Elementary school students' conceptions of chemical transformation

Rita de Cássia Reis and José Guilherme da Silva Lopes

Faculty of Education, Federal University of Juiz de Fora, Juiz de Fora, Brazil. Study Group on Chemistry Education - GEEDUQ, Department of Chemistry, Federal University of Juiz de Fora, Juiz de Fora, Brazil. E-mails: ritaeduquim@hotmail.com; guilherme.lopes@ufjf.edu.br

Abstract: Currently, many papers bring discussions on how to approach chemistry knowledge in a High School classroom. However, many concepts related to this knowledge are already part of the approach given to the Elementary School teaching of Sciences. This discussion of chemical concepts together with ones from other areas is important, for it introduces the students to some essential ideas so that they can develop their Chemistry knowledge. Among these, we highlight the study of transformation and composition of materials. For this reason, in this paper we investigate how the first contact with Chemical transformations is established during Elementary School by means of debates involving teacher and students in a Science classroom. Even though the students have shown a few difficulties, we emphasize the importance of this contact for their academic formation.

Keywords: Elementary school, chemical transformation, discoursive interactions.

Introduction

Nowadays, in the Chemistry Education area, it has been discussed ways to approach scientific concepts in the classroom. This offers us considerations both from a theoretical and practical point of view. We believe that this happens because scientific language differs from that used in the daily lives of most students, and also because of the need for establishing a more dynamic, modern and engaged way of teaching not only with the theory to be taught, but also with the student's social reality. Most studies on this subject aim at the High School classroom, and present the discussions on the adequate conceptual level for this age. Nonetheless, there are still only few researches dealing with Chemistry approach during Elementary Science teaching.

We must consider that many of the chemistry concepts are inserted in the approach given to the Elementary teaching of Sciences, even if this happens in the 9th Grade – the grade in which, in Brazil, Chemistry and Physics concepts are taught, even though the official documents tell otherwise. This discussion of Chemistry concepts together with other areas concepts is important, because it introduces the students to some fundamental ideas, which are structuring, so that they can develop a chemical knowledge. These ideas are called by Lima and Silva (2007) the key-ideas of Chemistry thinking.

This way, teaching sciences requires an introduction to ideas and practices of the scientific community and work in a way that the students can appropriate these ideas, this means, that they can internalize the scientific discourse (Driver, et al., 1994a). This process can be described as an acculturation of the student in relation to scientific culture and, at this point, Chemistry fits as a relevant area inside this culture.

For Tomasello, becoming a member of a culture means learning a few new things from other people. This would happen through emulation, instruction and collaboration. These kinds of learning only occur, according to the author, because the human being can understand con-specifics as beings like themselves who have intentional and mental lives like their own (Tomasello, 1999). That is, in the classroom, the process of learning a new culture, the scientific culture in this case, only occurs when the student identifies with the teacher, other classmates and the scientific discourse being shown. This way, for learning about the chemical symbols used, the student must understand why and for what purposes the teacher uses those symbols, what is the intention involved in that symbolic practice and what to do with that knowledge.

For Tomasello,

> Linguistic symbols are especially important symbolic artifacts for developing children because they embody the ways that previous generations of human beings in a social group have found it useful to categorize and construe the world for purposes of interpersonal communication (Tomasello, 1999, p. 11).

In a scientific point of view, this gives the child the ability of understanding the language used by the scientific community and, as the child masters these symbols, "she thereby acquires the ability to adopt multiple perspectives simultaneously on one and the same perceptual situation" (Tomasello, 1999, p.11). This mastery allows children to participate in complex discussions, which make her internalize the adult instructions and so begin to self-regulate and reflect on their own thinking.

So, teaching Chemistry in Elementary Science teaching is not anticipate the contents that will be taught in High School, or promote the memorization of names and formulas, or teaching how to classify substances and reactions as if it was enough for stating that one has studied chemistry. On the other hand, "(...) must be prepared to lead students to the desired conclusions with appropriate questions" as said by Steiner (1989) when stated the teach chemistry in elementary school. Chemistry during Elementary School should be treated as an area that dialogues with others, so as to give the student the opportunity to relate theory to daily life facts, and even creating models to explain it. In according with Justi (2006, p. 178):

> [...] as the students being involved in activities planned under this perspective also develop a mind set that includes at least the main elements of the model, can be used in other situations, related or not with the sciences; in addition to learning about the model, that is, to learn the curriculum model that the teacher intends to teach from their own ideas.

More specifically, taking in account the elementary school challenges, Lima and Silva (2007, p.97) stated:

> Teaching Chemistry in Elementary School assumes a wide and interdisciplinary dialogue with Biology and Physics. This, on the other hand, does not imply losing its specificity. It is necessary to reduce the number of Chemistry concepts and contents that are usually introduced in Elementary School to invest in the comprehension of key-ideas and develop the grounds of Chemistry thinking, whether for further studies, or for interpreting the chemical processes that are part of contemporary living.

The understanding of interdisciplinarity as "(...) a process of answering a question, solving a problem or addressing a topic that is too broad to be dealt with by a single discipline" (Andersson et al., 2010) is a current idea and a very important way of introducing Chemistry during Elementary School. In this direction, to use the chemical knowledge applying it to biological processes such as animal digestion, breathing, the photosynthesis process and the biochemical cycles (carbon, oxygen, sulfur and water cycles), is a useful strategy. In fact, in according with Tekkaya and Yenilmez (2006, p. 5-6):

> [...] understanding concepts of photosynthesis and respiration in plants require the ability to relate meaningfully to different concepts in biology, chemistry, and physics; however, studies showed that these topics are often learned by rote. Students often tend to learn photosynthesis and respiration in plants as separate, isolated topics and may not formulate conceptions of how the topics are related. In addition, photosynthesis and respiration in plants, though taught repeatedly at all levels of education, were perceived by teachers and students to be problematic concepts (Finley, Stewart, and Yarroch, 1982; Johnstone and Mahmoud, 1980) and were identified as being on an abstract level in science curricula, requiring formal reasoning (Lawson and Renner, 1975).

Beyond the international research, in Brazil, Froner et al. (2006), showed in a research made with Science teachers, they pointed out that it is important to acquire and to use chemical language before Elementary School 9th grade and, for doing so, they highlight the study of photosynthesis and breathing. For these teachers, the explanations on the microscopic level continue in the last year of Elementary School, but the comprehension of some concepts such as that of substance can already be taught since 6th grade.

Theoretical foundation

When we think of teaching Chemistry, the concept of transformation appears naturally in the curriculum and lesson plans, for it is not possible to study chemical processes without addressing the transformations that matter undergoes. The study of chemical transformations is crucial for the upbringing of a witty individual, once it allows studying the processes that occur in everyday life, such as the metabolism, the effects of medication and food cooking, for instance. These themes, when addressed, bring with them the students' ideas of common sense. However, when we think of industrial processes, their economical, social and environmental impacts, the study of this concept is important to form a more conscious opinion.

Throughout elementary school, there are many themes that allow introducing important concepts for the understanding of chemical transformation. Studying contents such as breathing, photosynthesis, digestion and others, which take into consideration chemical knowledge, helps understanding diverse phenomena. Thus, it allows the student to build, since the beginning, an explanatory model for the matter transformations based on a corpuscular model. For Lima and Silva (2007, p. 96), the study of "transformations that are part of our everyday life [...] is a key element of learning chemistry on elementary school".

From the point of view of the official Brazilian directions for teaching, the curricular proposal of the state of Minas Gerais for the elementary teaching of Sciences – Common Basic Content (Casteli, et al. 2005) points that the study of chemical reactions (transformations) involves the usage of explanatory mechanisms of the rearrangement of atoms. This implies that teaching scientific models and concepts must include, thus, a plan that permits the student to progress from the most external aspects of phenomena to the abstracts mechanisms. The document states that:

> For learning the concept of chemical reaction, we start with the recognition, from the students, of evidences of transformation in materials, which involve the recognition of similarities between phenomena that have different perceptive aspects (such as the oxidation of a nail, the combustion of a candle, the ripening of fruit or the reaction of neutralizing vinegar with baking soda). However, when learning the scientific concept of chemical reaction, the students find obstacles. Therefore, teaching sciences involves discussing and examining mistakes: many times the students think that matter simply turned into another thing, without mass conservation; or that, in combustion reaction, that the matter of the fuel became energy. On the other hand, the scientific concept of chemical reaction goes beyond what can be seen, using the atomic-molecular model: the atoms that make up matter reorganize themselves during chemical reaction, originating new materials, with mass conservation. Mass conservation is observed once we have an isolated system, what not always occurs (Casteli, et al., 2005, p.17).

We researched how the concept of chemical transformation appears as a facilitator in the discussion of themes seen during elementary school in the textbooks used in this level, getting to the conclusion that the concept of chemical transformation appears very little as a facilitator and with structuring effect of the approach of the analyzed themes (photosynthesis, breathing, soil and chemical reactions). Unless, regarding chemical reactions, which is related to the occurrence of a chemical transformation, according to the authors of the collections analyzed. The study shows that the usage of the word transformation to refer to the phenomenon happening does not allow the student to understand the real phenomenon itself. Besides, it indicates that, in the books, non-scientific language is used for explaining many different contents, and it can emphasize in the students alternative ideas concerning the phenomenon of chemical transformations.

One of the studies that goes in this direction is Andersson's (1990), which configures one of the categories of ideas of students about what happens in a chemical reaction. The author pinpoints the following five categories bellow:

A- Disappearing: for the students who think like that, during the chemical reaction, some substances disappear.

B- Displacement: for the students who think like that, during the chemical reaction, there is the displacement of a substance from one place to the other and, thus, there is the alteration of matter. In other words, there is a physical displacement.

C- Modification: for the students who think that, during the chemical reaction, the reactant changes physically or to a different shape, which generates the products.

D- Transmutation: it occurs when the students have ideas about forbidden transformations. As an example, the author mentions that a given substance is changed into energy, the energy is changed into the substance and the substance is changed into a new substance.

E- Chemical Interaction: students that think this way can comprehend the process of chemical transformation as being dynamic and involving the corpuscular notion of matter.

Students that think from the chemical interaction point of view make up 15% of the studies analyzed e that many students go from the transformations that occur at the macroscopic level to the microscopic level (Andersson, 1990).

> In general, pupils find difficulty in developing an adequate conception of the chemical combination of elements until they can interpret "combination" at the molecular level. Furthermore, the science idea of a chemical compound depends upon an understanding of chemical combination (Driver et al., 1994b, p.86).

Nussbaum (1999) affirms that the school hopes the students abandon the perceptively concrete model to embrace the abstract one, developed by the scientist for interpreting the results of their investigations about physical and chemical properties of matter. Effectively, the representation of particles contradicts, sometimes, the own sensitive perception of matter. In a study made with 150 students, the author highlights that the most difficult aspects of the theory of particles to be assimilated by the students are the ones that are different from their previous conceptions of the nature of matter. He mentions the aspects: empty space (the concept of emptiness), intrinsic movement (particles kinetics) and the interaction between particles (chemical transformation).

For Driver, Guesne and Tiberghien (1999, p. 27), the concepts that seem obvious and that must be known for the progress of the classes may not be understood by the student. Not understanding these fundamental ideas, in this case, can take to serious learning problems further on. Thus, the understanding of a chemical transformation can seem simple for the teacher when he discusses that in the classroom. After all, if we consider only the representation of the chemical transformation – in other words, the chemical reaction – it is similar to the mathematical equation. In algebra, x + y = z; but, in chemistry, x + y can be z if certain conditions are fulfilled. If not, the result can be other.

Behind a simple chemical transformation, there is the concept of matter, explanatory models, the notion of mass conservation, atomic rearrangement, the energy conservation during the process etc. From the biological point of view, which are the implications of these variants for the organism (consuming and/or providing energy, or the formation of free radicals, for example)? From the industrial point of view, which are the implications of these variants (the reaction has high productivity)? From the environmental point of view, which are the implications of these variants (is there the usage of toxic materials, are the residues treated)?

Keeping these questions in mind, we believe that the concept of transformation is crucial for forming the students' opinion because, this way, they could have a more inclusive view of sciences during elementary school. Even if this is a key concept for the study of sciences, we can see in what has been said by many of the authors here mentioned that there are many learning problems around this concept, which go from the students' alternative ideas to the lack of discussion found in textbooks. Therefore, the teachers play an important role in the classroom, and they must be aware of the needs of their students so as to try to overcome possible misconceptions they might have, as well as to try to articulate the contents seen in the classroom, pursuing an integrated vision of teaching.

We can extend these reflection and try to understand the different discoursive interactions that happen during the teaching and learning process of scientific concepts that involve chemical knowledge, as well as to understand the different signs used in the explanations given by the teachers and by the students, in order to analyze the sense it has for them, observe the verbal interactions, what are the teacher's intentions. This way, we can try to elucidate the appreciative value it gives to some words rather than to others, and to reflect on how this influences the conception of a particular disciplinary content that the student will form.

In the Science classroom, the language used for communication is the scientific language, which is different for presenting specific terminologies of the area, and which does not appear, normally, on everyday language. For the student that is in a classroom like this, many times, the language is shown as something ready-made through closed speeches elaborated by the teacher of by textbooks.

Voloshinov (1973) call our attention to the fact that the language is not acquired as something ready-made, but is built in the interaction of the subject through verbal interaction that one acquires conscience of the meanings, and begins to use the language to express oneself. It is important to perceive that there are different verbal communication situations, each one coming from one different community: artistic, scientific and philosophical, for example. They show different characteristics according to the way their members communicate and to the society they are part of. Thus, there is no way of trying to understand these communities' specific language out of the situations in which they happen. That is, in order to master the scientific language used in the classroom, the student must get involved in the learning process, as well as with the way of thinking and expressing used by the scientific community.

This need of getting involved with the scientific culture to understand its language is important because it presents, in its structures, signs and signals that characterize and present specific meanings for that particular culture. But how is the scientific concept shown in Science classes related to the spontaneous concept that the student already presents? How is knowledge build in the classroom?

A concept, when it is conveyed by means of a word, represents a generalization, but the meanings of words evolve. When a child learns a new word that has a certain meaning, the development of the concept is only starting. As new words are added and learned, the generalizations that were elemental before start to tend to the formation of true concepts by the child. Thus, the negotiation of meanings between teacher and students and the way the teacher takes control of the students' knowledge in his explanation system are fundamental aspects to understand the dynamic of knowledge building in the classroom (Mortimer and Scott, 2003).

Vygotsky, quoting researches by Usnadze, presents one of the findings the author makes on the usage of words by children. According to Usnadze, words work as concepts and can be a communication medium right before reaching the level of concept characteristic of the fully developed thought (Vygotsky, 1986, p. 69).

For Vygotsky, children learn two kinds of concepts: the spontaneous and the scientific, both which are necessary for knowledge building. According to the author, the development of scientific concepts during school age is, above all, a practical matter of great importance considering the point of view that the school tasks have before them (Vygotsky, 1986). That is, the scientific and spontaneous concepts correspond to different processes.

The spontaneous concepts are related to the everyday relationships, and are elaborated by the language use, while the scientific concepts are those conveyed by school relationships, through the explicit mediation of other subject, in that case, the teacher. So, in the spontaneous concepts, words are related to its corresponding objects. As for the scientific concepts, the connections established are of words to other words. In this sense, Mortimer and Scott (2003) says that the difficulty in learning school science would be the difference between everyday and school science social languages.

As we analyze the dialogical interactions (discoursive interactions established during a dialogue), we perceive in the discourse of the agents of speech the evolution of the use of words with more elaborated ideological meanings. A school community, and especially the classroom collectivity, is, all the time, interacting for the comprehension and structuring proper of the signs, inside each school subject. For Voloshinov (1973, p. 95),

> [...] the word is always loaded with content or an ideological or experiential meaning. This way, we understand the words and we only react to those that awaken in us ideological resonances, or concerning live.

> The meaning of a word represents such a very narrow amalgam of thinking and language that it gets difficult to say whether it refers to a phenomenon of speech or to a phenomenon of thought. A meaningless word is an empty sound; the meaning, thus, is a criterion of the "word", its indispensable component (Vygotsky, 1986, p. 104).

Therefore, in a Science classroom, the simple usage of a word does not imply that the student has understood it in its meaning extent. We notice that when the student uses a word to convey a concept, but does not know how to apply it to other contexts, feeling uneasy for doing so. Thus, we think it is necessary to understand how it is established the inclusion of Chemistry knowledge during Elementary school and, mainly, the key-ideas development, among which we highlight the study of the transformation and composition of materials.

In this paper, we investigate the first contact of elementary students with the chemical transformation, observing how they understand and deal with the chemical transformation representation through the chemical equation.

Context and methodology

As a starting point, we have considered that, in the Science classroom, each word said by the teacher generates in the students, during the comprehension process, a series of other words that are theirs, forming a reply, and the more these words are numerous and consistent, the more real the comprehension process. We noticed, then, the need of observing how the interactions are established in the classroom, for they could show us the level of comprehension and understanding of the students about the representation of chemical equations. In order to do this, we have chosen a research theme which is part of the Science curriculum, and which allows a direct application of the chemical concepts.

Thus, we analyzed a sequence of classes about the theme Biogeochemical Cycles. For the discussion in this paper, we have selected the class that presented the Carbon Cycle and the process of photosynthesis, which is part of this cycle, with emphasis on the chemical equation of photosynthesis.

The observations took place in a 6th grade classroom, which means the students were 11 or 12 years old, in a public school in the city of Juiz de Fora, in the state of Minas Gerais, Brazil. The students in this group had different social backgrounds, considering we had, in this group, the child of a professor of a public superior education institution, the child of a private kindergarten owner, of a salesperson and of a maid, for example. Most of these students had studied at this institution in the previous years.

During this period, we have made audio and video records of the classes, as well as field notes. In order to do it, we received an authorization of all people involved in the process of research (schools, teachers, students and legal guardians). These classes were transcribed and subdivided into episodes characterized by the discussion of a specific subject with a clear beginning and a clear ending, from the building of meanings of the entities that participated on the discourse (Mortimer and Scott, 2003). They present turns of speech representing the utterances by the teacher and the student.

In those turns, the symbol (/) means a pause in the speech, (...) a longer pause, (*) indicates that the turn is going to be retaken during the discussion of the episode. The commentary between double brackets (( )) were made by us, so as to elucidate the context in which the speech happened, and the utterances in capital letters indicate a emphasis in tone in the teacher's speech. All the names shown in the transcriptions and discussions are fictional.

Results and Discussion

The classes that happened before a discussion on the chemical equation dealt with matters such as the chemistry of carbon, how this element presents itself in the environment in a cyclical form, focusing on its participation on the process of photosynthesis. The teacher presented a figure that represented the process and explained the phenomena that happen during it. To explain the photosynthesis from a chemical point of view, the teacher asked the students to pay attention closely, because something new was about to be presented – the chemical equation – which she called "a very simplified form" for the representation of the photosynthesis process:

$$CO_2 + H_2O + \text{MINERALS} \xrightarrow[\text{Light}]{} \underset{\substack{\text{Glucose}\\ \text{(sugar)}}}{C_6H_{12}O_6} + O_2$$

Figure 1: Equation written by the teacher on the board representing photosynthesis.

As she presented the chemical equation on the board (figure 1), some students could follow her reasoning, by this is not done by most of them, because that is the first time they study a concept through this kind of representation. Hereafter, we present a sequence of three episodes that express this matter:

Conservation of matter and rearrangement of atoms

In the following episode, the teacher proceeds in her attempt of explaining the chemical equation that represents the process of photosynthesis. Thus, she ends up giving sense to that representation when she shows the conservation and rearrangement of atoms to make the products. In the following transcription, we shall see how the students participate, showing to be willing to decode the new symbology.

Episode 1: Attempt of showing the conservation of matter and rearrangement of atoms

1-Teacher: Continuing from this point here/ so guys/ shhh[1]... Continuing from here / so/ so oh/ Laís/ oh... the glucose/ the organic matter produced by the plant that results from that photosynthesis process is going to become leaves and fruit for the herbivorous animals/ right?/ And then the carbon/ the atoms of carbon of the plant will pass to the herbivorous.

2- Carla: They will what?

3- Teacher: The carbon/ because you see/ the carbon dioxide it has two chemical elements/ CARBON and oxygen/ that's right! These two substances together compose what we call carbon dioxide/ can you see that when the plant produces glucose/ look who's here ((pointing at the glucose formula written on the board)) Where did this carbon here come/ ((many students answer that it came from the plants)) where is this carbon in the glucose from?
4-Bianca: From the plants?
5-Teacher: The plants produced... ((some students interrupt trying to guess a correct answer, such as: the air, the animals, the light))
6-*Teacher: Look/ Did this come from the light?/ Where is there carbon here ((pointing to the equation))/ The plants use carbon dioxide/ water and minerals to produce? ((pointing at the glucose))
7-Tabata: From the water?
8-Teacher: Where is there carbon?
9-Diego**:** In the air.
10-Teacher: Where is there carbon here? ((Students try to answer))
11-Teacher: Look at this guys/ In the CO_2. ((Students make comment among themselves))
12-Teacher: Where does this hydrogen here in the sugar glucose come from...
13-*Bianca: From the water?
14-Teacher: From the water!
15-*Bianca: And the photosynthesis of O_2?
16-*Amanda: And the minerals glucose/ right teacher?
17-*Teacher: And this glucose oxygen ((pointing at the formula))/ comes from the carbon dioxide!
18-Teacher: And then/ the plant besides the glucose releases other thing during the photosynthesis...
19-Amanda: Oxygen.
20-Teacher: Exactly/ it produces glucose/ I will even make it a little harder here/ but the O_2 that is the oxygen ((writing on the board))
21-Paulo: Teacher/ I'm not understanding that!
22-Teacher: This here is the photosynthesis ((pointing at the equation on the board))/ the plant uses the carbon dioxide/isn't it?/ The water it absorbs through its roots/ and the minerals in the presence of light to produce its own food.
23-*****Paulo: But that thing there/ C/ H...
24-Teacher: Ow/ alright/ No/ Don't get scared with the formulae, alright?/ This is just for you to get used to it/ you don't have to learn by heart/ This is the chemical formula of sugar ((pointing at glucose)) which is produced by the plants during photosynthesis and here we have the formula of oxygen that is O_2/ just like H_2O is the chemical formula of...
25-*****Paulo: The water.
26-Teacher: Water/ Alright?
27-*****Bianca: So this is the photosynthesis of the plants?
28-Teacher: This is the photosynthesis of the plants/ in a simplified way.
29-*****Laís: Teacher/ are these numbers there the quantity?

30-Teacher: These numbers are the amount of oxygen atoms/ carbon atoms/okay.

As we go on in the dialogue, we perceive that the central theme of the utterances goes beyond the concept of conservation of matter and, thus, the foundations of the discussion about rearrangement of atoms are brought in, as seen on turns from 6 to 17. For us, these concepts are important for the comprehension of Chemistry in Elementary School, because they reaffirm the construction of a model of subject that explains the chemical transformation that the students learn in this level.

By means of a simple approach of the matter of conservation is seen, using the comparison of elements found in the reagents and the products, in such a way the teacher questions them about where the carbon, the hydrogen and the oxygen that form the glucose come from. At first, the students could not perceive that the answer was in the equation itself, and they made attempts by saying that the elements came from the air, from dead animals and from the light. However, when the teacher shows how they should reason, Bianca, for example, showed that she had understood it as she gave a correct answer, on turn 13. At this moment, she is emulating the teacher's way of thinking. According to Tomasello (1999), learning through emulation, as a form of cultural learning, is very important, for it represents the initial entrance of the child in the cultural world that surround her, in that now she can understand the adults. Likewise, for Vygotsky, the emulation is important for learning in the zone of proximal development, because it introduces the child to the way of thinking used by the adults, and to culture.

However, that what Bianca did does not mean she fully learned the subject shown. When she asked, on turn 15, if photosynthesis came from the oxygen, the student ended up treating it as if it were a substance, a compound. That, on the other hand, was not considered by the teacher in that she did not investigate the idea of photosynthesis presented by Bianca, and she only went back to the matter on turn 27, when Bianca asked her if that all the teacher was presenting on the board is the photosynthesis.

We can see, then, that there are other students that express their difficulty, like Amanda, who, on turn 16, asked if glucose comes from the minerals. Probably, she could not perceive during the teacher's previous explanation what was the origin of the atoms that formed the glucose molecule using the reaction between carbon dioxide and water in the presence of light. As the teacher added the minerals, which had not been mentioned up to that moment, to the reagents (figure 1), she considered glucose as something apart from all that discussion, which makes us think that in that moment the student could not make the correlation expected by the teacher. Also, we could not understand why the teacher presented the minerals in the photosynthesis equation. A hypothesis is that she considers the photosynthesis process as a way through which a plant obtains its nutrients (food), and, as the minerals are seen as necessary nutrients for the development of plants, they would fit into this representation.

It is important to notice that with a simple utterance we could make considerations about how complex it is for a student in this level of learning to understand the key ideas for the full understanding of a chemical transformation and, thus, of Chemistry itself. These discussions are usually shown only to 9th grade students, also causing such surprise and incomprehension. That is why we defend, as other scholars also do (Tekkaya and Yenilmez, 2006; Lima and Silva, 2007) that the teaching of Chemistry should be present throughout all Elementary school years, and not only the last one so that events like this one above can happen and allow the student to develop a scientific concept in timely fashion and through the application of other contexts.

There are students that can incorporate this new language very quickly to their own discourse, while other only do so intending to build a new answer to teacher's questions. Also, there are other students that have difficulties and have to relate the new language to usual language. Paulo is an example of student that does not get familiar immediately with the language. He asked, on turn 23, what were the "C" and "H" in the equation. That is noticed when he used the phrase "that thing there". The "there" indicates that he has not understood that "C" corresponds to the chemical symbol of carbon, and that "H" corresponds to the chemical symbol of hydrogen. Discussions on that had already been made in the classroom, reinforcing the idea defended by us in the paragraph before. Nonetheless, as an example that Chemistry, as well as the chemical knowledge, is part of the everyday life of these students, being thus natural that they use this knowledge without even understanding it in a scientific point of view, Paulo, when asked about what would be the chemical formula H_2O, answered correctly on turn 25: water.

To give a closure to this episode, we could see that Lais, on turn 29, mentioned the numbers shown in the molecular formulae, which indicate the amount of atoms of each chemical element in the molecule. We can notice that this question brought up by the student is confirmed by the teacher, indicating, that the student at this age uses the terms of Chemistry quite naturally, and are interested in its matters.

Exploring the chemical equation

In the next episode, the discussion is about the comprehension of the chemical equation. Thus, the students show to the teacher that they still have not fully understood the meaning of that new way of representing photosynthesis.

Episode 2: Understanding the chemical equation.

31-Teacher: So look at this/ now the text ((she begins to read the text about the carbon cycle)) "Carbon is the fundamental chemical element of life"/ why?/ "It is part of the composition of the living organisms".
32-Carla: Teacher/ is everything you explained in the text?
33-Teacher**:** Yes, it is/ let's read that with me to make sure it is all clear/ alright/ This is the carbon cycle...
34-Amanda ((interrupting)): Wait a minute/ let me ask you something teacher! Is the glucose in the sugar O_6 plus O_2?
35-Teacher: Yes.../ no/ Sugar is $C_6H_{12}O_6$.
36-Amanda**:** What?
37-Teacher: $C_6H_{12}O_6$.
38-Amanda: So $C_6H_{12}O_6$ is... /is/ glucose.

39-Teacher ((interrupting)): it is the symbol/ it is the chemical formula.
40-Amanda**:** Okay/ and O_2/ why is it there ((referring to the equation on the board))
41-Teacher: O O_2 é o oxigênio.
42-Amanda: But why is it in the glucose formula?
43-Teacher: No!/ It isn't /shhh / guys/ Here we have two substances /this is glucose PLUS/ and this here is the O_2 ((referring to the equation))/ Glucose plus oxygen/ These are different things.
44-*Amanda: Oh okay/ CO_2 plus H_2O and the minerals equals $C_6H_{12}O_6$ and produces ((waiting for the teacher))/ and it also produces $C_6H_{12}O_6$ / and does it also produce oxygen?/ O_2?
45-*Bianca: Hey, teacher/ so it's CO_2 plus H_2O plus minerals that produces/ that produces $C_6H_{12}O_6$ plus O_2/ plus O_2 which is also.../ which is also glucose?/ ((At this moment, the teacher calls the attention of other student beside her because he was chatting and Bianca asks for attention)) Huh teacher!
46-Teacher: Yes/ take a look...
47-*Bianca: No/ The C/ these things CO_2 plus that/ that what makes $C_6H_{12}O_6$ plus O_2 is this it that becomes glucose/ how so?
48-Teacher: This here ((pointing at the equation on the board)) is glucose.
49-Paulo: Hey teacher/ hey teacher!
50-*Bianca: Oh/ so/ oh/ so we can say that this result is transformed into glucose.
51-Teacher: It is glucose/ the formula.
52-Carla: Hey teacher is glucose all this?
53-*Teacher: Chemistry.../ Chemistry is the science that studies the.../the.../ the substances that exist in nature/ And the substances/ the Chemistry gives the formulae/ gives the symbols/ formulae to the substances/ So that is the formula of glucose. ((While the teacher explains, Diego tells Amanda that glucose is $C_6H_{12}O_6$))
54-Paulo ((insisting)): Hey teacher/ does sugar come from that? (pointing at the equation on the board.)
55-Teacher: This thing here ((putting the finger on the formula on the board)) is the formula of sugar, okay.

In this episode, we perceive the difficulty of the students of understanding the equation corresponding to the photosynthesis process, written on the board by the teacher, as seen on figure 1. At the beginning of the episode, Amanda, turn 34, believed that glucose is represented by O_6 plus O_2, reaffirming that what we had said on the analysis of the first episode: that, for her, glucose was something fragmented. C_6 would be a substance that came from CO_2, and H_{12} would be another substance that came from H_2O. O_6 would be a remainder that would represent the glucose from the minerals, as she had affirmed. Nevertheless, when we observed the evolution of her speech in the turns 34, 36, 38, 40, 42 and 44, we noticed the reformulation of ideas, and she was able to elaborate a coherent explanation for the chemical equation of the process of photosynthesis.

Bianca, on her turn, needed the attention of the teacher, and also to verify if her discourse is also correct. We perceived, because of her utterances during turns 45, 47, 50, that she still could not understand that, in the equation written by the teacher on the board, glucose and oxygen are different things. We noticed that, in the turn 50, the student uses two terms (result and transformed) which allow us to consider that, for her, that representation is similar to a mathematical equation that has a result, as stated by Driver, Guesne and Tiberghien (1999, p. 27). But it also indicates that she believes that the compounds there represented will undergo a transformation.

That representation of the scientific discourse does not make sense for her, because it asks for a high degree of abstraction. If asked what gas is liberated during the process of photosynthesis, she would say oxygen, as she already had done in other episodes. This demonstrates that the evolution from common knowledge to scientific knowledge is not immediate, nor happens the same way for all the students. Other issue that contributes to the difficulties the students have in understanding the equation is that they do not have a concrete view on the concept of substance. Nevertheless, we already expected this, and we believe that this concept should be seen during Elementary school gradually.

In turn 54, when Paulo asked if sugar comes from the photosynthesis process, we see the opportunity for the teacher to explain that the sugar used by us to sweeten food and drinks comes from the sugarcane, and that it results from the process of photosynthesis made by that plant.

This episode appeared at the end of the class as a complement to the episode before it, which dealt with conservation of matter. We believe that it consists in one of the moments for the conceptualization of a model for transformation of matter which can be developed throughout elementary school years. In turn 53, the teacher presented a definition of chemistry as a science that studies the substances that exist in nature, giving them formulae and names. This definition fits what the teacher believes she has used of Chemistry (only its representations), but leaves aside the main application seen during the class, which is the study of the transformations of matter. Besides that, it does not contemplate Chemistry as a cultural construction (Driver, et al., 1994a), thus, as something that creates and articulates models for explaining the phenomena that occur in the society in which it is inserted.

Photosynthesis comprises a chemical reaction

This episode concludes the teaching sequence that the teacher had planned and, then again, brings back the chemical equation, aiming at ending what had been said before. Next, the teacher, as she repeated her explanation on photosynthesis using the chemical representation, made it clear that during the photosynthesis process a chemical reaction happens.

<u>Episode 3: During photosynthesis, it happens a chemical reaction.</u>

56-Teacher: Pay attention, guys/ hold on/ Carla ((asking for the students Carla to speak))

57-Carla: That there is the light / plus H_2O/ plus CO_2 / which equals the food and energy plus O_2?

58-Teacher: This thing here/ that thing there/ is a simplification ((talking about the chemical equation written on the board, represented in equation 1))
59-Carla: No/ I know/ but it is the last one I don't understand / is it the food plus the oxygen that equals to energy?
60-Teacher: Pay attention! ((Diego and Amanda try to answer, but the teacher interferes))
61-*Teacher: Amanda please ((Asking for silence))/ What happens/ Carla/ the plants use carbon dioxide/ the water and the sunlight to produce their own food/ their own.../ What is the food?/ It is the substances that have energy/ right?/ So/ it will produce these sugars/ these substances that have energy that will be food for the plant/ that will be an energy source for the plan/ alright?/ But during the photosynthesis process the plant liberates oxygen it happens a chemical reaction/ It liberates oxygen/ alright!

In this episode, we can see that the student Carla, while posing her question to the teacher, made use of the chemical language when she used the molecular formula to refer to the compounds, making it clear that, somehow, she can read the equation. As well as she did, other students in the later episodes also read the chemical equation emulating the teacher's initial speech. It is interesting that they always do so willing to obtain the teacher's validation about their definition of photosynthesis. What is even more important is that the teacher did not affirm whether if the utterance is correct or not, directly and objectively. On the other hand, she made a new reflection on the equation. We believe that she assumed this position for she could see in her students the intention of obtaining a ready-made answer for the exam they would have on the following class.

However, in this dialogical movement set around reading the chemical equation, the students, through the emulation of the teacher's speech, intentionally end up getting used to the chemical symbols and the names of the substances involved in the process and, right after that they master this discourse as being theirs. This corresponds to a starting point for the study of Chemistry in Elementary school.

Generally, the problem created by this episode, and which constitutes its motivation, is the association established by the teacher between the food and the energy. On turn 61, when she affirmed that the food consists of substances that have energy, she did not make it clear whether if the food has energy stored in chemical bonds, or if this energy is the result of the energetic balance from metabolism of these substances considered food to the plants. It is important to highlight that the chemical energy is not present (stored) in the chemical bonds of compounds formed during the process of photosynthesis, but it results from the energetic balance that occurs after the metabolism of these compounds, which comes from the process of bond breaking and the making of new bonds. It is important to highlight that such question has been addressed in other studies (Ariza and Parga, 2011; Bañas, Ruiz and Mellado, 2011; Khadhraoui, Dumon and Trabelsi, 2013).

In the same direction, Oliveira and Santos (1998, p. 20) says that,

> [...] during the reaction of combustion, among the many factors that contribute to the production of energy, the most significant ones are those referring to the breaking and the making of intra and intermolecular chemical bonds: the process of bond breaking of the combustible substance(s) and the oxidizing is endothermic, while the process of making new bonds in the products is exothermic.

Finally, the teacher advanced on the same turn 61, when she affirmed that the photosynthesis process corresponds to a chemical reaction. By means of this approach, the teacher ended up using the phenomenon to introduce to the students the notion of chemical reaction, emphasizing the symbolic language.

Conclusion

We can reflect that chemical knowledge has gained evidence during the discourse, for the teacher chose to discuss the chemical representation of the photosynthesis process using a chemical equation. With the introduction of the equation, the teacher, facing the questions raised by the students, ended up discussing the ideas of conservation of matter and rearrangement of atoms that occur in the equation. We have seen that some students showed difficulties in accepting this new scientific language, as Paulo, who asked about what those chemical symbols meant, and the student Amanda, who had difficulties to understand which formula corresponded to glucose, among other difficulties caused by the fact that the teacher had stated that the food equals to energy.

We understand that these doubts are pertinent, since that is the first time these students see this way of representing a phenomenon. Even with the difficulties, the chemical approach is justifiable, because it allows the students to get used to the language and symbology of chemical knowledge. Andersoon, (1990) pointed how the students understand the concept of chemical transformation which presents diverse notions to explain what happens with matter during the transformation, for example. He mentions that some students associate the chemical transformation to the changing of state of matter.

> It appears difficult for pupils to appreciate that, in a physical or chemical change involving two or more materials, there is a mutual interaction. Pupils tend to focus their attention on one of the participating materials and then regard that one material as the cause of an observed change (Driver, et al., 1994b, p. 88).

We believe that incentivizing the study of chemical equations, together with the phenomena they represent, is more effective and likely to lead to knowledge building by the student than studying them as an isolated discipline in the last year of elementary school. Thus, even thought the use of chemical representations allows the beginning of the building of a explanatory model for what happens during a chemical transformation, and that a few times the teacher followed this direction, we cannot affirm how much that happened – specially for the fact that maybe this was not her intention when using that approach.

As for the adoption of the study of the chemical reaction in 6th grade, Lima and Silva (2007, p.103-104) state that, since the 2nd grade of elementary school, photosynthesis and its nourishment functions are studied, and these are related to the idea of a chemical reaction. Thus, it is necessary that the students get in touch with this approach so that they can understand it and know how to associate processes such as breathing and fermentation to other processes that produce energy from food.

We believe, as the aforementioned authors do, that approaching chemical concepts in elementary school does not mean anticipating some concepts studied in High School, treating them superficially. But it also concerns discussing a few necessary concepts so that the students understand the chemical processes that are part of the phenomena studied. These concepts do not need (and certainly should not) extinguish all its potential, for they demand, in many cases, a high level of comprehension and abstraction. However, they should be articulated in such a way that, as the students advance from one grade to the next one, they are retaken and expanded so that the generalization, that was wide before, narrows down to the concept accepted by the academic community.

Implications

We discussed in our investigation that, at first, the relationship of students to the chemical knowledge taught is made by the emulation of the teacher's speech. This attitude derives from the will (and need) of entering the linguistic game established in the classroom. In this process, unconsciously, they students get used to the chemical terminologies and symbols as ways of representing a phenomenon, and end up incorporating that to their own discourse. As this knowledge is seen again in other moments, during elementary school, this will allow the student to build a view of what is matter and how it is formed. This model will be important for the study of chemistry in more advanced grades, and may avoid possible difficulties on the learning and the contact with the subject. Thus, we highlight the important role played by the teacher as the mediator of these new knowledge and new culture.

So, we can perceive that the insertion of chemical knowledge during elementary school, at first, passes through the intention of the teacher in providing her students an integrative view of the scientific knowledge shown in the classroom. This attitude demands a lot from the teacher, because they do not have a solid formation on the three big areas of science (Chemistry, Physics and Biology) most of the time. In Brazil, mainly, this teacher has a degree in Biology, and lacks knowledge on the other two areas. Therefore, putting into practice the integrative approach demands from the teacher research on the topic to be debated, looking for different sources and resources for their class. Finally, an integrative teaching of sciences does not involve only the discussion of teaching methodologies and didactical approaches to be brought into the classroom, but it also passes, or should pass, through a discussion that involves also the academic formation of the science teacher.

References

Andersson, B. (1990). Pupils' conceptions of matter and its transformations (age 12 – 16). *Studies in Science Education,* 18, 53-85.

Andersson, S.; Nyberg, S.B.; Dumbrajs, M., Dumbrajs, S., Martelin, V. and, T. Westerlund (2010). Interdisciplinary education in comprehensive school: Can a deep understanding occur? *US-China Education Review*, 7, 9, 34-46.

Ariza, G.L. and D.L. Parga (2011). Conocimiento didáctico del contenido curricular para la enseñanza de la combustión. *Educación Química*, 22, 1, 45-50.

Bañas. C.; Ruiz, C. and V. Mellado (2011). Un programa de investigación-acción con profesorado de secundaria sobre la enseñanza-aprendizaje de la energía. *Educación Química*, 22, 4, 332-339.

Casteli, A.P.; Martins, C.M.C.; Paula, H.F.; Santos, M.B.L.; Lima, M.E.C.C.; Silva, N.S.; Aguiar Jr. O.; Castro, R.S. and S.A.M. Braga (2005). *Proposta curricular, Conteúdo Básico Comum de Ciências, Ensino Fundamental*. Belo Horizonte: Secretaria de Estado da Educação/ Minas Gerais–Brasil.

Driver, R.; Asoko, H.; Leach, J.; Mortimer, E. and P. Scott (1994a). Constructing scientific knowledge in the classroom. *Educational Researcher*, 23, 5-12.

Driver, R.; Squires, A.; Rushworth, P. and V. Wood-Robinson (1994b). *Making sense of secondary science: Research into children's ideas*. London and New York: Routledge.

Driver, R.; Guesne, E. and A. Tiberghien (Eds.) (1999). *Ideas científicas en la infancia y la adolescencia.* 4° edición. Madrid: Morata.

Froner, D.; Bianchi, V. and M.C.P. Araújo (2006). Fotossíntese e respiração: conceitos biológicos, físicos e químicos resignificados na 8° série do ensino fundamental. In: 2° Encontro Regional Sul de Ensino de Biologia, 3° Jornada de Licenciatura em Ciências Biológicas da UFSC, Florianópolis. *Anais Eletrônicos*.In:http:<//www.erebiosul2.ufsc.br/trabalhos_arquivos/comunicacoes%20fotossintese.pdf>.

Justi, R. (2006). La enseñanza de ciencia basada en la elaboración de modelos. *Enseñanza de las ciencias*, 24, 2, 173-184.

Lima, M.E.C.C. and N.S.A. Silva (2007). A química no ensino fundamental: uma proposta em ação. In: Zanon, L. B. and O. A. Maldaner (Eds.) *Fundamentos e propostas de ensino de química para a educação básica no Brasil*. (pp 89-107). Ijuí: Ed. Unijuí.

Khadhraoui, I. M.; Dumon, A. and M. A. Trabelsi (2013). Analyse comparative de pratiques enseignantes en situation de classe ordinaire lors du primier contact d'élèves tunisiens avec la modélisation de la transformations chimique. *Revista Electrónica Enseñanza de las Ciencias*, 12(3), 392-419.

Mortimer, E.F. and P. Scott (2003). *Meaning making in secondary science classrooms*. Philadelphia, Open University Press.

Nussbaum, J. (1999). La constituición de la materia como conjunto de partículas em la fase gaseosa. In: Driver, R.; Guesne, E. and A. Tiberghien (Eds.), *Ideas científicas en la infancia y la adolescencia* (4ª Edición) (pp. 196-224). Madrid: Morata.

Oliveira, R. J. and J. M. Santos (1998). A energia e a química. *Química Nova na Escola*, 8, 19-22.

Steiner, R.P. (1989). Chemistry in the elementary school: Can we make it work? *Journal Chemical Education*, 66, 7, 571-572.

Tekkaya, C. and A. Yenilmez (2006). Relationships among measures of learning orientation, reasoning ability, and conceptual understanding of photosynthesis and respiration in plants for grade 8 males and females. *Journal of Elementary Science Education*, 18, 1, 1-14.

Tomasello, M. (1999). *The cultural origins of human cognition*. Cambridge, Mass.: Harvard University Press.

Voloshinov, V.N. (1929/1973). *Marxism and the philosophy of language*. Cambridge, M.A.: Harvard University Press.

Vygotsky, L.S. (1986). *Thought and Language*. Cambridge, Mass: MIT Press.