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Paper Title: **WHAT IS CONSERVED IN A CHEMICAL CHANGE? OPINIONS OF SECONDARY SCHOOL PUPILS.**

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Our intention is to know what the pupils conserve in a chemical change in order to know how they explain that change to themselves. As most research works on eduaction recommend, we will work with the pupils' ideas, through its material translation into written graphism as a thinking tool. We start from the fact that any rational explanation bases itself upon a conservative scheme, therefore if we get to know what the pupils actually conserve, we will know how they explain themselves chemical change. We think that this workline would allow us to go further into the analysis of the pupils' explanations and to know if the fact of working on the consevative aspects in class permits us to progress in the interpretation of chemical phenomena. The objective is not to carry out a simple descriptive study of the pupils' ideas about the questions and the phenomena analysed, we also want this to be an explanatory analysis of the results.
The exploratory study includes an analysis of two questions about two phenomena closely linked to daily life and the explanations corresponding to a laboratory experiment carried out during the instruction.

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WHAT IS CONSERVED IN A CHEMICAL CHANGE? OPINIONS OF SECONDARY SCHOOL PUPILS.

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INTRODUCTION.

A majority of the work investigating students' conceptual understanding has been conducted since the mid 1980s. Studies reveal that even after a year of chemistry instruction, secondary students lack conceptual understanding of basic chemical concepts.

The last research on education (Andersson, Bjorn 1990, Briggs i Holding, 1986, Meheut, Martine 1989) focus on the necessity of not confining to the analysis of only one phenomenon or question. We ought to explore more thoroughly the level of construction, on part of the pupils, of the basic concepts that lead to the interpretation of phenomena in chemistry.

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The exploratory study includes an analysis of two questions about two phenomena closely linked to daily life and the explanations corresponding to a laboratory experiment carried out during the instruction.

INSTRUMENTS USED FOR THE INVESTIGATION WORK.

We are interested in qualitative explanations of chemical phenomena because studies have shown that explanation is a challenge not only for many middle and high school students, but also for many undergraduate and graduate students. Students use the "correct" words and apply formulas to obtain correct answers but lack understanding of the underlying chemical concepts.

Fortunately, we are starting to dispose of new analysis instrument to categorize the students' explanations. Andersson (1990) synthesized several studies related to students' understanding of chemical reactions and developped a classification scheme to describe how students explain chemical change. He proposes to use five categories to explain the students' thinking process and he called them: Disappearance (A), Displacement (B), Modification (C), Transmutation (D) and Chemical Interaction (E). What caracterizes the A,B,C and D categories is that the students imagine that a new substance appears and another disappears as a result of a separate change in the original substance, or possibly changes, each one separate, in several original substances. The original substance can itself interact with another substance, but it does not form a new substance with it.

Tim Brosnan (not published), bases himself on the consideration that the classification of material changes as physical change / chemical change does not reflect the different types of explanation given by "non experts", as it is the case for students. So, he tries to establish a type a classification permitting a structuration of the elements so that it is possible to carry out an anlysis of the pupils' explanations more detailedly. His system of

categorization is an attempt to reduce the apparent diversity of students' explanations to a manageable number of different types. In this perspective, Brosnan proposes to analyses what changes and what the changing agents are in their explanations by means of a network.

In our exploratory study we have partially used Brosnan's network to analysis the aspects that he had pointed himself.

We met some difficulties managing this network, deriving not from the construction of the instrument but from the material we work with and from the polysemy of some terms or phrases used by students. We hope we can get over theses difficulties in the following phases of our resarch, through interviews. One of the problems we met could be the possibility of a confusion betwwen supposing that it is a matter of an **Associative agent** of the change, that is to say a latent power that reveals itself in determined circumstances, and supposing that it is a **Permessive agent**, which means that its presence is necessary for the change to occur. It is when they say, for example: that **"the nail goes rusty because osf the air"** or that **"the nails** goes rusty because of the presence of air".

In addition to this, we have had to add a new category, for the cases where the students neither describe the change nor pressupose the existence of an agent to make the change possible and simply establish a comparison with another change, normally more familiar, or use a metaphor or an analogy. An example would be the following explanation: **"The nail goes rusty because it is the same that happens to an apple when it goes rotten".**

Since our vision is communicative we try to consider the way the question can condition the answer, how the question itself can be the cause of a modification of the students' explanations and how determined formulations activate different phenomenological fields of reference.

THE QUESTIONS ANALYSED.

Question 1. When an iron nail turned rusty. What type of change has occured? Justify your answer.

Question 2. An apple or a peeled potato turns dark after a while, say why that happens?

The sample used corresponds to two groups from two schools in Barcelona: one of 18 girls and 18 boys, who answered the question before the instruction and another one of 36 boys who answered the question after the instruction. The average age is 16. During the schoolyear, which represents the last one of Secondary School, the students receive 3 or 6 months of chemistry classes.

The two questions were meant to know what type of interpretation the students make of a chemical change which is very common in daily life. Let's report to the summary-table of Brosnan's categories with the answers analysed:

Brosnan's Network

					nail		apple	
					pretest	postest	pretest	postest
	/	Labelled			22	20,23	4,10,13,16	14,17,21
	|		/	Existence			7	1/3,13,37
	|		|	Nature	12			
	|		|	Potency	31	7,4,14,15	18	6,31
	|	Described	<			16,18,24,28		
What change	<		|	Form	3/11,24,26,29	6,22	5,8,22,23	5,11,12,15,22
	|		|	Location	13,15,18,28,36	8/10	0,17,21	
	\		\	Arrangement	14,16,17	5,12,17,19 25		
	/		/	Natural	11			
	|		<					
	|	Non-Agentive	\	Associative	20,23,34	6,7,8/10,13		
Why change	|					16,20,27,28		1,2,11,14
	|		/	Permissive	4,6/8,	4,5,25,26,29	0/3,6/8,12	
	|		|		13/15,18		14,17,18,20	
	<	Agentive	<		20,30,32,		24,26,28,31,	
	|		|		36		36	
	|		|					
	|		|	Direct action	2/5,12,27	1,3,2,12	6,9,19,21,	20,24,26,28
	|		|		28			31,36,25,30
	|		|					35
	|		\	Interactive	9,12,14,			
	|				16/17,35	19	11	19,27
	\	Analogie				15,16	7	7

QUESTION 1. THE IRON NAIL.

In the case of the nail, the way the question is formulated should not represent any comprehension problems. We suppose all the students have seen nails go rusty. It is true that the question includes the word "change" which can have different meanings, but precisely this is one of the objectives of this research work.

To answer the question, we expect a text of an explanatory nature. The question wanted to point out the level and the type of interpretation that 16 year old pupils make of such a familiar chemical change as the oxidation of a nail. It was logical to expect daily language words like rust, corrosion, etc.

In the case of the apple, the fact the phenomenon is placed in a context which is very close to people's life (food) and to biological processes like digestion could activate a conceptual context closer to daily rather than scientific language.

According to Brosnan's network, the analysis of what changes, the classification of type transformation, in question 1, is poor before starting the instruction in the last Secondary School year. On the contrary, the analysis of the causes that provoke the change is more interesting. The students seem to have difficulties to describe the change and avoid them saying it is a chemical change or using the word rust but without specifying what they mean in each case. It seems easier to find an agent for that change.

In some cases, 2 girls and 1 boy gave a causal explanation which nevertheless did not correspond to a direct external agent. In that case they do not express themselves

speaking of the change, they associate it to the human factor, introducing criteria of action and usefulness: **"Tha nail went rusty because nobody used it and it went rusty"**, **"The atoms of the nail melt and leave marks"** or **"Atoms change form".**

There is one Non-Agentive explanation of the Natural type: **"Iron goes rusty because oxygen atoms are changing in this way"** and three explanations of the Associative type: "**The nails goes rusty when it gets wet** ..."

Other explanantions includes an agent that permits to explain the reason of the change. A majority of students try to find a reason of a Permissive type that allows the change: **"The oxygen forms a thin layer of ferric oxyde"** or **"The oxygen penetrates into the iron, into the structure of iron".** Others find a Direct action type: **"It is a physical and molecular change: it goes rusty when the air acts over the particles oxygen"**, **"It is a chemical change** due to the action of the air and the wind" and "The action of the air and the atmospherical phenomena makes it go rusty". In some other cases the action of the agent is Interactive: **"The oxygen reacts with the iron on the superficial part"** and "It is an oxidation due to the fact that the oxygen of the water mixes with the iron and makes Fe_2O_3.

It happens that paradoxically it is this explanation which is incorrect in the use of the verb "mix" is among the closest to the scientifical explanation in the sense it considers an interaction between the material (iron) and the agent of the change (oxygen).

"The oxygen has gone into the molecular structure of the element that is forming". Although that explanantion uses the verb "go into" it has a more interactive and dynamic vision of the phenomenon that in the case of a Permissive cause.

The following explanantion is of a substantializing type: **"Is a chemical reaction,**

because as the iron in contact with the air, the properties of these two elements combine themselves and have a type of reaction". Although this explanation corresponds to the Arrengement category with and Interactive cause, it is the properties of the elements that combine themselves.

There are some students explanantions that share two categories of Brosnan´s network. It is the case of **"The action of the air and of the atmospherical phenomena make the nail go rusty"**. The first part corresponds to the Direct action category but the second one belongs to the Permissive type **"makes the nail ...".**

We can observe that there is generally a type of verbs associated to each category when the students give a reason for the change:

Category	Verb
Direct action	"act" "attack"
Permissive	"form", "go into", "produce", "appear"
Interactive	"react"

In any case, one should notice that the use of a determined verb, for example in the case of "react" does not automatically imply the explanation belongs to such or such other caregory. The student may say "react" and consider that there is no need to look for a reason for the change, it is a natural change, and viceversa.

The same formulation of the question concerning the nail, made immediately after the instruction, outside the chemistry class, by someone external, obtained different answers.

There was a reduction of the answers that simply qualified the change, trying maybe

to avoid explaining it and corresponding to the Labelled category. There were more answers that described the change in terms of Potency, most probably conditionned by the image of usefulness that iron has got. "The particles of oxygen get wet and as they are in contact with open air, they get spoiled". "The nail deteriorates in contact with oxygen and water"."These particles leave the nail useless".

That categoy did not appear in the pre-test sample. There can be several reasons but one of them could be that the post-test sample is exclusively masculine and boys are usually more familiar with the world of metals and their uses.

Six boys described that change with a Location or Existence type answer: "it is a chemical change because a new substance appears". Five boys make a description of the change that can be related to the Arrangement category: "the oxygen alters the structures of iron molecules".

The new category added to Brosnan's network, Analogy, allows us to regroup the following explanations: "The nail aged because it was exposed to ambient environment", "The nail ages and its components decompose little by little".

QUESTION 2. THE APPLE.

The students, like for the question about the nail wich goes rusty, have difficulties to describe the change and the solution they find is to qualify it. But in their answers, this time, they use terms belonging to the scientific language less frequently: chemical change (2 girls, 4 boys), oxidation (1 girl, 3 boys). And they also use terms belonging to daily language: "it

goes rotten" (7 girls, 4 boys).

The proximity of the phenomenon to daily life can have catalized the word "rot". If we compare with the question concerning the nail, there, the term equivalent to "rot" in daily language would be "rust" and rust was already included in the formulation of the question. This made it necessary to reformulate the question, as it happened in some cases.

In the case of the apple, if we apply Brosnan's categorization about what changes, to the type of changes present in the students' explanations, it is clear for everybody that it is the potato or the apple that changes, but it is difficult to know the reach of this change. It is difficult to know if it is a change of the Existence or of the Nature type, for behind the words "went rotten" we cannot know if there is continuity or not of the substance.

Two girls said that "The dioxide of carbon or the particles that form the air of ambient environment have eroded and decomposed it" and "The air makes some of its particles go rusty after some time and these dead particles are responsible for the rot" which are explanations that correspond to the Existence category since there does not seem to be any continuity of the substance.

There is a type of changes which is conditionned by the way the question is formulated when "the apple gets dark". They are the changes which are included in the Form category and they refer to the change of properties, in this case to the change of colour. At times students give macroscopical explanations, a boy said that "the apple had lost the water inside". But 3 boys thought the change of properties corresponded to a change at a microscopic level: "the atoms of the apple get darker", "the atoms of the apple, with the chemical change of the air, can make it turn dark".

It would be worth checking if the question formulated without sayin that the apple

gets darker would obtain the same result.

For the question about the apple, asked in the post-test situation, the totality of the sample, 30 boys, gave a first qualification of the change in terms belonging to daily language: "it went mouldy", "it went rotten", "it got spoided", "it deteriorated", it ripened" or "it is not good any more" but afterwards, 13 boys completed their explanations in terms of chemical or physical reaction. This first qualification in terms of daily life can be justified by the proximity of the object, the potato or the aplle, daily life environment and by the fact that the explanations of this post-test sample are richer and more complete than the ones obtained in the pre-test situation.

The proximity of the phenomenon to biological processes has oriented the explanations towards this side. A boy explained what "mouldy" means. "It means that some mushrooms of the air have settled and reproduced on the surfaces, giving this colour".

A group of explanations corresponds to the Existence category and speack of the disappearance of part of the material, probably thanks to a parallelism with the finitude of biological processes. In the question about the nail there was not a sole reference. Another possible influence over this type of explanations may have been the characteristics of the sample that has work on a lot of questions linked to environmental phenomena and that still have them in mind in their explanations. We are left with a doubt about which one for rhe two following factors will have had more influence: the especific instruction about environmental themes or the context of the question.

The explanations linked to the change of properties are grouped in the Form category. This sample did not try to explain the darkening process of the apple in spite of the fact the question was formulated exactly as in the pre-test situation. Only one boy says "that a change of colour occurs", another boy says that "the contact with the air makes the

apple go dark" and another one says that "a chemical reaction takes place with the air particles and change the properties".

Only in one case does a boy explain that "when the apple goes rotten it is the same as when a nail goes rusty". In that case, the rust of the nail functions as an analogical pattern for chemical change since he only speacks of the structure.

As to the type of changing agent, like in the pre-test situation, there is no change of a Nature type. The agents are external (the air, environmental factors atmospherical agents, biological agents) in 26 of 30 answers obtained. In half of them there is again a reference to environmental and atmospherical agents and we suppose that is due to the characteristics of the sample we have already mentionned.

The oxygen, as changing agent, is mentionned in 7 explanations out of a total of 30, while in the pre-test situation it was only present in 5 out of 36, oxygen and other gas in 6 explanations out of a total of 30.

The recurrent presence of the argumentation about environmental themes incites us to question the capacity the students have to stock the information in a structured way. In pre-test, the agents were the air and oxygen and in post-test, these agents share the main part with environmental factors.

QUESTION 3. COPPER CYCLE. FIRST VERSION.

1. We have seen that in chemical changes, unlike physical changes, the initial substance, the reagent, is not conserved and that a new substance forms: the product of the reaction. What do you think may be conserved?.

2. Observe the copper thread. Make the experiment of the reaction of cooper with nitric acid for 10 minutes. Take the copper thread, wash it and look carefully to see if there has been some change in its dimensions. Describe what you see. What has happened to the copper? Where has it gone?.

3. Add a little distilled water to the test tube and introduce a dry an clean iron nail. Then answer again the questions you hace already answered. What explanation can you give to the fact you obtain the copper?.

The question, in this first version, was asked to a total of 14 girls and 10 boys, aged 16. The second version was asked to a sample of 12 girls and 10 boys of the same school level.

The analysis of the question show that one of the aspects that one has to take into account in the formulation of the question is the polysemy of the word "copper". It can refer to 4 different entities: the copper object, the chemical substance, the "dissolved copper" that the students say and that corresponds to the copper ion and to the chemical element. And that polysemy is reinforced by the way the question is formulated for we put on the same level the copper thread, the nitric acid and the iron nail. For the teacher it is easy to distinguish when it is being referred to and object or to a substance but not so easy for the students.

As in all the questions concerning an experiment, there is a supplementary complexity since it is a matter of getting down to interpret an experimental fact that implies a high level of conceptual requirement, that is to say the level an expert may have and for someone who is just constructing the meaning of chemical concepts it is not so obvious.

The question in its formulation tries to give patters and to establish mediations so

that the student can interpret the experiment. So, the student tries to compare the initial situation "observe the copper thread" the final one "observe if there has been any change in its dimensions". Although the questions focuses on the copper, because it seemed that the formation of a new substance could be deduced from the change of colour of the nitric acid, this pattern has not been shared by the students.

The fact the question spoke of a "reaction of the copper with the acid" does not seem to have conditioned the answers. The term "reaction" is not an identity marker of a chemical change. What did condition the answers were the very punctual final questions "what happened to the copper? where did the copper go after the reaction" for it is the only part that actually did get an answer.

The difficulty for the student to accept any explanatory scheme, even a very elementary one, peculiar to chemical change, makes them speak of "formation of new substances", use the verb "dissolve" in the case of 5 boys and the verb "melt" in the case of 15 girls and 2 boys.

If we apply Brosnan's network to categorize the type of transformation and the causes of the change, we observe that this time very few causes were given
for the change. One girl corresponds to the Labelled category: she does not describe the change, she says that "a chemical reaction happened". Two boys and 5 girls correspond to the Existence category, that is to say, they do not see any continuity of the substance: "the copper has been eliminated, it has been reduced to nothing" or "the copper disappeared in the end", "apparently, the copper seems to have disappeared".

A total of 15 girls and 12 boys, that is the majority of the class said that "the copper dissolved, it merged". This type of explanations can either correspond to the Existence or to the Location category, depending whether there is a continuity of the substance or not. One

girls spoke of a Potency change: "The copper blurred" and 3 girls and 2 boys spoke of Form changes: "The copper went away under the form of a gas", "The copper melted", "The copper has unthreaded".

As to the causal character, the distribution of the causes that were pointed out, the explanations of 10 girls and 2 boys that only say: "The copper merged into the nitric acid" or the answers of 2 boys that say: "The copper dissolved" are ambiguous for they may mean that the nitric acid is the agent of the change or that the students have an interactive vision of the dissolution.

Those difficult to classify answers can be included in the Permissive category. Nobody considers that it is a matter of a natural change or that it is a change associated to a specific condition. Everybody, when they give an explanation of the change, considers that there is an agent.

The agent can be: "Permissive" "The copper merged into the acid".
"Direct action" "The acid broke its structure". "Interactive" "The copper particles have mixed with the ones of the acid" or "The copper merged into the nitric acit. It now forms part of its structure since the molecules are all mixed".

If we analyse the polysemy of the word copper in the answers, it is quite difficult to know exactly to which one of the different entities the students refer to in their explanations without the help of an interview. Anyway we can make a first approach.

The answers that refer to changes of form speak of the object "copper", for example: "the thread has melted", "there is nothing left from the thread", "the copper has remained in the nitric acid, it has merged and disappeared", "the copper has merged and is now in the nitric acid".

We do not know if the students are speaking of the object as well as of the chemical substance when they explain that "the copper has dissolved and mixed with the acid", "the copper makes the acid turn greenish".

It seems that they refer to the term copper as a chemical substance when they say: "the nitric acid has turned green and part of the copper goes away under the form of a gas", "the copper thread has unthreaded". There are also some explanations at a microscopic level, like: "the copper particles have mixed with the acid ones" and we are left with the doubt whether the boy who says: "the acid broke its structure" is speaking of the substance or of the object.

In some cases it is rather difficult to get to know what meaning they give to the term "copper": "the acid in contact with the copper change colour". And finally, in some explanations two meanings coexist, as in the case of a girl that says: "The copper has merged. The nitric acid is now forming part of its structure since the molecules have mixed".

The analysis of the relation between the macro and the micro levels shows that only 4 boys and 1 girl refer to the microscopic level. As we have already seen in other reserarch works, students only use the microscopic level in their explanations when they are explicitely asked to do so. In this experiment the microscopic level did not prove to be a useful explanatory pattern for the students. "The copper particles have mixed with the acid ones". "The copper forms part of the acid structure". "The acid broke the copper structure".

In the first question of the activity, which has an exploratoy character, the students were asked about their opinion on what is conserved in a chemical change. If we analyse the answers, we could say that the conservative aspects do not have any meaning for students of

this age and that we have not found an experiment that could catch their interest and that would be significant and comprehensible for them. Moreover, the concept of chemical change does noy exist for them and they still use an intuitive phenomenological scheme and to elaborate explanations they come out with "the formation of new substances".

COPPER CYCLE. SECOND VERSION.

In the idea of focusing the students' attention on changes, by menas of comparison between the initial and the final situations, in the conservative aspects of the change and to check the existence of possible analogies, we added the following points to the second part of the question:

What did you have at the beginning and what did you have now?
What has changed? Why?
What is conserved?
What can you compare this change?

The majority of the explanation given in the first sample come out again as it can be seen in Brosnan's network categories. Some references disappear such as **"the copper has merged"** or **"the copper has melted"**. New explanations appear: **"The copper has turned rusty", "The copper got rid of thr thread and was suspended in the nitric acid"** or **"With the vibration of the nitric acid particles the union of the copper got broken and it dissolved"**.

As to the question referring to the initial and final products, in the reaction of the copper with the nitric acid, the students experiment some difficulties to answer, above all for the final part where almost nobody sees that there is a dissolution of the copper nitrate.

Only one boy speaks of **"the acid and the dissolved copper".** Two girls and one boy do not answer the question. Two girls speak of a **"copper thread at the beginning and of the iron of the copper thread at the end of the experiment"** or **"a copper thread and now it is the same thread but a little amaller and without color".** One boy says that **"we still have everything, the same mass and number of particles".**

When students were asked to compare the change, the majority do not answer. It seems that there is no habit to stimulate analogical thinking. Only one boy says **"it seems to iron and to sulfur"**, the rest do not answer or identify the change with a dissolution. One boy even says that **"the chemical change can be assimilated to the dissolution of water with salt or suggar"**. That means that it is not only yhe use and accurate scientific term at first that implies a correct conceptualization.

A girl explains explains the reaction of $Cu(NO_3)_2$ with the Fe saying: **"the iron transforms into copper and merges"** which shows a particular idea of transmutation. Another girl said that **"now the nail has solidified again"**. Other explanations are: **"The copper adehres or sticks to the iron"** and they coincide with a girl and a boy that say at the beginning they have **"the nail with the copper stuck with the acid".**

Finally the explanation of the fact they get the copper again show some conservative aspects: **"The copper had not disappeared, it had only disolved", "The copper has always benn there and when it got into contact with the iron reacted alloying with it", "Because the copper was in the nitric acid and when the nail was introduced it stuck to it", "the copper atoms get back together and the copper ones separate"**.

The answers closer to the idea of chemical change identify with transmutation but the ones that speak of conservation do not have an underlying concept of chemical change, thay simply reflect a thinking process in terms of dissolution or of a change in the situation

of the atoms or the substances.

In the light of the answers we have obtained, the teaching strategy will include:

1. Work on the different polysemic meanings of the word "copper" so that the can distinguish each time whether we are speaking of the object, the chemical substance or the elemnt.

2. Work on the first part of the cycle as a chemical reaction and on the second one on how to obtain copper from $Cu(NO_3)_2$, through indirect questions that would alloow us to interact with their explanations. For example, how we could obtain copper again from $Cu(No_3)_2$ or asking for a discussion about the explanations we have mentioned before.

CONTINUITY OF THE RESEARCH.

Even bebeginners' chemistry texts dedicate relatively little space to explain what chemical reactions are and how they are represented. The main conceptual stages that students have to overcome to get to a comprehension of chemical phenomena are:

0. The necessity of concept.
1. What is conserved and what is not in changes.
2. The discontinued nature of matter connected with phenomenology.
3. The quantification of relations.

Our research work wants to explore the group of conceptual problems concerning conservation. Up to know some research works have been carried out, in mathematics and physics, to reinforce the students' intuitive thinking. These works show that the students' ideas about "conservation", "permanence" form part of a thinking system which is stronger

than any other one.

We share the idea of the necessity of searching teaching intervention lines that would allow a better learning of chemistry elementary concepts. The channel of the differentiation of chemical change in relation to physical change, that is very often taken for granted, in elemntary levels of education seems to have run out of teaching possibilities.

Although the interpretation of chemical phenomena is a long term process, difficult to get in its complete form before students finish their Secondary School, we are interested in knowing what level, or levels, they actually reach.

Analogical reasoning can play an important role in scientific learning and explaining abilities. It is one of the most effective ways for students to integrate their personal knowledge to scientific knowledge. We would like to say we think it may be an error to suppose that the students' ideas about the world of chemistry are the same nature and are submitted to the same changing processes as their ideas concerning such tangible worlds like floating, movement or gravity. So, the use of analogical patterns is probably of great importance in the process of construction of knowledge around chemical phenomena. We would like to see if the analogies that the students spontaneously establish with the chemical change and with what is conserved in chemical change can be useful in the instruction acoording to Thaggard's indications.

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