Modeling as a Teaching Learning Process for Understanding Materials: A Case Study in Primary Education

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ABSTRACT: Modeling is being used in teaching learning science in a number of ways. It will be considered here as a process whereby children of primary school age exercise their capacity of organizing recognizable and manageable forms during their understanding of complex phenomenologies. The aim of this work is to characterize this process in relation to the modeling of properties of and changes in materials. The data are discussed by establishing relationships between the modeling process with three different aspects: the specialized scientific knowledge, the physical manipulation of phenomena, and the interaction among those participating in the class. The results show how 7–8-year-old students generate a modeling process that leads them to explain the behavior of different materials by using a “model of parts” created ad hoc. This model, built up from some kind of a discrete vision of the material, proves to be coherent for children of this age and evolves by relating the visible continuum with an imagined discontinuum. © 2007 Wiley Periodicals, Inc. Sci Ed 91:398–418, 2007

INTRODUCTION

Both those in philosophy of science (Giere, 1988, 1997; Nersessian, 2002) and science education from American and European traditions (Clement, 2000; Duschl, 2000; Duschl &
Hamilton, 1998; Gilbert & Boulter 2000; Gobert & Buckley, 2000; Grandy, 2003; Harrison & Tregust, 2000; Lehrer & Schauble, 2005; Rumelhard, 1988; Tiberghien, 1994; White & Frederiksen, 1998 among many others) have acknowledged the need to consider modeling as a key process in teaching and learning science. The agreement is based on considering models as intermediaries between children’s capacity of interpreting natural facts and the multiple aspects of these facts that substantially work by representing hidden semantic connections and organizing them in a comprehensive meaning. The agreement has also grown on considering models as flexible ways to understand children’s knowledge constructions in their efforts to master their own experiences because they provide organized support guiding their interpretation of a complex phenomenon, creating the possibility of attaining the comprehension of new phenomenologies. As an external form of representation, models have the twofold function of being representational of something concrete and being a concrete thing to work with.

Few studies have been done on modeling in the early years of schooling, since students of this age are usually considered to be unable to construct, or abstract, entities and processes of scientific consensus models, and consequently the science taught tends to be descriptive. We nevertheless believe that it is possible for young students to carry out a school scientific activity of modeling in which new entities and processes, which are appropriate to the school level in which these are constructed, are generated. These entities and processes need to have the double condition of being useful for the students in order to give meaning to the phenomena observed and, at the same time, have some degree of coherence with the scientific consensus models.

The genesis of these entities and processes implies carrying out a set of actions in which modeling, physical manipulations, and discussions are interrelated in order to promote a rational reconstruction of the phenomena. By way of this network of actions, different aspects of the scientific consensus models are put into play, using linguistic and nonlinguistic representational systems (e.g., words, gestures, drawings, three-dimensional representations) appropriate for the age of the children.

The aim of this article is to analyze a learning experience with 7–8-year-old children in which a modeling process on the structure of materials was promoted. In this process, the teacher selected a set of ideas from those expressed by the students during the classroom interactions, supported students in the use of these ideas and placed them in order of importance. These ideas formed the basis for generating entities and processes that were useful for these students in explaining the material behavior of their physical manipulations.

THE MODELING PROCESS IN SCIENCE TEACHING AND LEARNING

It is known that students bring their own ideas into the classroom and organize them. These organized ideas are not usually used in order to generate a school science activity, but rather an attempt is made to transmit to the students “extracts” from the scientific consensus model and to contrast and highlight the differences between these and the students’ often alternative ideas (Joshua & Dupin, 1993). In this way, school tends toward the teaching of a “standard” science, a “true” science that is more or less related to the scientific consensus models (Clement, 2000).

Teaching and learning science seen as a modeling process is different from the transmission of a “scientific consensus model,” which involves a didactic transposition adapted to the pupil’s age. The various models that can be generated in early school years are provisional representations that explain aspects of reality which are gradually interrelated, thereby leading to the evolution of these models. As Giere (1988, p. 64) indicates, “The
model-reality adjustment is not overall, but rather relative to those aspects of the world that the models attempt to capture,” which is why the models the students construct have to be interpreted as adjustments between the questions-experiences, which make sense to them, and the interpretations that they come to form.

This study will deal with three aspects that we believe to be fundamental for the understanding of the modeling process in primary science classrooms:

a. Its relationship with the expert scientific knowledge,
b. Its relationship with the physical world, and
c. Its relationship with interactions among members of the classroom.

The Modeling Process and Its Relationship to Expert Scientific Knowledge

Many studies considering the importance of a phenomenological approach in science education have examined the student’s development of the concept of “material” linked to the “kinetic-molecular model of matter” (see a review of Smith, Anderson, Krajcik, & Coppola, 2004). This scientific consensus model is used to analyze students’ understanding difficulties by identifying “dissonances” with children’s ideas (e.g., Driver, 1985; Krnel, Watson, & Glazar, 1998, 2003; Mortimer, 1998; Stavy, 1991). The core of these difficulties, at early ages, is considered to be the children inability to differentiate between material (something which is visible, perceived and handled as a continuous stuff) and a “particle” related to a determined level of organization of atomic-molecular matter (something which is invisible and discontinuous, whatever were the degree of conceptualization), a situation which results in (micro) particles being bestowed with properties which correspond to visible (macro) material. All these difficulties were reported in the research literature as a source of children’s misconceptions (Andersson, 1990; Ault, Novak, & Gowin, 1984; Ben-Zvi, Eylon, & Silberstein, 1986; Meheut & Chomat, 1990; Renstrom, Andersson, & Marton, 1990) and come from understanding how “scientific concepts” embedded in the atomic-molecular model of matter resist to traditional instruction.

Learning to use the atomic-molecular model systematically to account for properties and transformations of matter and materials is a long, difficult process. As Smith et al. (2004) say “Research shows that for many people receiving traditional instruction, that learning process actually never happens: many students in high school and college science courses continue to provide narrative accounts for common transformations even after they have studied atomic molecular theory” (p. 17). The necessary progression from scientifically sound macroscopic accounts to atomic-molecular ones requires our understanding of learning from different perspectives, including those going beyond misconceptions in order to open other potential productive ways supporting children generative dynamics of knowledge.

By introducing a modeling process approach, we would like to discuss an alternative to the study of materials in early years, accepting the limitations (dissonances) brought with traditional misconceptions. This approach is based on encouraging young students to interpret observed facts (properties of and changes in materials) by way of a “model of imaginary parts.” The discrete “parts” or “units,” as they are imagined in the classroom, build up an interpretation of the “visible continuum,” without the discrete element being referred corresponding to a precise level of organization of matter (i.e., not atoms, not molecules). The characteristics of these “parts,” their interrelationships, and the way they are structured come to be closely related to the manipulations carried out in the classroom and have been chosen to guide the phenomenological interpretation encouraged in students for two fundamental reasons.
First, because it allows the use, in young students, of a basic strategy of thinking which is also used in the construction of the scientific consensus model for interpreting properties of materials. This strategy is based on the cognitive ability to separate a system into some of its constituting elements in order to later relate this discreteness into an identifiable continuum. This constant game of “making discrete–recomposing in continuum” works in a complementary fashion and plays an important role in the rational reconstructions of phenomena (Arcà, Guidoni, & Mazzoli, 1983, 1984; Guidoni, 1987). Students observe water, a metal, or other materials as something continuous and have to learn, however, to think on them by imagining it as discrete entities that are useful in reporting the behavior of the visible continuum. The use of this strategy is also part of a “systemic view” sustaining generative dynamics of knowledge that match with reasoning through the scientific consensus model (i.e., the identification of parts, the relationships between parts, and the structure of relationships between parts).

Second, because the same “particle” idea is being constantly refined in modern interpretations of the behavior of different materials. Especially, within material science, the idea of “mesoscopic organization” has been implemented to define the minimum unit in each material that can explain the properties of the material (Laughlin & Pines, 1999; Laughlin, Pines, Schmalian, Stojkovic, & Wolynes, 1999; Lhen, 1995). This minimum unit resonates with a “parts model” which is usable in school contexts with young students. This model’s characteristics allow the students to explain the behavior of the materials they are manipulating and enable the model itself to develop. From this same perspective, other science education research is also making use of this idea of “mesoscopic organization,” which is not analogous to the idea of the molecule, for the teaching and learning of the behavior of different materials (Beson & Viennot, 2004; Besson, Viennot, & Lega, 2003).

In the case analyzed in this study, the scientific consensus model corresponds to the particulate model of matter. Its coherence with the “parts model” has been based on four basic ideas:

- The idea of “making discrete”: In order to explain properties of, and changes in, materials, it is necessary to imagine them made up of “parts.”
- The idea of a large number of “parts”: The parts have to be many, and smaller than can be observed.
- The idea of a bond between “parts”: The characterization of the bonds between the parts can explain differences in the behavior of materials.
- The idea of the conservation of the “parts” in changes: “Making discrete” can be used to encourage explanations of transformations in materials.

The “parts model” constructed in the classroom using these ideas shows a consistency with the particle vision of matter and is at the same time useful to students when trying to explain their manipulations. Nevertheless, students can use other ideas in the framework of their model which would not be acceptable from a scientific consensus model that uses particles and molecules, such as giving the particles properties from a macro level—form, color, etc. In dealing with this point, we do not want to discuss whether children are considering these parts as homogeneous by themselves (Au, 1994) but their functional value for children interpreting the behavior of materials that is being also considered by modern views of the scientific consensus model and its treatment in science education with older children.

The “parts model” satisfies the role of a school science model (Izquierdo, Espinet, Garcia, Pujol, & Sanmarti, 1999), since it allows a reconstruction and an explanation of “school
experiments” in a way that makes sense to the students and keeps its potentiality to move them progressively closer to the scientific consensus models.

The Modeling Process and Its Relationship With the Physical World

There is a long tradition in childhood science education of carrying out activities that have, as an essential part, the direct manipulation of materials. The purpose of this manipulation can be extremely varied. For instance, it can have the purpose of using the senses to describe what is perceived (e.g., Pontecorvo, 1992), or of experimenting to check out a hypothesis or of encouraging the cognitive development of the students (e.g., Metz, 1993).

In our study, the manipulation of the physical world, while nor discounting these purposes, works as a referent that continually contextualizes the modeling process, encouraging and limiting the development of the model at the same time. In order for it to satisfy this objective, it must have the following characteristics:

– The situations involving manipulation of materials have to enable students to create the selected ideas in coherence with the scientific consensus model. For instance, comparing the color or taste of materials encourages the development of a view in which properties are treated as substances, whereas comparing the difficulties in breaking or dissolving tends to encourage the development of a mechanistic model (Sanmartí, Izquierdo, & Watson, 1995).

– The successive manipulations need to be sequenced so as to allow children to evaluate their first models generating successive interpretative approaches in the modeling process. The ideas generated by each manipulation need to be firmly anchored in the previous ideas.

– The manipulations need to belong to the children’s experiential world, thereby making it possible to pose questions that make sense to them and to imagine explanations.

In keeping with the above, our approach was to identify a series of manipulation situations that required students to make successive refinements of their interpretations. Each group of four students manipulated a different material—water, clay, wood, sponge, and rock—performing the same action, and by comparing the viewpoints, one of the ideas selected with regard to the expert consensus model was abstracted. The ideas imagined to interpret the first manipulation were used as a starting point for interpreting the second manipulation, a factor which brought with it the need to make adjustments between the new manipulation and the ideas used up until then. These successive interpretations seek to be more independent of the manipulation performed by each group, constituting models that explain more and more materials and manipulations (organizing increasingly complex phenomena).

The manipulations performed and the ideas related to the expert consensus model that they came to construct were the following:

– From constructing the same object from different materials (in this case, an ovoid form), they moved on to imagining first of all “parts,” and then subsequently a “large quantity of parts.”

– From breaking the different materials by striking them, they moved on to imagining and representing the bonds between the parts.

– From “breaking” the materials, now mixing them with water, now heating them, they progressed to relating the change in the materials to the conservation of the parts.

The aim of this type of manipulation was to get to grip on the experimental component in the construction of scientific knowledge at primary school level.
Another of the modeling process’s dynamic aspects rests on the relationship established among the class participants, understood as a form of social practical (Resnick, Salmon, Zeitz, Wathen, & Holowchak, 1993). Of the many aspects involved in this kind of practical, diversity of participant viewpoints is a fundamental condition in order for the modeling process to be produced, to an extent that, if these differences did not exist, it would be a required condition to provoke them (Duschl, 1990).

In the experience analyzed in this article, the diversity of viewpoints was provoked by encouraging each group of students to manipulate a different material and to communicate the way these manipulations were understood by way of an interrelated set of linguistic and nonlinguistic representations—drawings, physical models, gestures. These external representations were compared and discussed, therefore used as instruments (Hymes, 1972) with which to reduce the diversity of viewpoints and to construct explanations that have common ideas in tune with the scientific consensus model. In this sense, the function of the teacher was crucial, since his or her interventions had a fundamental influence in two aspects: they assisted in “seeing” the aspects in common, which were in line with the ideas selected from the scientific consensus model, and helped the students to proceed with the adjusting of their model to the results of the manipulations they were performing.

Because of their relevance in the modeling process, in the case analyzed in this article, we highlight the interactions among members of the classroom that are encouraged by the following:

- the communication of a variety of viewpoints expressed during a particular manipulation, and the group identification of common aspects among these viewpoints;
- the collective search for use of the ideas agreed by consensus in a first stage in order to deal with the interpretations of the new manipulations performed;
- the metacognitive moments of reflection on what is being learned, on what has changed each pupil’s way of thinking, etc.;
- the use of different linguistic and nonlinguistic expressions to encourage richness of perspectives and to encourage each child to discover the expressive form which best helps him or her share their viewpoints; and
- the intervention of the teacher, by selecting, from among all the ideas expressed, those that are the best for constructing the model, putting them in order of importance or helping to redefine them.

The three aspects chosen to characterize the students’ modeling process—the relationship with specialized scientific knowledge, with the physical manipulations, and with the interactions among class participants—are considered to be basic aspects of a dynamics capable of promoting the abstraction and organization of models in science classrooms in early years.

We produced this characterization through a reflection oriented by four main classroom-practical aspects:

- How was the new idea generated in relation to the scientific consensus model gradually introduced and consolidated?
- What role did manipulation play in this genesis? In what sense did the manipulation of a variety of materials encourage this genesis?
- How did the participants’ interactions support the modeling process?
CONTEXT AND METHODOLOGY

The Setting and Its Particularities

As a part of our in-service teacher training and in line with official curriculum, we worked with primary school teachers in developing activities focused on making children interact with materials and communicating their ideas about properties of and changes in these materials. The classroom object of this research was part of these teacher-training activities. The researcher participated in the classroom dynamics following two main agreements with the teacher regarding communication in the classroom. On the one hand, they would be guiding the communication by using a relational outline based on a systemic view (i.e., the identification of elements, the relationships between elements, and the structure of relationships between elements, considering these elements mainly as “parts” identified through the activity) meanwhile they encouraged children “to imagine and to represent what may happen at an invisible level.” On the other hand, they would be advocating for a concatenation of children representations in order to build up a model, always considering, and changing if needed, precedent steps of the modeling process. With these premises, the teacher developed their own “teaching style” framed into socioconstructivists and sociocognitives approaches of teaching and learning science (e.g., Driver, Asoko, Leach, Mortimer, & Scot, 1994; Herrenkohl, Palincsar, Dewater, & Kawasaki, 1999). She promoted flexible modes of participation and improvisations in classrooms talks (Erickson, 1982) involving children in whole classroom and small group discussions and considered collaborative aspects of knowledge construction viewing their own participation as a challenge for understanding how models could be promoted and constructed.

Data Collection and Analysis

Our research sought to comprehend the nature of a modeling process as a classroom practice. We have chosen to construct a case study by reflecting on registers taken from activities developed in a classroom with the hope of getting a better understanding of what these registers meant concerning three aspects, the relationship with the specialized scientific knowledge, with physical manipulations, and with the interactions among classroom participants. To carry on with this reflection, we considered interactional communication as a base of the modeling process. Small and whole group interactions were an essential part of the classroom dynamic. Children engaged in small groups’ activities manipulating different materials, though the constructions of models to understand these manipulations also involved communicating ideas among the whole classroom. We focused on analyzing this kind of group dynamics rather than in individual performances.

Sequentiality is a key aspect of communication in meaning-making activities (Coulthard, 1992). Based on a descriptive and analytic account of the sequentiality of the communication, we dialogued with our research registers aimed to characterize the modeling process and then generate assertions for this particular case that were grounded in the data. It would allow us to study the dynamics of a modeling process in their context on the basis of a descriptive and analytic account of a communicative process.

A total of nine lessons were developed over a period of 2 months, in a weekly lesson of an hour and a half. They took place in a third grade of a primary school located in a middle class district of Buenos Aires, Argentina. Two teachers and 24 students aged 7 and 8 years old have taken part in this experience. One of the teachers was the regular qualified teacher, and the other, a researcher-teacher, was the first signatory of this article giving a teacher training in service to the regular qualified teacher.
The classroom was organized into six groups of four children, each of which manipulated a different kind of material: clay, “sponge,” water, “stones,” wood, and metal. The choice of these materials was based on their availability in the classroom (i.e., familiar material for art activities) and its appropriateness in supporting modeling activities had not been evaluated a priori. All the groups followed the same tasks that consisted in building up a particular shape to further experience different breaking actions on this shape (mechanical actions, by using water and by using “fire”). Arguments for the choice of these particular actions are developed in the main part of this paper. Children alternated their participation working within their small group to explain the behavior and changes in their materials, comparing their ideas with those of another small group, and also by discussing openly among the whole class. Stimulated recall (Chin & Chia, 2004; Edwards & Marland, 1984) was used during part of the classroom activities. This was implemented to help children to do not dismiss previous steps in constructing their models, recalling their thoughts, feelings, and representations. For example, segments of the classrooms talks and drawings used to represent ideas in the first manipulated actions were used to continue modeling further actions.

Communication among participants during classroom activities consisted in linguistic and nonlinguistic means such as drawings, body expressions, and physical models. Two audio recorder machines were familiar elements during classroom activities. The researcher introduced them, and they were adopted by children as “things without eyes to which we needed to explain everything.” They circulated through the groups becoming some times particular target of the communication. We have kept transcriptions format of recorded talks as simple as possible, in that we have only included information about such things as overlapping speech, particular target of the communication, and nonlinguistic ways of communication associated with certain moments. We have also punctuated the transcribed speech, in accord with our own intuitions, to make it easier to read. Drawings, body expressions, and physical models were photographed. All of them constituted our research registers in which we concentrated the analysis. Reflections between teachers and personal opinions after sessions were noted down in the class diary proving a context for the interpretation of data.

The research registers were treated as “situated.” The analysis was developed respecting the sequentially of the oral communication conducting qualitative discourse analysis (Barnes & Todd 1995; Psathas, 1995). Descriptions and comments about key aspects that lead to the modeling process were organized in the analysis producing a case study following an interpretative style in which we integrate our comments with the observed data and opinions of other authors (Mercer, 1996; Merriam, 1998; Tobin, 2000). Registers were first read through several times to get a sense of the data. They were first sequentially organized following the number of lessons we have had to, afterward, determine “meaning units” in which participants treated a particular idea dealing with the systemic view promoted by the teacher and researcher (i.e., the identification of elements, the relationships between elements, and the structure of relationships between elements). For example, sequential segments of the transcripts, together with pictures and drawings, addressed to establish “elements” as constituents parts of different materials were determined as one of the “meaning units.” A criterion of communicative cohesion among participants (Pekarec, 1999) was also used to decide whether or not participants’ opinions were exchanged around the same idea.

In total, four “meaning units” or “analysis units” were established. Within the units, we selected sequences that vary in length reflecting differences in the kinds of activities that the children were engaged in. This particular selection has been made in order to illustrate the ways we observed participants constructing and manipulating models. We report the most representative sequences, including drawings and oral expressions, in order to produce
a characterization of the key aspects that lead to the modeling process in each of these units—the relationship with specialized scientific knowledge, with the manipulations, and with the interactions among class participants.

RESULTS AND ANALYSIS

First Analysis Unit: From First Perceptions to the Idea of “Making Discrete”

The first manipulation task consisted in shaping an ovoid with the material that each group was given. Direct contact with these materials and the overcoming of manual difficulties that the students encountered increased their perception and prompted a wide variety of reflections including some about the internal structure of the different materials:

Luli (manipulating stones): there are stones that are all dust and other things;
Sebastian (manipulating stones): but because the other stones aren’t round, we don’t know how to make them that shape;
Hernán (manipulating clay): With the 4 different parts together they make an egg;
Romina (manipulating water): all the water is water.

The way in which children’s ideas were used by the teacher is illustrated below:

Hernán (manipulating clay): The form has got a part inside that you can move and the outside holds it. It’s got a thick part, . . . I don’t know how to explain it.

This child, who was manipulating clay, differentiated perceptively an “inside” and an “outside” part, and this perception was taken up by the teacher as a pivot around which to guide the successive approaches with the whole group-class toward the idea of “making discrete” that was being pursued.

Teacher: Let’s stick with this last idea of Hernán’s, where he talked about the different parts of his form. On the sheet of paper that you’ve each got, let’s draw the shape that they had and let’s try to imagine, in as much detail as possible, how they are made inside. . . . as if you were Superman and could see everything inside with your x-ray vision. You’re going to imagine how the shapes you’ve made are made inside, and you’re going to draw it and then describe it, O.K.?

The teacher is appealing to the boys and girls’ imagination about a “nonvisible” interior of the materials, with the aim of spreading a first idea of “making discrete.” The “clay” group was the first to refer to the inside of their material, identifying millions of grains of dust in their ovoid form. One pupil in the “rock” group observed: “Flor: The stones have got dust and some of them make dust,” and the members of the group discussed among themselves whether the dust was produced when they scraped the stone because they were breaking it or whether it came from within when they took away the “skin.” The other groups constantly compared their idea of the “inside” of materials:

1 Transcription notes: The dialogues chosen for transcription are typeset, considering especially those of the group who worked with water.
Figure 1. Different visual interpretations of the inside of the materials: a, “water”; b, “stone”; and c, “sponge.”

Magali: They’re not the same as the sponge and wooden eggs. The same thing happens with us as with the stones and clay. The little threads inside the sponge are softer and thinner and the wooden ones are harder and thicker. They’re not the same and don’t look the same.

With these comparisons the different viewpoints were expressed (Duschl, 1990) and drawings were made that captured an initial idea of “making discrete” with which to approach the different materials (Figure 1).

In this first phase of the modeling process, the idea of “making discrete” was constructed by exercising a constant adjustment between direct perceptions of the physical world generated during the manipulation and the creation of a model of the materials. This adjustment was encouraged by the teacher by selecting the comments of some students that established a differentiation between the materials’ visible stuff (“the outside of the material”) and nonvisible stuff (“the inside of the material”). Their work instructions were consistent with this differentiation, causing a closer examination of the frequent comparisons between the materials.

From the point of view of the manipulation activities developed, this first idea of “making discrete” is the result of the joint manipulation of both materials that favor a discontinuous perception and of materials that do not favor such a perception (e.g., water). Manipulating the first type of materials gives rise to the initial idea of “making discrete,” whereas manipulating the second type gives rise to the need to use this idea in order to adjust to the characteristics of each material.

Second Analysis Unit: Generalization of the Idea of “Making Discrete” by Using the Idea of “Quantity of Parts”

Once the attention of the whole group-class had been focused on the nonvisible interior of each material expressed in the first drawings (Figure 1), the modeling process continued with the establishment of the idea of “making discrete” by imagining a “large number of parts,” understood as an extreme extension of the idea of “making discrete” initiated in the first phase.

As already pointed out, among the materials selected were some whose observation easily suggested their discontinuity and the idea of a large number of parts (e.g., sponge and clay). In this way, it was possible to record comments from the “sponge” group students which captured the extreme sense of this “making discrete”:

Lucas: When we draw the sponge it’s like this: a million little threads. Millions of little threads, all criss-crossing. Crossing in bends, or if not, with a long line that bends round.
From this intervention, the teacher extracts the idea of “many parts” and encourages comparisons between the materials so that the other groups can use them.

Teacher: What about in the wood? Are there millions or not?
Maga: There are millions. Millions of little threads and chips.
Kiroz: Stones have got dust, some turn to dust and others don’t because they’re made of another material. The dust comes to the outside bit by bit.

Of all the materials worked with, the materials perceived as homogeneous (e.g., water) were found by the students to be harder to imagine as discontinuous. Nevertheless, the teacher’s constant suggestion to generalize the idea expressed by classmates manipulating materials different to these homogeneous materials, forced the students to imagine parts that they were unable to see.

Teacher: Right, let’s stick with that: that both are millions of little bits or lots and lots of little bits. I’ll ask the water group: Are there these ‘millions’ or ‘lots and lots’ that the boys and girls say there are in the sponge and in the clay?
Leandro: Water’s a liquid, and when you pour it, little drops fall and spread out, lots more than we can see.
Romi: They’re there because there are lots of bits.
Juli: They’re there because there are lots of bits, so if these bits spread out there are a lot of bits, there are millions of them.

The different viewpoints generated in the first phase of the modeling process begin to find a “common place,” which consists of referring to their materials by describing them as “a large number of parts”: millions of little threads for the sponge (Lucas); of little drops of water (Diego), of dust for the stones (Natasha); of little bits of chips for the wood (Maga); thousands of little pieces of metal (Leandro).

Although the idea of “part” which they begin to build up is very much related to the perceptive level, the idea of a “great number of parts” encourages the gradual establishment of a discrete way of imagining matter. Juli’s drawing (Figure 1a) shows a “discrete” representation of water, although her vision of this discreteness, as with that of her classmates, does not necessarily correspond to that of expert scientific knowledge. Despite all this, the idea of “parts” as a generalizable entity for interpreting the behavior of materials requires a certain interpretative distancing from the first perceptive register. The children first draw parts that they can see—grains of clay—and then later move on to drawing entities that they imagine to exist in a great number but which they cannot see (e.g., “parts” of water or any other material). Although in order to imagine them, they have thought about drops of water or other “parts” that they have indeed seen or know, it is with this imagined entity that an attempt is made to generalize a way of looking at materials as a first idea common to all of them.

In this second phase of the modeling process, the role of the teacher is once again the key to establishing the idea of “making discrete” with which the materials are considered. His interventions focus attention on the idea of a “quantity of parts,” comparing all the manipulated materials by identifying expressions of the students themselves which might encourage the refinement of the first “discrete making” idea generated.

The unification of the discussion around the ideas, whose importance needs to be emphasized, obliges the students to concentrate on the aspects with which to establish the continual comparisons between materials. The dialogues reported in this second analysis unit are a demonstration of the importance of the interaction among students for establishing the thematic unit of the discussion.
Third Analysis Unit: The Idea of a Bond Between the Parts and of a Differential Identity of Parts

The subsequent manipulation consisted in the application of breaking actions to the materials. The idea behind these actions was to generate new perspectives and to exercise more interpretive adjustments that would explain from here on the differences between materials, using the ideas of “making discrete” and of “quantity of parts” developed earlier.

From among all the breaking methods suggested by the students, the teacher chose one, and in his intervention prompted explicitly the reflection toward imagining what would happen to the “parts.”

Teacher: This is what we’re going to do today: instead of the hammer, we’re going to use our feet. For instance, if Lucas steps on the sponge, will the same thing happen as if he stepped on the stone? So we’re going to step on the shapes we built, paying attention and drawing down what happens to the little bits of each material while we’re stepping on it. To see what’s happening, we’re going to step on them, but not ‘stepping for stepping’s sake’, but to ask ourselves this. What will be happening to the millions of little bits of our material?

And the second question is: How are these bits joined together? How are they joined together to stand up to or not the squashing we have given them?

The perception of the differences in the consequences of this breaking action caused the “force applied to break” to be related to the reaction offered by each material. An attempt was made to explain this differential reaction by using the “bond between the parts” as a way of continuing with the interpretive use of the “parts” and “quantity of parts” ideas developed thus far. The students respond by imagining bonds which they cannot see, but which demonstrate the behavior of each material. For instance, Romina, from the water group, remarked that “every time they stepped on it, it made little bits which were smaller each time because they were held together by something which stuck them together but not so much…” (Figure 2a). Her drawing shows how she explains the “breaking up” of the water as different parts of it separate.

In the modeling process, the importance of the comparison between the different materials is again demonstrated. For example, Sebastian from the metal group and Romina from the water group made a number of comparisons:

Sebastian: You see, the metal ones are ‘really stuck together hard’, not ‘stuck together, but not so much’ like the water ones (Figure 2b).
Romina remarks: That in the wood, the little pieces are more squashed together than the water ones, and that’s why it’s stronger, so when, for example, I step on it, they don’t scatter like the water does.

These differences in the bonds, in addition to being expressed orally and in drawings, became consolidated by being represented by way of hand gestures:

Teacher: Show each other with your hands what a tight metal bond means to you... Look at Santi’s hands, and Ivana’s, and Kiroz’s and Kevin’s... which do you think is the one that shows the bond between the little bits of metal best?
Diego: Kiroz’s, because the skin on his hands are stuck tighter together, and the metal’s harder like that.
Teacher: What about the sponge ones?
Lucas: Like this, a little bit crossed.
Teacher: You water experts: Would it be possible for you to do the same kind of bond as Sebastián does with metal?
Juli: it’s not like that, because water hasn’t got any shape. Sometimes, often, they separate, then it has no shape.

The children later drew first the “parts” of their material, and then, how they were bonded together. In some cases, they place the parts one next to the other, generally in the materials that are the easiest to “break.” In others, they represent weaves, which in the case of metal are very difficult to break and are very compact, and the parts fit together completely (Figure 3).

The depiction of these parts with the different bonds and different arrangements between them constitutes further evidence of a kind of interpretation that is distanced from the perceptive register encouraged by the breaking exercise, outlining in this way the integration of new ideas into the initial model at the start of the breaking activity. The drawings in which the different parts are defined (Figure 3) both show the differences in the bond, which for the students explain the differential behavior when faced with the same breaking gesture applied.

In this third phase of the modeling process, the role of the teacher is once again of key importance for the linked use of ideas that enable the progression of a model able to reflect the differential behavior of the materials. The teacher restricts interpretations to those that are elaborated with the idea of “large number of parts,” and thereby creates the need to define better these parts, their bonds, and the arrangement between them, thus succeeding...

Figure 3. Drawings of the parts of each material and the arrangement between them. Arcilla (clay), Piedra (stone), Espolja (sponge), Agua (water), Metal (metal), and Madera (wood).
in making the students explain the differential behavior observed using the set of ideas worked with.

**Fourth Analysis Unit: Transformation and Conservation**

The modeling process continued with the development of new breaking tasks whose aim was to introduce ideas of conservation and transformation. The new breaking tasks consisted of using water and fire to try and “break” the different materials with the aim of encouraging the perception of the water–material and fire–material interactions, and to once again channel the interpretations by way of the ideas of “parts,” “quantity of parts,” and “bond between parts” worked with thus far.

The first breaking task simply consisted of immersing the different materials in water and guiding the focus on the account of the observations toward the reversibility of the process triggered in the material–water interaction.

Teacher: Did the little bits that separated come together again?

Some groups, such as those using clay, for example, began to refer to the conservation of their material’s identity by way of its parts.

Kevin: Because they were already in the water and they got very small and they were so separated that we couldn’t put them back together again.

Ivana: and the egg began to change shape as well.

Kevin: They dissolved and turned into water but they were still clay, but in the water.

Others, like the water group, also insisted on the conservation of their material’s identity during the interaction:

Romi: when the water gets into the water, it joins up with the little bits that were already in the bucket.

Diego: It makes more water and it’s all together.

When the action proposed was the breaking of each material using fire, the teacher once more intervened by guiding the interpretations toward the use of the ideas of the model generated thus far, introducing the variable of time as a way of adding dynamism to the interpretations:

Teacher: This time we’re going to break our objects of different materials by putting them in the flames of the fire. Then we’re going to say what you think happened to each one of the parts you used to describe your shapes in drawing number 1. Also, when you are doing it, say what’s happening as time goes by with your material in the fire, using as much detail all the time in the description.

With this intervention, the teacher got the students to represent the changes using their initial material model (and therefore, what was happening to the “parts”) in relation to time (Figure 4).

The drawings in Figure 4 confirm that the modeling of the transformations tackles an idea of conservation of matter not previously dealt with. In the water group, for example, Julieta remarks that the little pieces “are not lost there,” but rather that “they become this steam.” In some cases, the conservation of the water parts in the two states is explicit (Figure 4a). In others, the inverse proportionality between the little parts and the steam expressed in
the drawings (Figure 4b) suggests in some way that this idea of conservation becoming a starting point to talk about another aspect of the model.

Teacher: What is ‘this steam’?
Romi: It’s the little bits that are separating, there are fewer and fewer in the water and there’s more steam.

The students build up their explanations from the model they created earlier. The new idea of conservation of the parts has been elaborated using the ideas of “quantity of parts” and of “bonds between the parts.” Figure 5 shows three of Romina’s drawings (water group) that demonstrate different states of the modeling process.

This sequence suggests that each of the new experimental situations has required the use of the preceding ideas. A new model is not developed for each of these situations, but rather an evolution of a common model. The process of construction and use of this model could have continued giving rise to further questions (e.g., How are the parts organized in this “steam”? and new experiences (e.g., When a material has been broken “with water,” does it weigh more or less than before breaking it? Could we try weighing it?). However, in this case, it has ended with the series of breakings proposed for our materials and the consequent observations.

DISCUSSION

In agreement with Arcà et al. (1984), we believe that models work as translators of “forms of perceived reality,” understood as attempts of rational reconstruction accessible to understanding. We consider that the capacity for organizing these forms, by imposing
them semantically on phenomena, is acquired by exercising modeling processes such as that analyzed in this study.

The analysis of the data from our research findings suggests the following points of discussion.

First, a “model” characteristic of school science is reached by establishing a balance between the phenomena analyzed, the scientific knowledge of reference, and the interpretations that children were able to generate by their own.

In order to make possible this balance, teacher’s role concentrated in identifying children’ ideas that “resonate” with the scientific ones and promoting its development. Rather than impose or transmit a previously defined point of view, the teacher intervened by strengthening, among the diversity of points of view brought by children, those points retaining the potentiality to be used by children to make the model evolve toward the scientific consensus model. In fact, teacher’s interventions consisted in making children focus on few ideas among the many expressed and, in some cases, making children focus on an idea articulated by a single child.

These interventions worked by assuring the circulation of a particular idea that, otherwise, would have probably been left aside. To practice these interventions involved two particular abilities: on the one hand, the ability of selecting some pivotal ideas from the expert consensus model and, on the other hand, the ability of intuited (Claxton, 2000) which ideas need to be strengthened to make possible for the students to interpret the phenomena they have at hand (Izquierdo et al., 1998).

In our case, the “parts model” was constructed using general ideas, which complied with this double commitment: to make an object discrete and to establish relationships between the resulting parts. The idea of “making discrete” has been very useful in selecting the general ideas that were consistent with the expert consensus model: the idea of parts and quantities of parts, the idea of a more or less strong bonds between the parts, and the idea of the conservation of the parts in changes are directly related to key aspects of the expert scientific model, and at the same time, they interrelate to form a conceptual network with possibilities for being used intelligently by children.

The “parts model” allowed, among other things, the pooling of a common view of different materials and the tackling of problems such as those of transformation and conservation. This initial interpretive power of the model defines lines of development by way of which the model itself can attain a greater interpretive power (Gobert & Buckley, 2000). In perceptively homogeneous materials like water, it proved harder to differentiate the parts of the visual continuum and to define them as a new entity with which to develop interpretations of different processes in which the material was involved. Nevertheless, the definition of this entity was the result of constant comparison with other, perceptively nonhomogeneous materials such as sponge or stone. This result can give us an indication of how to improve the development and use of the parts model as far as the materials to be chosen for the manipulations are concerned. At the same time, the parts model has allowed the development of more general abilities such as handling of scales and the representation of changes over time.

Second, the function of the experimenting focused on the introducing of new perceptions directed toward encouraging the formalization of knowledge.

The experiences introduced throughout the study allowed the students not only to manipulate objects and materials, observe properties and changes, or recognize similarities and differences but also to do so by constructing a model of the materials, which conditioned both their perceptions and their explanations. These experiences can thus be described as a process from which the students manipulate, talk, and think according to a school science model that they are building and using. From this point of view, the experiences
are transformed into “school science facts” (Izquierdo et al., 1999), i.e., into a set of observations that are perceived and interpreted according to a school science model that the teacher promotes by directing the “ways of looking” (Arcà et al., 1984).

In the activity analyzed, the experiences proposed allow the boys and girls to begin to imagine a material model that “explains” from the outset the properties observed in the set of different materials in a way that was believable. At the same time, the actions carried out—shaping, breaking, mixing with water, and heating—make sense according to the material model generated. The students, while experimenting, are not “seeing” water, clay, or other materials, but rather “parts.” These parts may be those which are the same or different (i.e., the idea of homogeneity and heterogeneity), are many in number, repeat themselves, are more or less united, are distributed in a more or less ordered way (the idea of structure), etc. It can be asserted that these actions form a part of the model, just as they form a part of the analogies used and the ways of talking about what happens and the thoughts that arise. That is, there is no theory separated from the practical, but rather the experiences, perceptions, analogies, and words form a part of the model generated, since without them it would not make sense.

This way of understanding experimentation implies a rethinking of the function usually attributed to the carrying out of practical work in the context of science learning. Experiments are not done to verify or “see” something known by others, but rather as attempts to use models generated in the classroom and to adapt ways of thinking, ideas, and expressions to the formalization of knowledge itself. The “parts model” introduced is therefore a compromise solution in order to be able to think about materials with a strong experimental component. This model is built up and changes as the actions being performed are discussed and is a starting point that will be able to continue evolving as new actions and the use of measuring instruments are experimented with (we may recall, for instance, the function of the scales as an instrument which can help students to think about the conservation of mass).

Third, the consideration of the interaction between the participants mediated by the teacher.

The children’s organization of ideas in the modeling process was reached gradually and in different times by different children. In sustaining this organization, the classroom dynamic was largely based on the teacher’s encouragement of expressing children’s ideas, using a variety of ways of communication and contrasting different representations. It was also maintained by the special attention paid by teachers to recognizing when was prolific to identify cognitive strategies to encourage formalization (Arcà, 1984) and when was possible to use them as cognitive tools.

The teachers’ purpose of maintaining this particular classroom dynamic seemed to be constructed on the basis of a particular set of actions repeated as often as necessary for the development of the model. The main actions we could identify were the following:

- **To remember and use the previous experiences/perceptions.** This action seemed to sustain children’s possibilities to test previous perceptions and reelaborate the ideas in each successive attempt to modeling.
- **To establish comparisons using different ways of communication, searching again and again for generalizations.** This action seemed to sustain children possibilities to readapt ideas communicated by others.
- **To focus attention, first on ideas that represent partial aspects of the model and then on the consolidation of the desired model.** This action seemed to sustain children’s possibilities of learning the value of the models as tools to think about the material world.
To encourage activities of cooperation and pooling of ideas, such as general discussions on activities, exchanges of accounts about manipulations, comparisons between pairs of materials, etc. This action seemed to promote children’s understanding of modeling as a social construction.

To generate questions constantly, shifting attention toward the thing being analyzed. This action seemed to be a teachers’ strategy guiding children to evaluate the value of a specific point of view.

To demand a focus on the growing abstract interpretation. This action seemed to be addressed to practice the abstract value of a set of interconnected ideas represented in the model.

From what was expressed by the students, the teacher was able to identify the key points in which to apply influence in order to ensure that the school model to be developed was consistent with the interpretive model of expert science. This led her on the one hand to pay special attention to identifying the most interesting ideas from amongst all those of the students and, on the other hand, to pose questions that created a relationship between what the students said, how they intervened in the system, and the aspects chosen from the expert consensus model. This interaction gave rise to the proposal of the “parts model,” which was proposed as a “translator” of ways of thinking about the structure of the materials.

This is a style of interaction that, adopting the expression used by Ogborn, Kress, Martins, & McGilligudy (1996), we could describe as “let’s all think together.” The skill for the teacher was not in “explaining” their model, but rather of recognizing which of the ideas arising from the different interactions are powerful enough to transform the students’ knowledge without losing sight of the reference scientific model.

All the participants, both students and teachers, used different forms of communication, which basically served to construct collectively a meaning from the experiences undergone, and not to describe them or to give a name to the phenomena observed (Sutton, 1992). It is from the words, gestures, drawings, and physical constructions that the model was gradually built up and shared among the members of the group-class. The adult interventions were able to stress the explanatory value of the multisemiotics (Lemke, 1990), and the students were able to take up this ability and familiarize themselves with it from outset of the school science activity.

CONCLUSIONS

The reflection presented regarding the three chosen aspects aimed to be of use in considering modeling processes in a school context during the early years of science education. Though they may not be the only aspects, it seems important to us to highlight them so that they can be extended to cover a greater number of different cases and contexts, in which no doubt the results will also be different.

We believe that it is important to encourage the modeling process from the earliest school ages. Although there is no doubt that the initial models built will have to evolve over the years, they could be considered as the starting points for that evolution. Putting this process into practice may enable a different way of approaching what is seen as “learning science,” and at the same time, how science knowledge is generated.

A model like the one generated in the experience analyzed is insufficient to explain and predict every kind of process, such as, for instance, that of the combustion introduced by the interaction of some materials with fire at the end of the study. It is therefore important for the teacher to be aware of the possible difficulties that may arise when using school science models.
Further research is necessary to find out whether students, immersed in such a kind of modeling dynamics, are able to improve and even replace their first “model of parts” during their future school science life. For the moment, we are engaged in conducting other research in which students, by modeling phenomena related with physical changes in materials, continue adapting previous models to construct new phenomenological interpretations in successive school years (Merino & Sanmartí, 2006). Nevertheless, for that to be possible, as the activity analyzed showed, the teacher needs to promote both new experiences/perceptions and new representations and ways of expressing them. This learning how to doubt, to imagine, and to evaluate is what makes it possible for initial alternatives to avoid turning into obstacles. The important thing is for the students to become aware that the knowledge acquired through research is subject to changes (Duschl, 2000).

Our analysis also discussed a pool of ideas that showed to be useful for the students to modeling. However, what our analysis did not tackle specifically was, for instance, the role of the teacher-researcher in supporting children understanding of competing ideas in the construction of the model. This aspect also remains pending in research and could be very useful in understanding why children were picking up on a particular idea and not others.

We have no doubt that one of the main difficulties in practicing modeling dynamics in early years depends on teachers’ abilities of selecting pivotal ideas from the scientific consensus model and establishing matches with the ideas expressed by the students in their representations. Our opinion regarding a possibility to overcome this difficulty is that teachers can be trained for this purpose in two essential ways: on the one hand, we can work on their awareness about the set of pivot-ideas inherent to basic models of school science. In early years of schooling, these models should be a few and general enough to talk and interpret an extensive amount of phenomenologies and, consequently, should be a few ideas defining these models. On the other hand, we have the chance to work on changing teachers’ conceptions about that children ideas are necessarily erroneous and usefulness to understand scientific consensus models.

The view promoted from studies in alternative conceptions has allowed teachers to think that children’s conceptions is something that “should necessarily be deleted of children’s minds” rather than taking them as a starting point to construct their interpretations. Without respecting this premise, we see as impossible that classroom’ interactions turn into dialogical settings (Mortimer & Scott, 2003) that are essential to sustain children learning science.

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