (Bernstein, 2003). This means transposed in action and thus in semiotic systems.

This concern about “living knowledge” brings the Joint Action Theory in Didactics (JATD; Sensevy, 2011, 2019) to develop another dimension, that one may call “cultural turn”. This expression refers to a twofold necessity we think at the heart of the teaching process.

Firstly, we consider the teacher as *representing culture*, not only in the general meaning of the term “culture”, but through the specific cultures that give their meaning to the various pieces of knowledge the students and the teacher deal with. For example, in that paper, we argue that the result of the teaching-learning process is a kind of acquaintance, for the students, with the geological culture, meaning the geological thought and practice. It is to say that culture, in this sense, is not seen as a general and loose notion, but as a system of patterns of acting and saying, *patterns of culture*, as Ruth Benedict (1934) coins the term, which concretely embed the *thought style* (Fleck, 1979) inherent to cultural practice.

Secondly, this concern leads the JATD to shape the theoretical notion of “cultural kinship”, which refers to the kind of kinship a practical connoisseur of a practice (i.e. a geologist) may identify between the practical connoisseurship and the teaching-learning practice.

Thirdly, we should clarify here what we mean by joint action. An action is joint when two (or more) participants occupy different positions and mutually adjust their actions to arrive at a common outcome (e.g. Gilbert, 2013). How are the actions of learning and teaching inevitably joined? They are joint because they share a common outcome, namely the student’s learning. However, where the student acts and learns, the teacher acts in order for the student to learn. They thus occupy dissymmetric positions. This dissymmetry is reinforced by their respective positions in relation to the knowledge at stake. The teacher already knows what the student does not yet know.

1.2. The joint action in didactics as the interplay of didactic contract and didactic milieu

In this paper, we mobilize mainly the concepts of the didactic contract (Brousseau, Sarrazy, & Novotná, 2014) and the didactic milieu (Sensevy, 2015). We begin with a brief presentation of these two concepts providing exemplars (Kuhn, 1977) of didactic situations, and then we show how the concepts allow us to understand the teaching–learning process as a joint action between teacher and student.

Our first exemplar, which illustrates the didactic contract, is that of the ‘age of the captain’ experiment. The Institute of Research on the Teaching of Mathematics (IREM – Institut de Recherche sur l’Enseignement des Mathématiques) in Grenoble carried out a study that consisted in asking approximately one hundred 2nd and 3rd grades students to solve the following puzzle: ‘There are 26 sheep and 10 goats on a boat. How old is the captain?’ (IREM de Grenoble, 1980). The researchers were astonished when just over three-quarters of the students responded by making use of the numbers in the wording of the puzzle. Even so, the students were not duped by its absurdity. When they were asked what they thought of the puzzle, they replied: ‘I think it’s okay, but I don’t see the connection between the sheep and the captain,’ or ‘I find this puzzle a bit strange,’ or ‘I think it’s stupid, because first they were talking about sheep and then they were talking about the captain.’ Chevallard (1988) explained this paradox between the students’ incorrect responses and their discerning viewpoints through a kind of *didactic contract* where: (1) any problem posed at school has a solution (and only one); (2) all the numbers in the wording must be used; and (3) the solution brings into play a mathematical procedure studied in class (in this case, addition). This exemplar shows that the student’s performance is determined by what they have appropriated, rightly or wrongly, from exposure to the normal way of doing things, in other words from previous didactic contracts. The didactic contract concept thus represents the strategic system, immediately accessible and specific to knowledge at stake, which allows the teacher and student to act. In the teaching–learning process, the didactic contract is, in a way, destined to be broken insofar as the essence of this process is to render the student capable of doing something they previously did not know how to do. The ‘age of the captain’ experiment provides a particularly striking exemplar of this rupture in the didactic contract phenomenon.

Our second exemplar, relating to the didactic milieu, is that of the tangram enlargement activity given to 4th and 5th grades students (Brousseau, 1997). The students were asked to enlarge a tangram so that ‘the segment measuring 4 centimetres on the model becomes 7 centimetres’ (Brousseau, 1997). They had not already been presented with the concept of proportionality prior to the study, which would have allowed them to come up with a reasoned solution to the enlargement problem they had been set. The students enlarged the pieces of the tangram by adding 3 centimetres to each segment, since that was the difference between the

two measurements provided in the instructions. However, they were then not able to reconstruct the tangram with the enlarged pieces. It was thus not the teacher but the resulting object itself that informed the children they had failed in the task. With the teacher's help, this failure then allowed the learning of proportionality to begin. This second exemplar highlights the fact that the act of learning is also determined by objects—concrete as well as symbolic—that the student encounters and which make up their *didactic milieu*. The didactic milieu concept thus also represents a possible strategic system that enables the teacher and student to act.

1.3. The contract-milieu dialectics

We analyze the teaching–learning process in the dialectic between the two strategic systems described by the didactic contract and didactic milieu, where the former accounts for what is already available in relation to knowledge at stake and the latter, for what is potentially available in relation to knowledge at stake. Hence, in the tangram enlargement activity, for example, the additive didactic contract ‘enlarge by addition’ does not allow the problem presented by the didactic milieu to be solved, but a new didactic contract formed within this didactic milieu does. From a cultural viewpoint, one may acknowledge that the contract-milieu dialectics can be seen as a cultural dialectics, between “the known” (by the student) and “the to be known”. This dialectics shows how new patterns of culture are built. The existing pattern of culture (that one may term “the additive culture”) is not able to deal with the enlargement problem. The didactic practice has to build up what one may term as “multiplicative/proportional culture”, which embeds specific patterns of culture (proportional enlargement) enabling students to solve the problem, and to progressively acquaint them with the “proportional thought style”.

The two exemplars above also illustrate that it is impossible to understand the action of learning independently of the action of teaching. The students who attempted to calculate the captain's age did so within a certain type of didactic contract. It is difficult to imagine the same students standing on a quayside counting the goats and sheep in order to find out how old the captain is. The action of learning is determined by the action of teaching. Likewise, in the second exemplar, the students are able to realize their error by themselves, because the teaching constructed a didactic milieu for them that made it possible. Here, too, the action of learning is determined by the action of teaching. Within the JATD framework, we also consider the reverse to be true, in other words the action of teaching is also determined by the action of learning and that *in fine*, learning and teaching both gain from being understood as a joint action under the description of contrat-milieu dialectics.

1.4. Semiosis process, multimodality and contrat-milieu dialectics

In line with Sensevy & Forest (2012), we believe that students have to enter into a process to learn, which involves them seeing and/or producing signs in the same way as the teacher sees and/or produces signs. This semiosis can involve different *modes*. According to Kress (2010) a mode is "a socially shaped and culturally given semiotic resource for making meaning" (p. 79). The gaze, the gesture, the speech, the images and the proxemics are examples of mode. Proxemics denotes the cultural uses of space and distance between people in communication (Hall, 1966). From a multimodality perspective it is important to emphasize that "different modes offer different potentials for making meaning" (Kress, 2010, p. 79). Multimodality can thus allow to gain insight into the semiosis process in the unfolding

of the joint action in science education (Moro, Mortimer & Tiberghien, 2020). We believe that it will also help us gain insight into the contract-milieu dialectics.

The semiosis process assumes that the student is able to understand a part of what is to be seen/done from the point of view of the knowledge under consideration and that they can ‘assimilate’ a portion of the situation to their prior experience, in other words they know how to read their teacher’s expectations. This dimension of the didactic contract inevitably leads to a point of rupture, because the learning process assumes that, at certain points along the way, a particular way of seeing/doing that had always previously been effective will be replaced by a new way of seeing/doing that is able to move beyond the resistances encountered in the situation towards the pattern of culture at stake. These resistances are defined under the notion of didactic milieu. To act effectively in a new didactic milieu, the student must ‘accommodate’ the initial contract, in other words they must produce meanings and actions that are suitable for the milieu resistance and thus construct new, better-adapted ways of doing and seeing. We understand here ‘seeing’ in the sense of Wittgenstein’s *seeing-as* (1997). It means not a mere direct seeing of things but a constructed seeing on the background of practices and experiences, a seeing that makes it possible to discern patterns.

Sensevy (2011) used the didactic concepts of contract and milieu in the Piagetian uses of the notion of equilibration through assimilation and accommodation but with the addition of a didactic and collective dimension to the assimilation–accommodation dialectic. This means the dialectic is individualized to knowledge at stake in the situation and strongly determined by teacher–student transactions. This *didactic equilibration* can be found in the implementation of the tangram enlargement situation described above. The additive didactic contract ‘enlarge by addition’ can be seen to fail through the didactic milieu. This milieu had been formed from the enlarged pieces that could no longer be fitted together to re-form the tangram. This contract to enlarge by addition did not therefore allow any assimilation of the tangram enlargement milieu, which necessitated being able to re-form the puzzle once the pieces had been enlarged. In this didactic milieu, only an accommodation of the additive contract towards a proportionality contract would result in the students being able to solve this enlargement problem.

The notion of learning game (Sensevy et al., 2005) can be used to describe the temporal space of a dialectic between a didactic contract and a didactic milieu. Along the same lines as Wittgenstein’s language games (1997), a learning game is a modeling of the didactic action. In other words, the description of a learning game aims to give an account of the joint teacher–students grammar of action in respect of the knowledge at stake being studied in the class. In our conception, language games are closely related to life forms, and the life-form-language game set refers to a pattern of culture, always seen as a structure of practice fundamentally related to a jargon for ‘speaking’ practices.

Using the tangram exemplar above, we can describe what the students did in class in a learning game relating to enlargement. The students’ failures in their attempts to enlarge by addition would have served to further justify the teacher’s initiation of new learning games on calculating images from a number by a linear function. From a didactic point of view, learning games thus correspond to an update of didactic contracts and/or didactic milieus. A new contract and/or milieu therefore initiates a new learning game. In the classroom, the milieu and the contract are supported by signs. As a consequence, describing the milieu and contract is the same as describing the signs, or more precisely, it is a semiosis.

1.5. Research questions

The objective of our work stems from our theoretical framing which extends the study of joint action in didactics in a multimodal dimension. In this text we study the following research questions:

1. How can a teacher make use of different modes to get students to engage with the didactic milieu?

2. How can these uses become elements of a didactic contract to act in the didactic milieu?

We investigate these two questions in a case study in earth science education that we present in the following.

2. Methodological elements

2.1. A qualitative study using video data

Our case study comprised two class sessions on volcanoes delivered by the same teacher. These two successive sessions were part of a set of sessions in the class's learning progression. The topic in the first session was the characteristics of volcanic eruptions and in the second, it was the structure of a volcano.

These two sessions originated from a larger set of data (Santini & Sensevy, 2011). Our initial research investigated four 5th grade classrooms all along the teaching of earthquakes and volcanoes which are part of the French mandatory science curriculum in primary school. We have requested written permission for audio and video recording from teachers and legal guardians of students. The four classes are divided into two pairs: a control pair and an experimental pair. The control pair consists of classes of two experienced teachers who are recognized as good teachers in their school. We do not intervene in the design of the sessions nor in the way of teaching with this control pair. The experimental pair consists of an experienced teacher, named Jean in the following, and one of the authors as a teacher-researcher (Roth, 2007). Jean and the teacher-researcher design the sessions together. Then each teaches in his own way in his classroom. We have made a pretest of students' performances of the four classes. No significant differences were found. We videotaped all the teaching sessions. It amounted to about ten sessions and ten hours per teacher. For the filming we used a digital camera with a wide angle lens. The camera was positioned in an angle at the back of the classroom to be able to record the whole class. The teacher was equipped with a wireless lapel microphone to be able to hear everything he said and everything he could hear. We also interviewed the teachers before the first session and after the last one.

In this paper, we chose to scrutinize the first two sessions of Jean and his self-analysis interview from the videotaped session. The two class sessions are approximately one hour and a few minutes each. The self-analysis interview lasts about two hours and we let John comment freely and move forward in the film of the sessions. We chose Jean since he happened to be the most effective of the four teachers. We consider him to be the most effective both in terms of the recognition he receives in his local district and in terms of the post-test results obtained in our research design (Santini et al., 2018). At that time Jean was over twenty years of teaching experience and acted as a teacher trainer in his local district. He was interested in the French hands-on program "La main à la pâte" (Foundation La main à la

pâte, n.d.). Jean's school was an ordinary one in the area with no noticeable particularities. His class was composed of 28 students which is an usual amount for French 5th grade classes.

We have chosen to limit ourselves to two sessions and one interview to conduct an in-depth analysis of these data. This is a comparable choice with the research works cited in the introduction. The choice to analyze two sessions also allowed us the possibility to compare between generic and specific dimensions between the two. This choice of data allows us to answer our research questions in very fine-grained analyses.

Our methodology aims to get as close to the didactic action as possible in order to understand it and give an account of it (Bulterman-Bos, 2008). It resembles the three analytical steps described by Kelly (2016, p. 399-400).

The first analytical step consists in "an ethnographic description of the educational context". As stated earlier in the paper our didactic approach includes knowledge as a "character" of the education context along with the students, their teacher, etc. It entails an epistemic analysis of the knowledge at stake during this first step (cf. Section 3.1). For this analysis our data includes materials used in the classroom, texts from official elementary school curricula, and scientific reference books on volcanoes (e.g. Bardintzeff & McBirney, 2000).

The second step is made up of "more detailed analyses [which] focus on the ways the classroom practices were constructed by the participants". This can be likened to our modeling of classroom practices as learning games (cf. Section 3.2). In short we consider that there is a change of learning game when there is a change of knowledge stake or a change of uses with the knowledge at stake.

During the third step "emergent themes start to be developed, including ways that knowledge is constructed, evoked and evaluated". In this third step we define, through a description of didactic contracts and didactic milieus their reciprocal semiosis in the investigated sessions, the generic elements of geologic practice(1) with regard to the specific elements of knowledge at stake (cf. Section 3.3). Each of these topics was delivered using a variety of modes (writing, modeling, speech, etc.). Since the connection between these modes, whether explicit or implicit, seemed to be one of the conditions of teaching effectiveness, we also aim at accounting for these connections between modes and of how they determined the didactic action (Forest & Mercier, 2011).

We divided the work in the following way. A first group of authors did their analyses of the video data with sound. A second group of authors did their analyses of the video data without sound in order to make the non-verbal modes more sensitive. The two groups then crossed their analyses to produce the results we present in this text. For our analyses we used Transana[®] software which allowed us to annotate our transcripts, insert time codes and create a database to structure our video data.

Another methodological issue was to make the semiosis visible both for analysis and as a result (cf. next section).

2.2. Making semiosis visible: from class video to silhouettes

The aim of this section is to explain how we constructed the visual data to give an account of the phenomenon of reciprocal semiosis between the didactic contract and the didactic milieu in the way in which the classes function. The data are used to construct a *seeing-as* in this context (Wittgenstein, 1997), where certain moments in the session are constructed to be seen as signifying a reciprocal semiosis between didactic contract and didactic milieu. In

order to do this, we produced photograms and silhouettes using the class video, as shown in the example below.



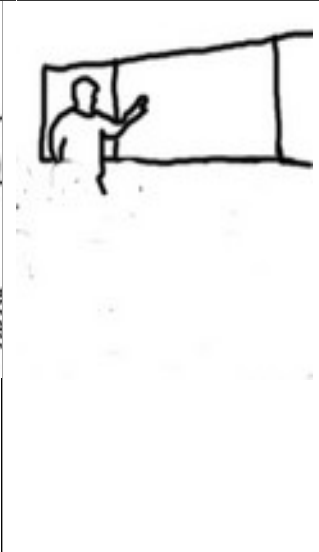
		
<p>Teacher (Jean) points to the place on the board where the expanded table will be stuck</p>	<p>Jean points to the place on the board where the expanded table will be stuck</p>	<p>Jean points to the place on the board where the expanded table will be stuck</p>

Figure 1. A photogram (left) and two silhouettes (center and right) representing the same action

This *seeing-as* must be viewed here as a particular mode of representing a form of reality extracted from the class video. Thus, as Selic (2005) indicated, silhouetting is a ‘manipulation of the image [which] is one of the missions in photography. It is not a faithful imitation of reality but a construction designed to render this reality intelligible from a pre-determined viewpoint’ (p. 18). In other words, the *seeing-as* that we wish to develop with the reader is the process that leads to the silhouette being seen as a stripped-down view of the photogram and the photogram itself, as the still image from the class video. We wish to make the reader see these images as they are described during the analysis.

In this sense, Winkin (1996) set down the principle of silhouetting, or delineation, as the assurance of ‘a transition between language and image’ (p. 167). At the very end of his book, Winkin (1996) concludes by suggesting that ‘the distance created by silhouetting breaks the illusion of reality and, consequently, the illusion of an immediate understanding’ (p. 185). In so doing, the silhouette can constitute a privileged point of entry from which the reader can gain a sequential understanding of what the researcher wishes him or her to see and understand i.e. of the *seeing-as* produced by the researcher.

We thus include a composite of words, images, language, and representation, which is rooted in a variation of scales of fine and/or dense description (Ryle, 2009). In doing so we aim at showing and accounting for the organic jointing between culture and semiotic processes, between patterns of acting and signs deciphered in the cultural *seeing-as*.

As mentioned when citing Selic (2005), the delineation process fits in with our objective of providing a potential reality that is to be seen according to the viewpoint we have defined and adopted. In so doing, some silhouettes in this paper have been stripped of all elements judged to be supernumerary in order to try to eliminate what Winkin (1996) called ‘superfluous

information' (p. 184). We therefore adopt the following quasi-paradox: to suppress elements judged to be useless or barriers to understanding in order to produce the salient representation.

It is clear from a comparison from left to right of figure 1 that the information contained in the three images is not the same. The silhouette image foregrounds the fact that the bodies are oriented in the direction in which the teacher is pointing, which is less obvious in the photogram. In turn, our interpretation of the silhouette, informed by the photogram, is directed towards recognizing this movement of the bodies to follow the teacher's gesture. Here the process of semiosis is twofold. Firstly the students have to look at what the teacher is pointing at. This refers to usual norms of the didactic contract. But successful learning will require more. So secondly the students will have to see what the teacher is pointing at as connoisseurs would see it. This refers to the deciphering of the didactic milieu. We scrutinize this intertwinement between semiosis and cultural acquaintance by analyzing the contract-milieu dialectics in the following.

3. A three-steps analysis of the case study

3.1. First step: an analysis of the knowledge at stake

In France, volcanism is a teaching topic in primary school for students in 4th and 5th grades. To prepare the didactic analysis of the sessions, we begin with an analysis of the volcanologic knowledge at stake relative to this teaching level. The table below relies on the epistemic analysis grid developed by Buty, Tiberghien and Le Maréchal (2004) and contains a summary of our epistemological analysis work. Along with these authors we consider that the essence of science education lies in the links between theories/models and objects/events to be constructed by the students. To analyze *a priori* these relationships we have made a content analysis of the materials used in the classroom, of the texts from official elementary school curricula, and of scientific reference books on volcanoes (e.g. Bardintzeff & McBirney, 2000).

	Already learnt	Already known from general knowledge	To be taught (volcanology)
Theory/model	Matter comes in three different states: solid, liquid, and gas. Matter can change state. Temperature is a factor in the change of state. A gas can be dissolved in a liquid.	A volcano is a mountain that emits lava. A volcano has the shape of a mountain. Volcanic products are extremely hot.	A volcano is the point of exit for magma. Magma (lava) is molten rock containing gas. Lava is magma that reaches the earth's surface. Eruptions can be either explosive or effusive. A volcanic cone is formed from volcanic rocks. Volcanic activity is intermittent and finite. The distribution of volcanoes partly corresponds to tectonic plate boundaries.
Relations between theory/model and objects/events	Ice and liquid water are the same body. A body is colder in solid state than in liquid state, and vice versa (except for when changing phase). The bubbles in a liquid contain gas.	The extreme heat causes damage.	The liquid lava solidifies into specific rocks. The holes in these rocks are the traces from dissolved gases. Gas makes the magma rise. The quantity of gas is a factor in the type of eruption. The viscosity of magma is a factor in the type of eruption. The cone is formed through accumulation during eruptions. Magma comes out through cracks in the earth's crust. The different stages of volcanic activity follow on from one another over time.
Objects/events	Ice <--> liquid water. Thermometer. Temperature readings. Fizzy drinks, carbonated water.	Damage linked to volcanism. Articles, photographs, media reports.	Volcanic rocks. Temperature of the lava. Boiling water. Sudden degassing of a bottle of hot fizzy pop. Volcanoes at different stages (active, inactive, extinct). Videos of explosive/effusive eruptions. Animations or scaled-down models (volcanoes, convection). The earth's crust is solid (analogy modeling earth/egg). Volcanism maps.

Table 1. Epistemic analysis grid for the teaching of volcanology to primary school students in 4th and 5th grades

It is possible the reader might think that some of the items in the table above could feature in a different box or indeed in several different boxes to the ones we have selected, however our choices are justified by our methodological aim to give an account of the knowledge such as it is “transposed” or “recontextualized” (cf. introduction) in the primary school’s official documents and manuals.

3.2. Second step: a narrative of the two sessions studied

The first session, S1, can be summarized as follows. First, the teacher, Jean, showed the children video extracts of an effusive eruption from Piton de la Fournaise and an explosive eruption from Etna. He then gave out a set of texts and photographs relating to the two different types of eruptions, which illustrated the contrast between them. After a period of individual work, which was supported by a table to complete (cf. fig. 2), each group of students produced a poster showing the characteristics of a volcanic eruption under headings (events/duration/effects–damage) imposed by Jean.

The characteristics of a volcanic eruption

event:	
duration:	
effects/damage:	

Figure 2. Table given out by the teacher, Jean, for individual work, which was copied onto A3 format for the group work

These posters were then arranged on the board for a teacher-led discussion. Jean also demonstrated a model of the formation of a volcanic cone using toothpaste. The session finished with a ‘written record’ in the form of a gap-fill exercise completed by the children.

In the second session, S2, Jean relied on the elements constructed in S1 when he asked the students to use their knowledge to construct a cross-section of an erupting volcano. This collective construction work followed the same type of generic strategy that had been used in the poster production–comparison, with production in this session taking the form of sketches.

We present below a synoptic view of the two sessions analyzed. The aim here is to give the reader an understanding of how the sessions unfolded by way of successive learning games headings. We use the code Sx to refer to session number x and $SxGy$ to refer to learning game y in session x . We consider that there is a change of learning game when there is a change of knowledge stake or a change of uses with the knowledge at stake. We should also mention that the inclusion of the photogram numbers in the synoptic table below, which pertain to the analyses that follow, allows us to introduce the links between the different scales of analysis (Lemke, 2000).

Session date and duration	Learning Game	Excerpt/Silhouette	Method	Duration
S1 16/01 68'21"	G1- watch 2 video extracts of volcanic eruptions (Etna and Piton de la Fournaise)		C	6'23"
	G2- fill out a table on the characteristics of a volcanic eruption using information from the video extracts watched in S1G1 and a collection of texts describing eruptions	Excerpt 1 Silhouettes 1–4	I	15'12"
	G3- in groups, fill out an A3 format table identical to the one from S1G2 using the information in the individual tables		G	9'29"

	from S1G2			
	G4- compare the group results from S1G3, displayed next to one another on the board	Excerpt 2 Silhouettes 5–8	C	18'27"
	G5- recognize the formation of a volcanic cone in a concrete model produced by Jean squeezing a tube of toothpaste through a hole in some cardboard	Excerpt 3 Silhouette 9	C	3'20"
	G6- complete a gap-fill exercise on the characteristics of a volcanic eruption		C	15'30"
S2 18/01 63'56"	G1- recap the elements studied in S1 to continue the study of volcanoes in S2		C	4'50"
	G2- make a poster showing a labeled cross-section of a volcano	Silhouettes 10–13	G	11'20"
	G3- copy the group poster onto a sheet of paper for their science folder		I	9'34"
	G4- compare the cross-sections produced in S2G2 displayed next to one another on the board	Silhouettes 14–17	C	12'27"
	G5- look at an analogical model of the internal structure of the earth displayed as 3 nested balls (a tennis ball inside a foam ball, which is inside a leather ball)		C	7'54"
	G6- label a cross-section of an erupting volcano and a cross-section of the internal structure of the earth as classwork		C	17'51"

Table 2. A synoptic view of the two case study sessions, described as learning games (C = Collective, I = Individual, G = Group)

This table gives an account of the course of these two class sessions at an intermediate scale between the broad scale of the session and the fine scale of an utterance or a gesture. This table is thus a synoptic view of our data which makes it possible to make links between these different scales. It also makes it possible to situate the extracts and the silhouettes analyzed in the following sub-section in the course of the sessions.

Below, we give an account of the fine-scale analyses carried out on the learning games sequences, whose descriptive headings form the headings for each subsection.

3.3. Third step: analyses of excerpts of learning games

3.3.1. Fill out a table on the characteristics of a volcanic eruption using information from the video extracts watched in S1G1 and a collection of texts describing eruptions, individually (S1G2) and then in groups (S1G3).

At the beginning of this learning game, Jean described what the students had to do as follows:

Excerpt 1

Jean: (...) you will have one document with the little text taken from a newspaper article and the photo you are going to try to fill out this table [cf. fig. 2] so I don't want you to write sentences just the important things the words [Jean points to it at the same time, cf. silhouette 4] so I mean events like what you see when there is a volcanic eruption what do you see you

only need to write the words down don't write a sentence you see no no what are the characteristics of an event in other words all of a sudden there's an eruption what do you see what's happening duration if ever in your texts rather they tell you in the texts how long it lasts you can note it down maybe you'll see don't have that information and then what are the effects and the damage it's not necessarily the same thing eh I mean there is an eruption it only lasts a moment and what does it produce after after the eruption [Jean points to the 'events' column] so that's during the eruption and that's more [Jean points to the 'duration' column] after the eruption that can be the positive or negative effects they can be good you will see (...)

This extract shows the care Jean took when explaining the different categories (events, duration, effects) that the students had to work with. His explanation was coupled with gestures, which we report on with the photograms below.





<p style="text-align: center;">Silhouette 1 (8')</p>  <p style="text-align: center;">Jean points to a student's workbook (where the picture, the outcome, will be usually stuck)</p>	<p style="text-align: center;">Silhouette 2 (8'12)</p>  <p style="text-align: center;">Jean points to the place on the board where the expanded table will be stuck usually (the same as the one in the workbook)</p>
<p style="text-align: center;">Silhouette 3 (8'50)</p>  <p style="text-align: center;">Jean gives the table out to each student to complete (and to stick in the workbooks)</p>	<p style="text-align: center;">Silhouette 4 (11'26)</p>  <p style="text-align: center;">Jean puts the table up and shows it is identical to the one the students had to complete (and will have to stick in the workbooks)</p>

Figure 3. Silhouettes from the S1G2 learning game

From the point of view of milieu, the semiosis focuses on a table with rows and columns. This table contains, in its form, what the children have to do, using the milieu constituted of videos of eruptions that they had watched during the preceding learning game. They were required to transform a flow of images and commentary into a graphic structure through the notions of events, duration, effects, and damage, as explained by Jean.

If learning is seen as a process of equilibration (that is of assimilation–accommodation, from the milieu and contract respectively), this sequence involved assimilating the milieu constituted by the two popularized scientific films with a contract of observation report using the properties of a table (see fig. 2) and the already known or learnt (cf. table 1). Jean asked the students to watch video extracts, look at photographs, and read texts, all describing volcanic eruptions (Paricutin, Etna, Kilauea, Hekla, and Piton de la Fournaise). Their

observation was guided by the table, presented by Jean at the beginning of the session, and by the category labels for each row in the table (events, duration, effects/damage). The semiotic mode of the double-entry table and the categories it contained were elements that Jean assumed the students already knew, and we can see he checked this during extract 1. The didactic contract can therefore be categorized as a contract of analysis of volcanic eruption accounts using a table of categories. The didactic milieu was composed of elements that were fairly unfamiliar to the students, namely films, photographs, and texts on the subject of eruptions (as below, cf. fig. 4) that they have to structure as a meaningful whole.

An interview with Jean revealed that the volcanoes studied (Paricutin, Etna, Kilauea, Hekla, and Piton de la Fournaise) were specifically chosen to be able to illustrate the contrast between explosive and effusive eruptions. The winning strategy for the students consisted therefore in classifying into two groups the different elements of eruptions studied in the table (Paricutin, Etna, and Hekla in one group; Kilauea and Piton de la Fournaise in the other). In comparison with the ‘age of the captain’ and ‘enlargement of the tangram’ exemplars cited above, the assimilation of the didactic milieu by the didactic contract does not necessarily end in a failure of the action undertaken. Continuing with the equilibration model, we can see here a dominant assimilation of the didactic milieu on the basis of a didactic contract that is efficient in this situation.

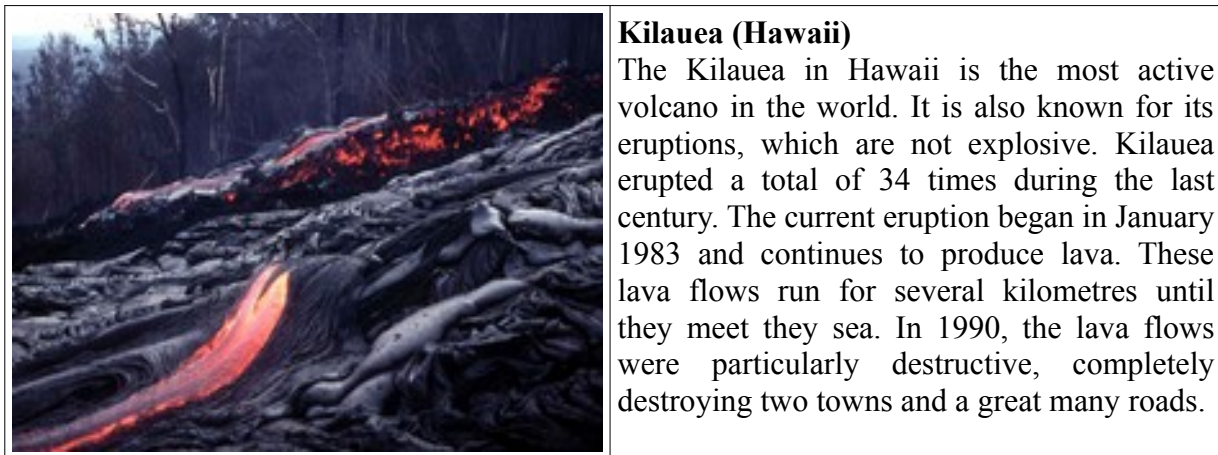


Figure 4. An example of a photo and text studied by the students

We also note Jean’s uses of different modes to organize the semiotic space in the classroom. He showed a student’s workbook at the beginning of the situation (silhouette 1) to indicate the individual and written approach. He did that a second time by distributing a pre-constructed table to each student (silhouette 3). Jean pointing to the table (silhouette 2) also indicated that the work fell within the framework of normal habits (it was a lesson for writing in the workbook, with a title). Jean’s stance (silhouette 4), which was both directive (pointing with his finger) and effaced (body to the side, looking at the students), signified that the job of completing the tables now fell to the students. At the same time Jean was pointing to a representation of the work to be done, keeping a distance from it by standing aside and looking explicitly at his students. Doing all of this Jean used the modes of gestures, stance, proxemics, and tables in a multimodal ensemble for making meaning.

However, the very presence of this enlarged table, aside from being a visual aid to clarify what Jean wanted from the children (see excerpt 1), already showed that there was a collective just as much as an individual angle to the work. While they all had the same table, the descriptions produced varied (see Appendix 1).

This first excerpt shows how semiosis and cultural acquaintance are entangled in the unfolding of action. The teacher works in such a didactic contract that the students look in the right place (silhouettes 1 and 2) and can engage in a seeing-as of volcanoes as geological phenomena (silhouettes 3 and 4). This didactic contract enables us the students to assimilate the didactic milieu (films, photos and texts about volcanic eruptions) towards an acquaintance to the geoscience culture (volcanoes as geological phenomena). This continue with the second excerpt.

3.3.2. Compare the group results from SIG3, displayed next to one another on the board (SIG4).

The individual table work (cf. fig. 2) was followed by working in groups of four. Each group had to complete the same table in A3 format (cf. Appendix 1). These tables were then stuck on the board and Jean asked the students to compare them. The students in the rear half of the classroom have moved up to sit behind those in the front half, and Jean alternates between standing beside the board to standing behind the group. The transcription below is an extract from this comparing-posters learning game.

Excerpt 2

P: So when after it's finished because of the rocks it's three hundred when it's just appeared well after the first eruption it's three hundred metres high the volcano and when it's a year old it's four hundred and fifty metres high
Jean: What did you understand from what she just said
P (several): No
Jean: So it's interesting but what she's just said that that goes she is saying that goes in the effects that for example I'll put it another way eh she is saying that the volcano the first year it is three hundred metres high and when there has been an explosion they measured it measures four hundred and fifty metres so what does that mean
P: Well when the lava falls down again it crashes it crashes again onto the volcano
P: With the
Jean: And so
P: It turns into rock like that that goes higher and higher
Jean: And which
P: Because
Jean: Where can we find that who wrote that which poster is it on there it is look [Jean points to a poster—cf. silhouette 8—and reads] the volcano forms a cone three hundred metres high and after one year it reaches the height of four hundred and fifty metres

This excerpt illustrates the way in which Jean bases his didactic action on the milieu constituted by the tables grouped around the central section of the board. The sequence of silhouettes below show that Jean has altered the class layout.

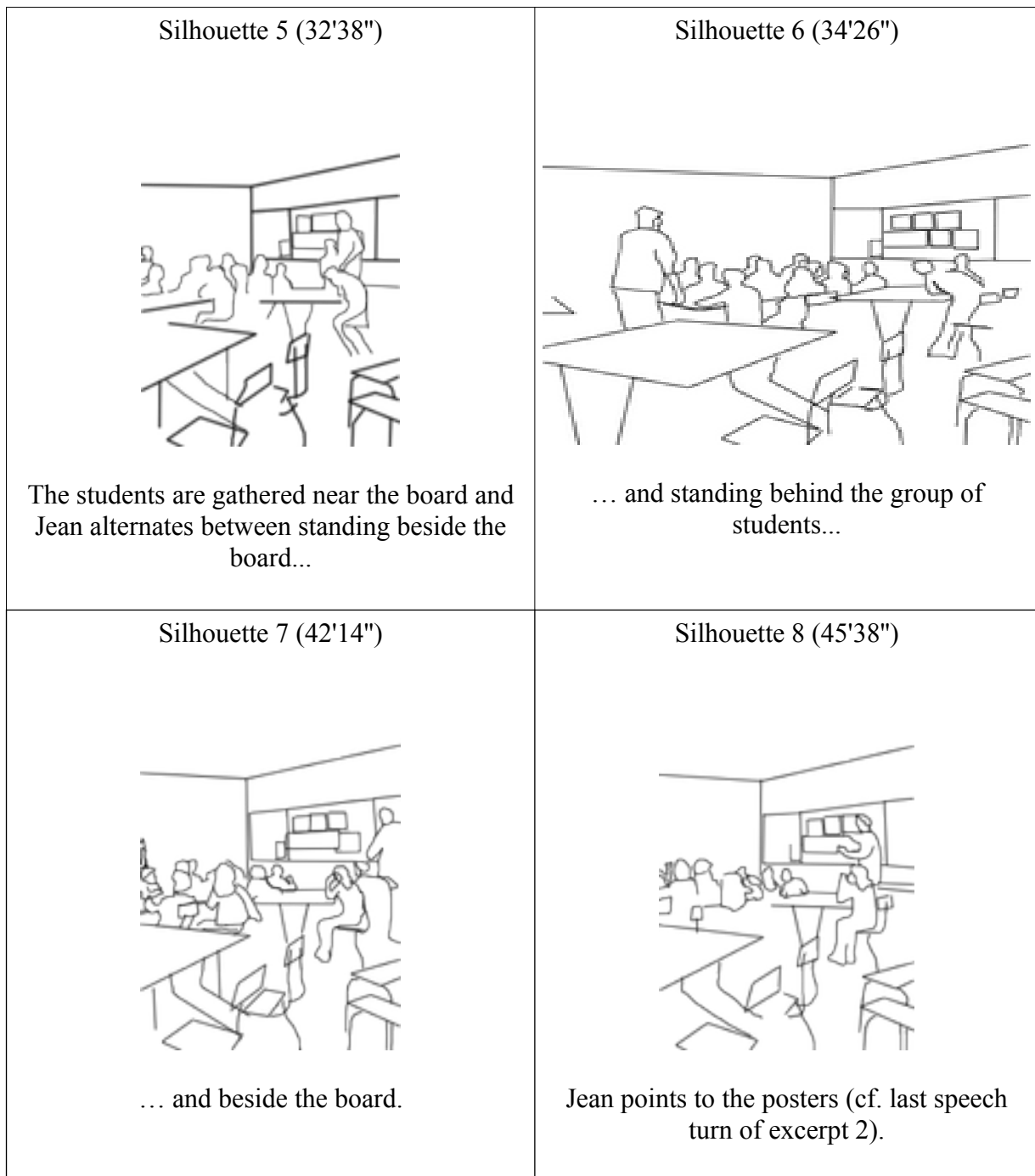


Figure 5. Photograms from the S1G4 learning game

On the central section of the board, the milieu was constituted by the posters that the students had produced. Photogram 6 shows the temporary effacement of Jean, leaving the milieu unobstructed for his students. It should be noted that this effacement was entirely relative. Through the modes of position and gaze, Jean used his body to indicate where he expected his students to focus their attention. He thus allowed the posters, which he had arranged for the purposes of comparison, to be seen. In this sense, it was a didactic layout, that is to say the milieu, such as it had been arranged by Jean, served to reinforce the comparison challenge presented by the contract. This was moreover what Jean signaled by drawing attention back to the board again (last speech turn in extract 2; silhouette 8). Here again the teacher works to produce signs for his students looking at the 'right place' (the

posters are displayed in the center of the blackboard) in the 'right way' (the posters are juxtaposed to facilitate comparison).

In this learning game sequence, the process of accommodating the contract by the milieu results in the relationship between the posters working as a result of their contiguity. Conversely, the process of assimilation of the milieu by the contract results in written output on the right-hand section of the board (silhouette 8, behind Jean). This new written output, contributed this time by Jean, serves to participate therefore in the milieu of the next learning game analyzed in the following.

3.3.3. Recognize the formation of a volcanic cone in a concrete model produced by Jean squeezing a tube of toothpaste through a hole in some cardboard (SIG5).

After comparing the posters, Jean models how a volcanic cone is formed by using a specific kind of analogy. He shows how toothpaste solidifies after it has emerged from the surface of a piece of card by squeezing the tube placed underneath. In this modeling, Jean places a tube of toothpaste under a piece of card with a hole in it. He squeezes the tube, the toothpaste comes up through the hole and spills out around it. He repeats this with a second tube of toothpaste in a different color. Jean uses this modeling to represent the formation of a volcanic cone by accumulation during successive eruptions.

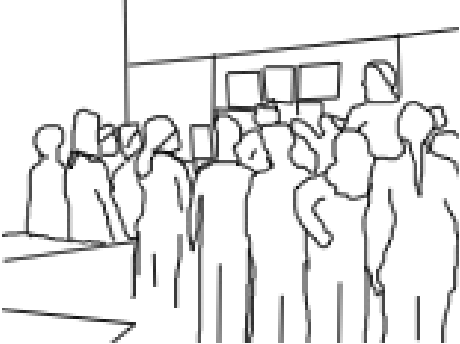

<p style="text-align: center;">Silhouette 9 (51'14")</p>  <p>Students are gathered around a table and Jean shows them a toothpaste tube he will use to model a first volcanic eruption.</p>	<p>Transcription excerpt 3</p> <p>Jean: ha that's good [the toothpaste comes out] there we go + what's the lava going to do [exclamations] we'll clean it up the lava what's it going to do what's it going to do</p> <p>P: it's going to run down</p> <p>Jean: yes and then</p> <p>P: it's going to dry</p> <p>Jean: no + somebody said it earlier</p> <p>P: (inaudible)</p> <p>Jean: yes and after once what happens</p> <p>P: it will go hard</p> <p>Jean: it will go hard change</p> <p>P (several): into rocks</p> <p>Jean: into rocks you can imagine a few years later another eruption so I'll use another color so that you can see the difference (...)</p>
<p>Toothpastes of two different colors are used to model two successive eruptions</p> 	

Figure 6. Photogram and silhouette 9 (51'14") from the excerpt 3 during S1G5 learning game

Silhouette 9 shows that Jean set up two modes together i.e. the practical modeling of the formation of a volcanic cone with toothpaste against a background of the posters (on the left) and the written summaries (on the right). The arrangement he produced thus favored a connection being made between the old (the board and posters in the background) and the new (the practical 'toothpaste' model produced). The contract of ostension(2) the model thus assimilates the replacement of the previous milieus by a new milieu, which results from the working of this practical model.

We will now look at how, in session S2, Jean was able to rely on this modeling to steer his students into creating a schematic cross-section in an approach based on the students' output, similar to the one we have just analyzed. Following a brief recap of what they had learnt in S1, Jean asked the students to produce cross-sections of an erupting volcanic cone and the earth's crust on a piece of paper. These cross-sections were then stuck on the board and discussed in a similar way to the posters discussion in S1. At the end of the discussion, Jean

presented the structure of the earth using three nested balls. The session finished with a 'written record,' composed of two cross-sections (an erupting volcano and the earth's internal structure), which were collectively labeled.

3.3.4. *Make a poster showing a labeled cross-section of a volcano (S2G2).*

In this learning game, the students had to sketch a longitudinal cross-section of an erupting conical volcano to answer the question "what's going on underground?" in an eruption. This cross-section represented the visible, upper third of the volcano and the subterranean lower two-thirds. Jean drew the visible aspects of an eruption, as below, on a sketch of the upper third during the S2G1 learning game as he was carrying out a quick recap of the previous session.

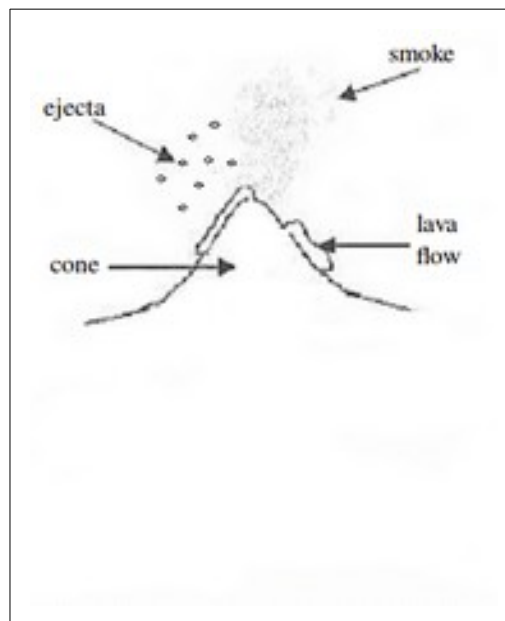


Figure 7. Reproduction of the start of the cross-section produced on the board in the S2G1 learning game

In a way, by making the results from the previous session 'visible' with the diagram, Jean recalled the milieu that had been organized during the first session. The empty space corresponding to the invisible section was therefore very noticeable because the visible part was 'saturated.' Our analysis thus demonstrates how Jean takes charge of everything pertaining to the generic semiotic mode of the longitudinal cross-section, while he leaves his students the epistemic challenge of explaining the formation of a volcanic cone. The series of silhouettes 10 to 13 below (fig. 8) shows that the teacher's gestures contribute to giving the students a role to play by underlining the empty space.

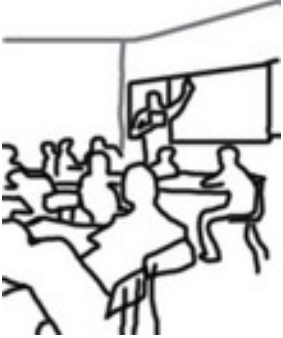



<p style="text-align: center;">Silhouette 10 (6'05")</p>  <p style="text-align: center;">Jean points to the top (what is done, known)...</p>	<p style="text-align: center;">Silhouette 11 (6'14")</p>  <p style="text-align: center;">...and points to the bottom (what we are interested in, what is unknown)</p>
<p style="text-align: center;">Silhouette 12 (7'57")</p>  <p style="text-align: center;">Jean points to the top of the paper (what has been drawn on the board)...</p>	<p style="text-align: center;">Silhouette 13 (7'59")</p>  <p style="text-align: center;">...and points to the bottom of the paper (what has to be drawn, to be found out)</p>

Figure 8. Photograms from the S2G2 learning game

The milieu arranged by Jean presented a twofold sign. There was a semiosis of the milieu that represented what was already known (studied during S1), where Jean assumed the responsibility for the drawing (during S2G1, cf. fig. 7). This semiosis referred to all the work they had already done. A comparison of silhouettes 4 and 10 shows this clearly.

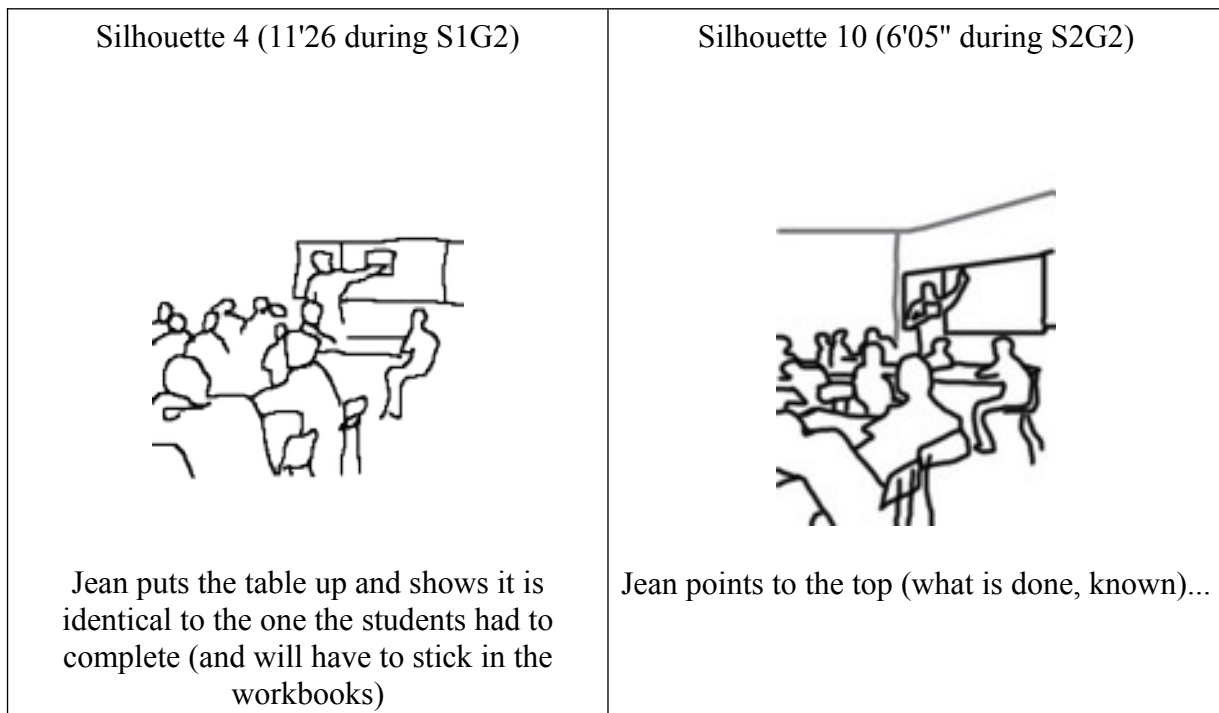


Figure 9. Comparison between silhouette 4 and silhouette 10

In these contracts of producing semiotic systems (tables or posters), Jean assumed the responsibility for the framework, for what was already known, and left an empty space to be filled with information from what was yet to be studied, the didactic milieu. The milieu semiosis was accompanied by a contract semiosis, both simultaneously supported by the arrangement of the class around the board (as in the previous session) and by Jean's words and gestures. The important thing, the thing that was expected from the students, was at the bottom. It was what could not be seen, the empty area on the drawing, the representation of what was invisible. It was up to the students to make it visible. The drawing contract, which the students were already familiar with, was thus accommodated by the specific features of the milieu, arranged by Jean, concerning what was already known (the upper third of the cross-section) and the uncertain (the lower two-thirds of the cross-section).

3.3.5. Compare the cross-sections produced in S2G2 displayed next to one another on the board (S2G4).

This learning game is comparable to the S1G4 learning game analyzed above. As with S1G4, the didactic milieu of S2G4 is made up of posters produced during the session following a series of learning games. Figure 10 also shows a similar organization of the class to that shown in Figure 5.





<p style="text-align: center;">Silhouette 14 (27'16")</p>  <p>The students put their posters on the board.</p>	<p style="text-align: center;">Silhouette 15 (28'14")</p>  <p>Jean is standing beside the board and points to the posters</p>
<p style="text-align: center;">Silhouette 16 (29'12")</p>  <p>The students (except one) are gathered near the board and Jean alternates between standing behind them...</p>	<p style="text-align: center;">Silhouette 17 (30'48")</p>  <p>... and beside the board pointing to the posters.</p>

Figure 10. Photographs from the S2G4 learning game

We see here another didactic equilibration, similar to that in S1G4. It should be noticed that the students' outputs occupy each time a central place and provide the basis for the teacher's work. In doing so the students play a real role and their outputs contribute to the didactic milieu. Furthermore there is the same proxemic behavior, made up of guidance through modes and a particularly visible effacement in the final silhouette. The students can thus rely on their teacher's organization of the semiotic space for a contract semiosis (what needs/had to be done, relating to the already-there knowledge) and a milieu semiosis (what is to be known/deciphered, relating to the already-there knowledge).

4. Discussion

Our first research question focuses on how a teacher can use different modes to engage students in the didactic milieu. All along this case study, we have shown how the students rely on Jean's uses of different modes (gestures, stance, gaze, speech, proxemics, writings, and modelings) for semiosis of the teacher's expectations and of the knowledge at stake, i.e. for a didactic contract semiosis and a didactic milieu semiosis. Here we agree with the conclusions of Moro, Mortimer and Tiberghien (2020) regarding the use of a multimodal ensemble as being able to characterize good teachers. To sum up, during the first session studied, Jean was able to get his students to assimilate a didactic milieu (videos, photographs, and texts on the subject of volcanic eruptions) through a certain type of didactic contract (contract of producing a table and contract of comparing the tables produced by the different student groups). These written notes, accompanied by a concrete model, allowed the teacher to constitute a new milieu during the second session on the basis of a new contract (a drawing contract). This new milieu, through the blank spaces it represented, therefore served to accommodate a new contract (hypothesizing about the internal structure of a volcano), which itself led to the production of a new milieu (the posters produced). This, in turn, was assimilated by a new contract, etc. In other words the process of multimodal semiosis and the process of contract-milieu equilibration are intertwined in the unfolding of action. This claim of an organic relationship between multimodal semiosis and didactic equilibration is consistent with the elaboration of Eco on the Peirce's claim that "a sign is something by knowing which we know something more" (CP 8.332, in Eco, 1984, p. 26). This can be made more clear with an expanded version of this Peirce's quotation:

It appears to me that the essential function of a sign is to render inefficient relations efficient, not to set them into action, but to establish a habit or general rule whereby they will act on occasion. According to the physical doctrine, nothing ever happens but the continued rectilinear velocities with the accelerations that accompany different relative positions of the particles. All other relations, of which we know so many, are inefficient. Knowledge in some way renders them efficient; and a sign is something by knowing which we know something more. (CP 8.332, in Deeley, 1994, p. 2745)

"To render inefficient relations efficient" could be seen as the assimilation of a didactic milieu through a didactic contract, and "to establish a habit or general whereby they will act on occasion" could be seen as the accommodation of a didactic contract through a didactic milieu. The notion of didactic contract models the actual strategic system to play learning games whereas the notion of didactic milieu models the potential strategic system. The didactic milieu is assimilated so far as the relations between the elements composing its strategic systems turn from potential ones, and thus inefficient, to actual ones, and thus efficient. These efficient relations between elements of the strategic system to play learning games then constitute a new didactic contract. In short the processes of semiosis and didactic equilibration have an organic relationship in science education: they intertwine in the unfolding of action as our analysis of the case study presented in this paper illustrates.

Our second research question asks how a teacher's semiotic uses can become elements of a contract to act in the didactic environment. Describing the *in situ* didactic equilibration process offers an account of the dialectic between the old and the new in the didactic relationship and shows how the teacher used the didactic time by writing down (almost quite literally in this case) in the session what had happened in the previous session. In this way our findings answer to a suggestion from Lehesvuori & Ametller (2021). These authors suggest that the way in which teachers make pedagogical links between what has been studied and

what is being studied in a coherent way across modes can be decisive for students' learning. In our study, this coherence is achieved in the teacher's multimodal ensemble in the classroom. In particular this multimodal ensemble repeated in the two investigated sessions as figure 11 shows.


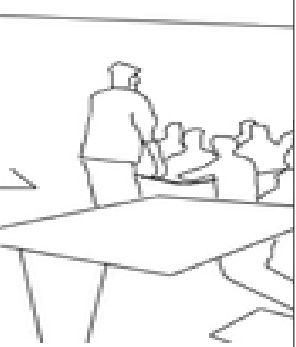






<p>S1G4 silhouette 5 (32'38")</p>  <p>The students are gathered near the board and Jean alternates between standing beside the board...</p>	<p>S1G4 silhouette 6 (34'26")</p>  <p>... and standing behind the group of students...</p>	<p>S1G4 silhouette 7 (42'14")</p>  <p>... and beside the board.</p>	<p>S1G4 silhouette 8 (45'38")</p>  <p>Jean points to the posters.</p>
<p>S2G4 silhouette 14 (27'16")</p>  <p>The students put their posters on the board.</p>	<p>S2G4 silhouette 15 (28'14")</p>  <p>Jean is standing beside the board and points to the posters</p>	<p>S2G4 silhouette 16 (29'12")</p>  <p>The students (except one) are gathered near the board and Jean alternates between standing behind them...</p>	<p>S2G4 silhouette 17 (30'48")</p>  <p>... and beside the board pointing to the posters.</p>

Figure 11. Comparison between silhouettes of the S1G4 and S2G4 learning games

Learning games S1G4 and S2G4 have several proxemic resemblances: the students put posters on the board, they gathered near the board, Jean alternated between standing behind the group of students and besides the board, and sometimes he was pointing to the posters. The posters in these learning games also had semiotic resemblances: they were significant of the knowledge at stake, the frame was designed by the teacher (cf. fig. 2 and 7) and the students were responsible to fill in the blank spaces. Together these repetitions of the organization of the classroom's semiotic space contributed to the didactic equilibrations of these two sessions. In their work on multimodality in science lectures Pozzer and Roth (2020) analyzed how repetitions and differences of gestures played an important role for teaching. In our case study there are repeated elements between the didactic equilibrations of these two sessions, but there are also significant differences in the knowledge at stake. It seems appropriate therefore to mobilize here the notion of *family resemblance* (Wittgenstein, 1997) to account for it, all the more so since Jean had noted a sort of resemblance between his sessions during his interview. Wittgenstein forged the concept of family resemblance to discuss why what we call games (board-games, card-games, ball-games, Olympic games, etc.) can all be termed games despite their obvious differences. He claimed that the best way to understand that is not a common set of resemblances but their various resemblances like between the members of family. Under such a description the S1G4 and S2G4 learning games had a family resemblance. They had the proxemic and semiotic resemblances described above but also differences in the knowledge at stake. Tiberghien and Venturini (2018) have shown how repetitions in learning games can be constituted as generic elements of a classroom's didactic contract. We believe that the proxemic and semiotic family resemblance we discuss here contributes to this structuring of generic elements of didactic contract.

Our analyses have enabled us to describe how the teacher in our study proposed the learning games to the students, during which the didactic milieu of subsequent learning games was constructed. This teaching technique allowed the students to connect with the production of signs in the succession of didactic milieus. This seems to us to be a very favorable way of realizing the possibilities inscribed within the milieu by the students, in other words this milieu could have been a *resistant* milieu for most of them. We use the term *resistance* in both senses of “the refusal to accept or comply with something” and “the ability not to be affected by something” (Lexico, n.d.). In the sense of “refusal” the didactic milieu can resist and constraint the didactic action. For instance the excerpt 2 showed how a student relying on an object of the didactic milieu (the description of a volcanic eruption) to claim that the formation of the volcanic cone must be put in the category of effects because it happened after the beginning of the eruption. In the sense of “not being affected” the didactic milieu can withstand the didactic action to go in a specific direction. In our case study the large amount of blank space below the volcanic cone in figure 7 withstands the investigation of subterranean causes for the volcanic eruption. In this line a key element of teaching practices could be seen as making more likely the learning in action of the knowledge at stake by the means of an adequately resistant milieu. In such a sense we agree with Bezemer and Roth (2020) that it turns “the role of “teacher” into that of “designer” (of learning environments)”. In the line of this paper designing learning environments should mean designing the multimodal representations of the instructions along with the multimodal representations of the knowledge at stake. We think that the notion of learning game presented in this paper could help to do so.

5. Conclusions, limitations and implications

We have shown how, in the two sessions studied, the reciprocal semiosis of the contract and milieu is at work in a process of didactic equilibrations that is multimodal, where the contract allows the assimilation of the milieu and the milieu constrains the accommodation of the contract. In this sense, this case study contributes to an empirical documenting of the reciprocal semiosis of the didactic contract and the didactic milieu. Our case study shows how this reciprocal semiosis is performed in a classroom in an equilibration between accommodation of the contract by the milieu and assimilation of the milieu by the contract.

We have also set out an argument concerning a comparison of the didactic equilibrations of the two sessions. While these are similar to a certain generic degree, they are also differentiated from one another when considered in relation to the specific nature of the knowledge at stake. This family resemblance in the semiosis processes at work within the different learning games or different sessions appears to respond to the concern for continuity of the students' experiences (Santini et al., 2018). A comparison of the silhouettes shows similar multimodal semiotic configurations, such that a student who had already undergone a first experience was better equipped for the next.

Our study has two limitations. The first limitation concerns the amount of data. Focusing on a small amount of data was necessary to produce our results, but it will be interesting to analyze more data to test their robustness. A second limitation concerns our analysis of the didactic contract and the didactic environment from a global and not individual point of view. This can inform us about the thought collective in development but not about what it is for individual students. In a future project we plan to conduct interviews with the students as well, in order to be able to report on individual points of view.

Finally, through a shift in perspective, it seems interesting to consider the overlapping of the old and the new in this teacher's practice as heuristic in the production of class sessions. Our results thus imply to consider the interest of multimodality in the joint action beyond its immediacy in the continuities that it can make favorable with what is studied or what will be studied. In particular, this teacher organized the semiotic space so that the signs produced (tables, posters, cross-sections, etc.) by the students during one learning game came to feed into the didactic milieu of the next game. This *modus operandi* appears to be particularly suitable in terms of giving the students a real role to play in the situation and is, as a consequence, very favorable for their learning.

Note

(1) We rely on the works of Frodeman (1995) and Raab and Frodeman (2002) to describe a generic grammar of geological practice. In a nutshell geological practice is concerned with reconstructing the history of the Earth from the traces of its activity. This practice is thus a matter of retrodiction: it is a matter of explaining the present from speculations about the past. These speculations are based on geological traces, which also makes it an investigation based on clues. However, these speculations are double. These speculations are functionalist but also historical. They are functionalist because they aim to explain events (volcanoes) by constructing a phenomenon (volcanism). But they are also historical because they want to explain an event (a given volcano) for itself, with its share of contingency. In this text we do not go into more detail than this generic grammar of action. This seems sufficient for the case study presented here. We have worked on the specifics of geological practices and epistemic practices in the geology classroom in another text (Santini et al., 2018).

(2) Brousseau defines the didactic contract of ostention as a didactic contract in which "the teacher "shows" an object, or property, the student agrees to "see" it as the representative of a

class whose elements he will have to recognize in other circumstances" (1995, p. 25). Here Jean shows a set of one piece of cardboard and toothpastes and wants the students to see it as a concrete model of volcanic eruptions.

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Appendix 1. Transcription of the output produced by the groups of students in the S1G3 learning game

The characteristics of a volcanic eruption

event:	cloud of smoke. molten lava. fragment of rock. ash. spectacle. lava flow. explosion. rock debris.
duration:	For days.
effects/damage:	It has destroyed several villages. the ash covered the region. the lava reached the main road. the lava continues to flow.

The characteristics of a volcanic eruption

event:	There is some lava running down from the summit of the pyiton de la fournaise. lava flow.
duration:	3 months.
effects/damage:	flows in two branches and almost reaches the main road. The volcano forms a cone 300 metres high. After one year it reaches the height of 450 metres.

The characteristics of a volcanic eruption

event:	- Fragments of rock, ash - Volcanic rocks and lava Gaps of lava flow - non-explosive eruption
duration:	3 months
effects/damage:	- The village is covered in ash - The lava almost reaches the main road - Broken rocks - mountains of ash

The characteristics of a volcanic eruption

event:	6 km crack. rumbling. eruption. earthquake. lava flow. Explosion
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duration:	9 days
effects/damage:	made the islands bigger. destroyed two towns and a road.

The characteristics of a volcanic eruption

event:	There is lava (several kms), throws out fragments (ash), noise.
duration:	several years and days (3 months)
effects/damage:	The lava destroyed everything (6 km crack)

The characteristics of a volcanic eruption

event:	Lava, cloud of smoke, flying rocks, ...
duration:	8 days, 3 months,
effects/damage:	Devastates everything in its path and makes the islands bigger.

The characteristics of a volcanic eruption

event:	Cloud of smoke. It buries a church with its lava. the lava is shot out
duration:	A few weeks
effects/damage:	Cracks in the ground. The house destroyed