Learning physics as *coherently packaging* multiple sets of signs

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Abstract: This paper studies the multimodal reformulations that teachers and students make when they talk about and do physics experiments in class. Using the framework of semiotic bundles, we show that reformulating aspects having to do with physics knowledge while moving between talk, gestures, drawings and manipulations is done differently by experts and novices. Analysis of video excerpts illustrate that teachers are able to coherently package multiple sets of signs throughout their discourse and actions in the classroom, but students who are learning physics have specific problems that this framework makes evident. In particular, successfully reformulating from one semiotic resource to another implies that the first resource be correctly constructed. In addition, specific *tool affordances* hinder students in their attempt to coherently package multiple sets of signs while this is not the case for teachers. We conclude by suggesting ways in which teachers can ease students' difficulties in constructing semiotic bundles.

Introduction

Our research team has many years of experience in designing teaching sequences for upper secondary school in physics and chemistry (e.g. Buty, et al., 2004). These groups are based on the collaboration of practicing teachers and researchers in which instrumental and theory-oriented approaches are combined (Brown, 1992). One main hypothese stemming from research on the design of these teaching sequences is that the modeling activities of students in relation to an epistemological point of view concerning physics' functioning must be taken into account (Bécu-Robinault, 2002). In addition, other theoretical underpinnings are taken into account, such as the role of social interactions in learning (e.g. Doisy & Mugny, 1984) and research results concerning misconceptions (cf. Duit & Von Rhöneck, 1998 for a meta-review). Since 1997, we have developed a range of teaching-learning sequences, concerning learners aged from 15 to 18 all of which have been implemented in classrooms and evaluated from teaching and learning perspectives. Our results show that teachers are able to use the teaching-learning sequences and associated documents and they also perceive improvements in student learning. Despite this, evaluations also show that, unexpectedly, a variety of teachers devote a great deal of time to the reformulation of the ideas in the elaborated documents (Lund & Bécu-Robinault, forthcoming). We know teachers have a fixed duration to teach their class and do not purposefully waste time, so we hypothesize that this phase is important for helping students grasp the knowledge to be taught. In this study we explore the implicit reasons for which teachers may perform such a reformulation activity and this prompts us to look more closely at the initial lessons of a particular physics teaching-learning sequence.

In what follows we will present our theoretical framework, describe our empirical study, present our analyses and results and conclude with perspectives for further work.

Theoretical framework

Physics learning in the classroom is a complex activity that is both cognitive and social where teachers and students use talk, gestures, drawings and the manipulation of objects to co-construct physics concepts. It has been shown that embodiment through gesture plays a role in learning new concepts (Goldin-Meadow, et al, 2009) and Roth & Pozzer-Ardenghi (2005) propose that for understanding communication in everyday settings, one must take into account not only words and gestures but also all other semiotic resources co-participants produce or find in the setting. In this paper, we choose to address students' conceptual difficulties in the particular case of learning electricity through the study of multimodal reformulation as a tool to co-construct discourse (De Gaulmyn, 1987; Apotheloz, 2001; Lund, 2007), thus taking into account all the semiotic resources that co-participants do. We will use the notion of semiotic bundles as a method for explaining students' difficulties (Arzarello, 2004) and illustrating teachers' expertise. In the sections that follow, we present these notions and set the scene for showing how reformulating aspects of one particular semiotic resource into another one is an expert activity for teachers but fraught with difficulties for students.

Multimodal reformulation

The term multimodal is often used to signify the medium in which a particular message can be expressed, for example text or graphics (e.g. Pineda & Garza, 2000). The authors Kress & Van Leeuwen, (2001) distinguish between modes and media: modes are the abstract, non–material resources of meaning-making whereas media are the specific material forms in which modes are carried out. The mode of gesture is carried out in the media of movements of the body. Different media afford different kinds of meaning (Dicks, et al. 2006), e.g. expressing an idea in writing or speech affects what is conveyed. Here, we use the term multimodal to describe the addition of non-verbal human face-to-face interactive phenomena such as gesture, gaze, posture, object manipulations, etc. to speech, studied extensively as a phenomenon in its own right by researchers such as Kendon (2004), Cosnier, (2000), McNeal (1992) and Brassac, et al. (2008).

Many interactive situations whose objective is learning presumes a dissymmetry of knowledge between interlocutors. This dissymmetry calls for adjusting discourse so that interlocutors reach mutual comprehension and common ground. Teachers' discourse does not escape from these adjustments and they often occur as reformulations; what learners say is put by the teacher into more conventional words (Chouinard & Clark, 2003). In this study, we borrow a different focus for the definition of reformulation, elaborated in the context of collaborative writing (Apotheloz, 2001). This is an oralo-graphic situation that articulates two different modes, speaking and writing. For Apotheloz, cooperation during such a task consists in "continuously exhibiting, that is at each step, the manner in which what is formulated articulates with what has already been formulated" (p. 62, our translation from French). We study this same phenomenon of reformulation, but in a situation where there is a plurality of multimodal activity: teachers and students speak, write, gesture, draw and manipulate objects and we see that the reformulations between modes that are carried out by teachers and those that are carried out by students differ greatly in how such a reformulation provides for the construction of meaning.

Semiotic Bundles

We use Arzarello's (2004) semiotic bundle to interpret such multimodal reformulation, originally defined to analyze interactions around mathematics learning. A semiotic bundle is a collection of semiotic sets and a set of relationships between the sets of the bundle. A semiotic set is composed of three elements. The first component is a set of signs that may *be produced* with different intentional actions (speaking, writing, drawing, gesturing, handling an artifact). The second component is a set of modes *for producing* the signs and possibly transforming them. The modes can be rules or algorithms, but can also be more flexible action or productions modes, such as the modes referred to in the previous section, comparable to the intentional actions of Arzarello (speaking, writing, drawing, gesturing, handling an artifact). The third and final component is a set of relationships among the produced signs and their meanings embodied in an underlying meaning structure. A semiotic bundle is a dynamic structure changing over time due to the semiotic activities of the participants who are constructing it.

Our research questions focus on describing how expert teachers and novice students reformulate aspects having to do with physics knowledge while moving between talk, gestures, drawings and manipulations of physical objects. We hypothesize that experts and novices will reformulate differently and that the theoretical concept of the semiotic bundle is useful for understanding students' difficulties in physics while illustrating how teachers' expertise in multimodal reformulation can potentially be leveraged for helping students.

Empirical study

This study has been carried out in the context of a research-action group that designs teaching sequences for physics (Bécu-Robinault, 2007; Buty et al, 2004). All the teaching sequences have been co-elaborated by researchers and practicing teachers, implemented in classrooms and evaluated from teaching and learning perspectives. In this presentation, we focus on the electro kinetics sequence, lasting 3 months, for grade 7 in the French school system. The teaching and learning of electricity has been the object of many investigations in science education. From international research results, we know that students encounter deep-level conceptual and reasoning difficulties in understanding introductory electricity. The main difficulty concerns notions of current, electric current and energy that are not differentiated by students (Psillos et al., 1988). Many teachers spontaneously use analogies, such as a water analogy, to teach electricity. Indeed, using analogies in teaching is thought to provide learners with tools that facilitate science understanding and promote conceptual change. We thus chose to introduce an analogy, in order to predict and interpret phenomena without using any formal concepts and to help students to develop an understanding of electricity and energy concepts (cf. Scott et al., 2006). This analogy relates these concepts to familiar every day objects (loaves of bread represent energy, delivery vans in motion represent the current, the bakery and the supermarket are respectively the analogues of the battery and the light bulb). The analogy is intended to help students to differentiate the concepts of current and energy. The lesson is set up so that questioning why a battery has a life span prompts thinking in terms of energy while questioning how a bulb lights up prompts thinking in terms of current.

Short description of the lessons studied

In the French curriculum, electricity at grade 7 is taught through a phenomenological study of electrical circuits. In this presentation, we will focus on the first two lessons dedicated to the study of the simple circuit (how to light a bulb with a battery) and to the introduction of an analogy used for teaching (differentiation of current and energy, although we will not focus on energy in our examples). The first lesson is a necessary preliminary, in order that students understand how to handle electrical devices, identify the different terminals, and have no choice but to build a loop with the battery, wires and bulb. To understand how a simple circuit functions, students are asked to draw their experiment before handling electrical devices. This lesson begins with the presentation of a well-known object, a Maglite™ flashlight. Students usually question a battery's freshness and this cannot be interpreted in terms of current so the second lesson addresses this concern. With the help of the analogy, we suggest that the current implies thinking with a circuit perspective and that energy implies thinking with a chain perspective. Students are thus asked to connect each term of the analogy and its corresponding physical object in the world and use a variety of semiotic resources (modes producing signs).

Methodology

Video recordings and partial multimodal transcriptions of one pair of students and a teacher involved in the research-action group were made and written documents distributed by the teacher were collected. The transcriptions (cf. Atkinson & Heritage, 1984) were done according to the following conventions (cf. Table 1).

Table 1. Conventions for multimodal transcriptions

Multimodal transcription conventions
^ : rising tone
' : falling tone
[: overlapping speech
a : underlining words implies insistence
: ou ::: : a sound is drawn out
= : immediate chaining with next utterance
(.) : micropause
(3 s) : pause in seconds
(...) : a cut in the recording
(inaudible) : inaudible passage
** gestures are described and shown in relation to the discourse that was spoken when they were performed

Verbal and non-verbal behavior of the teacher and students were analyzed in relation to the classroom production. Written teaching-learning materials were used to define what type of resources students had at their disposal to build semiotic sets and bundles.

Analyses and results

We present three short video extracts and their corresponding analyses. Before the third extract, we describe three groups of students' drawings. The first extract corresponds to the presentation of the analogy: the teacher defines each term and correspondence. In the second, the teacher constructs an experiment (lighting the bulb by connecting two wires to a battery) that corresponds to a physical object, a drawing of that object and a drawing of the experiment. In the third, the students attempt this same experiment.

A teacher's complex yet coherent semiotic bundle

The first extract (second lesson) concerns an integration of two semiotic sets into a coherent semiotic bundle. The first semiotic set contains the model of the electrical circuit (Figure 1, left) and the second contains the analogy of the electrical circuit, built around a bakery that delivers bread to supermarkets (Figure 1, right).

Model of the electrical circuit | Analogy built around a baker delivering bread

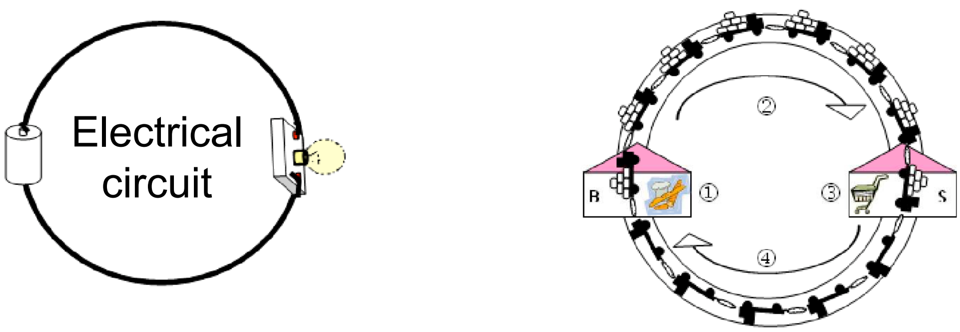


Figure 1. Two semiotic sets: the electrical circuit and the bakery analogy.

The elements of the analogy are presented below; each numbered element corresponds to the circled number on the figure at the right.

1. Each bakery always loads the same number of loaves of bread at into each delivery truck.
2. All delivery trucks move at the same speed. The speed of the delivery trucks is adapted to the demand of each supermarket.
3. The delivery trucks arrive at the supermarket where the loaves of bread are delivered, transformed and then sold to clients. All of the delivery trucks delivery all of their loaves of bread.
4. After delivery, each truck returns empty to the bakery in order to get a new load of loaves of bread.

The relations allowing the coherence of the semiotic bundle are provided by teacher's talk and gestures concerning each semiotic set and by written documents distributed at the beginning of the lesson (cf. Table 2 where T stands for teacher and S for student).

Table 2. Teacher discourse and gestures during her presentation of the bakery analogy.

Time	Discourse	Gestures
7'33	T: the electric current can can circulate	traces a circle with her hand, then traces another
	Ok and this electric current what is it in the	rapidly traces a smaller circle with her hand
	delivery truck analogy^	raises her right hand in order to indicate the change from the domain of electricity to the analogy
	S: the delivery [trucks	
	T: [why yes ^	points her finger at a student
	S: the lineup of delivery trucks=	
7'43	T: =the lineup of delivery trucks very good	traces a circle with her hand
	it's the lineup of delivery trucks	traces a circle with her hand, then traces another circle
	uhh it's the fact that	traces a circle with her hand
	it's the circulation of the delivery trucks	traces a half circle, pauses at the bottom
	the trucks	finishes her circle
	are moving	traces a half circle with her hand, pauses between the bottom and the top, finishes her circle
	so the electric current circulates	traces a circle pauses between the bottom and the top
	ok it's all of the trucks that circulate very	traces a circle that is almost complete with her hand
7'52	good	

Our videotape shows that gestures are identical when the reference domain changes (from electrical circuit to bakery analogy). The teacher makes a circular gesture to mimic both circulation of electricity (first semiotic set) and traffic of delivery trucks (second semiotic set). This circular gesture is repeated eleven times (cf. Figure 2), in association with the verbalization "circulation of delivery trucks" or "circulation of current". The rhythmic gesturing emphasizes the continuous aspect of the electrical circuit (delivery trucks) and allows the teacher to insist upon the systemic point of view. Moreover, she makes pauses corresponding to the positions of the supermarket (bulb) and of the bakery (battery). We argue that these similar gestures within two separate semiotic sets help students to integrate the analogues in a single and coherent semiotic bundle.

Figure 2. Teacher gesturing in order to make the link between circulation ofdelivery trucks and circulation of current.

However, problems begin for students at a much earlier stage. This paper's aim is to show that building complex semiotic bundles such as this one can be difficult for students unless each semiotic set they add to their bundle under construction (indeed each semiotic resource that they add to their set) is done in a coherent way. In order to illustrate this, we look at the bundle at an earlier stage, before the analogy has been introduced, when the objective is to build a simple circuit. In this context, a first semiotic set will consist of a drawing, written comments on that drawing, gestures about that drawing and a verbal description of that drawing, all done by the students. A second semiotic set will consist of handling the experimental apparatus, talking about handling it, performing gestures to show objects, all mostly done by the students alone. Having said that, semiotic sets and bundles can be co-constructed between teachers and students, adding to the complexity of our analytical viewpoint.

A teacher's initial coherent semiotic bundle

Figure 3 shows an example of how an expert teacher is able to construct a coherent semiotic bundle from a variety of physical objects and functional representations of those objects (following her own instructions given to the students during the first lesson, as stated below):

1. Do a drawing that represents what happens inside the flashlight when it is turned on and is shining (a photo of this object is given – it's a familiar object for all students).
2. Draw diverse experiments with the proposed objects that will permit you to verify what happens inside the flashlight when it is shining.
3. After the teacher gives permission, ask for the necessary objects and perform the experiments.
4. Is your drawing for question 1 correct? If it isn't, do another one that shows what is happening inside the flashlight when it is shining.

Figure 3 shows that it is easy to link each part of the drawings with the experimental apparatus, because aspects and locations of objects (battery, bulb) are similar. These relations are also facilitated because drawing and experimental apparatus are built on the basis of the electrical diagram the teacher has in mind (far right of Figure 3). The teacher is thus able to move from one mode to another while maintaining coherency and building meaning. We also notice that the teacher does *not* draw the clamps of the crocodile clips in her drawing of the experiment, as they are not relevant to carrying out the experiment. As an expert, she is able to model the physical objects in a way that is pertinent for the experiment she will be carrying out, only paying attention to the characteristics that are relevant for that objective (see discussion on affordances in the next section).

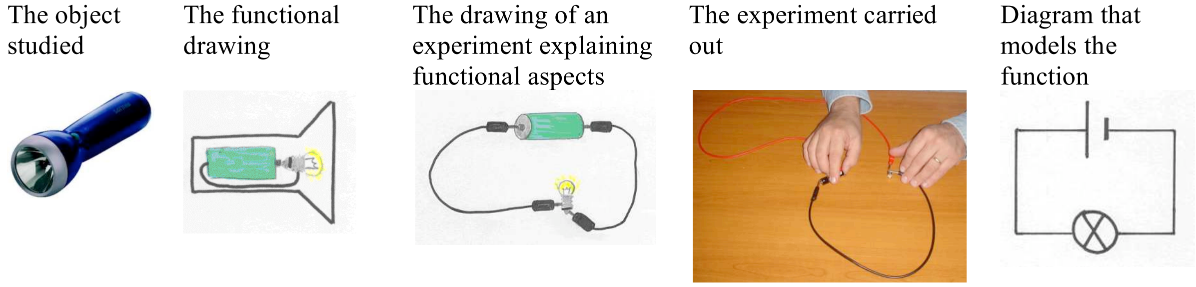
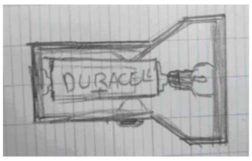


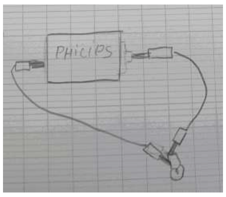
Figure 3. An *a priori* didactical analysis of multimodal and polysemiotic coherence for the simple circuit

Students' difficulties in constructing the initial semiotic bundle

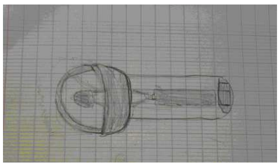
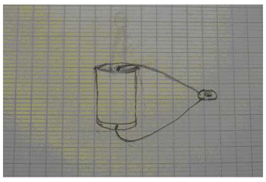
We first show an analysis of three different student groups' drawings in order to illustrate the range of difficulties students have when they propose experiments that fit to their representation of what happens inside the flashlight when it is turned on and is shining (cf. Figure 4). One of the first difficulties students experience while building the semiotic bundle is connecting the experimental apparatus to the initial 'thought objects' that represent the flashlight parts in their drawing. From an expert point of view, the real object (the flashlight), the drawings and the experimental apparatus as well as discourse and gestures about these, form one semiotic set. On the other hand, we see that students already have difficulty relating these elements to each other, *within the semiotic set itself*, so adding another set to this one (e.g. the bakery analogy) to make a semiotic bundle seems, at this stage, to be out of these students' reach.

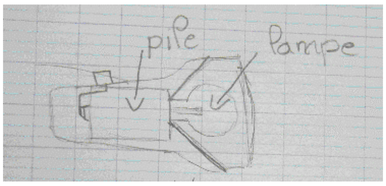
Group#	The functional drawing	The drawing of an experiment explaining functional aspects	Comments

1 



There is no wire in the functional drawing. Names of batteries are different from one drawing to another although the battery is the same. However, the drawing of the experiment is correct.

2 

Students use one wire to connect either the battery to the bulb or the battery to itself. They tell their teacher that there is a button they can press to initiate battery functioning.

3 

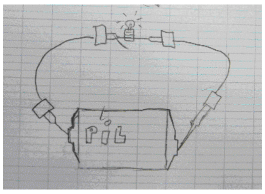

The functional drawing reproduces the general look of the bulb.
The drawing of the experiment takes into account the objects students have to use and the physical affordances of their experimental apparatus are evident in their drawing, even though this is not pertinent.

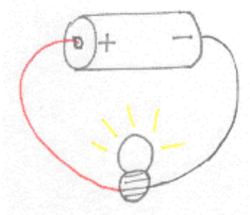
Figure 4. Example of students' polysemiotic incoherencies for the simple circuit.

The second extract (cf. Figure 5) concerns two students (Pierre and Jacques) who experience many difficulties in attempting to perform the simple circuit experiment as described above. Firstly, the students' drawing of the experiment is not correct. In order for the bulb to light up, one wire must be touching the very end of the bulb and the other wire must be touching the middle part (cf. the teacher's drawing in Figure 3).

So in this case, Pierre and Jacques are attempting to create coherency within an underlying meaning structure between two modes while trying to respect a drawing that will not help them. Secondly, the physical affordances of the crocodile clips (not shown in their drawing, but visible in the photo), entice the students to clamp them onto something, but the bulb does not allow clamping. Instead, one must just maintain the clamps stable (without trying to open them) so that they are touching the correct parts of the bulb and battery (cf. the teacher's experiment, above). According to Suthers, et al. (forthcoming), a given medium offers particular affordances (potentials for action in relation to the actor, following Gibson, 1977) of which salient affordances are expected to be the most pertinent (Norman, 1999). In this case, the crocodile clips were salient, but their function was not pertinent. Contrary to instructions, Pierre and Jacques do not redraw the experiment in an attempt to focus on how the electrical connections must be made, although this could have helped them.

The object studied

The drawing of an experiment explaining functional aspects



The experiment carried out a first time

Figure 5. Analysis of two students' multimodal and polysemiotic *in*coherence for the simple circuit.

Later on, another student shows Pierre and Jacques how to light the bulb with one wire. On this basis, they make several trials and suddenly, it works. Pierre says “it’s magic!”, but since he hadn’t drawn any new representation of the experiment, this event remains at the level of the magic trick for him, because it is not integrated into the semiotic bundle. This interpretation is also illustrated by a final trial made with the teacher that does not work either. Figure 6 and Table 3 with the associated discourse of the teacher shows that Pierre has not yet understood how to hook the wires up to the battery. In fact, Pierre and Jacques followed their drawing, but this did not result in a lighted bulb and so they were stuck.

Table 3. Teacher discourse when a student helps him to hold the experiment.

Time	Discourse	Gestures
32’44	T: no, not really here well we’ll see that later on but it should not be placed on the same area of the bulb,	points to the wire on the bulb
	it should be on this area and on the contact	points to the lower side of the bulb and the bottom of the bulb

Figure 6. Pierre is called upon to help the teacher hold the experiment.

Conclusions and further work

In this article, we have used the notions of multimodal reformulation and the semiotic bundle to describe how meaning-making occurs when students and teachers speak, gesture, draw and manipulate objects. Choosing to look at meaning-making through the construction of such semiotic bundles allows us to meet two goals. Firstly, we render explicit teachers’ expertise (i.e. their ability to seamlessly change modes, to select the appropriate characteristics of experimental apparatus to model in relation to a known objective and finally to coherently construct a complex semiotic bundle). Secondly we pinpoint where difficulties appear for students. In particular, if students erroneously construct a particular semiotic resource (e.g. the drawing for the experiment), they won’t be able to build an underlying structure of meaning between it and the next semiotic resource they reformulate into (e.g. experimental apparatus). Secondly, the physical affordances of experimental materials (e.g. the crocodile clips) can hinder reformulation between a semiotic resource in one set and a semiotic resource in another (e.g. between drawing and experimental manipulation). Finally, although we did not show the data in this paper because of lack of space, some subsequent student interventions indicate that the multimodal reformulations produced by the teacher in order to broaden the semiotic bundle facilitate the understanding of the electric circuit: students reproduce similar gestures to those of their teacher and they discuss new metaphors based on the systemic point of view. We can conclude that it is useful to consider teaching sequences from the viewpoint of the *complexity* of the semiotic bundle that is being built. Each new semiotic resource and set that is added to the bundle must be constructed without error so that students are able to reformulate a given resource into another mode. Physical objects to be manipulated must be carefully chosen so as to not mislead students by material affordances that are not relevant to the task at hand. In sum, each step of the construction of each semiotic set that makes up a semiotic bundle can be seen as a checkpoint for student understanding. Future work will include the documentation of additional examples of representational mode changing and semiotic bundle building, both by teachers and students. We will also further explore how students can appropriate teachers’ expert multimodal reformulation practices and the extent to which this affects their learning.

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