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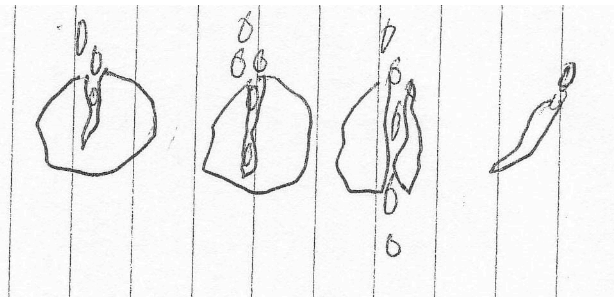
Salt-water mixture

I9Y11



Sugar being broken down by water

I14Y9

As has been noticed before, when students talk about particles, they are often speaking of something completely different to what the teacher is talking about. If students do not have enough opportunities to think about particles and particle properties, they probably do not find any reason not to keep attributing macroscopic properties to particles.

Final considerations

From the analysis of the interviews it is evident that students have different conceptions regarding the structure of matter and use different premises of particle theory to explain different phenomena. Even though we have not yet spotted any pattern that could help us relate the use of these different conceptions, it is quite evident that students tend to use particle ideas in the context of changes of state and not as much in the context of mixing and reacting. There is, as well, within this limited sample, some evidence of progression within age groups: older students tend to use the particle theory spontaneously to explain a wider range of phenomena.

Students in this age group know about particle theory, although, that does not mean that they can actually use particle theory to construct explanations for more complex phenomena, or that they can actually explain phenomena they have already encountered in school. Sometimes it seems evident that students are not used to being asked to think critically, and see this knowledge as problematic; sometimes just the mention of a scientific term such as “dissolving” can be considered as an explanation.

For many students, being asked to think about particles to explain mixing represents a challenge. It is probable that they have not encountered enough opportunities to think about particles and to explain different and more challenging phenomena. Consequently, in the following interviews we will try to present different phenomena that could be less familiar to the students and could pose an opportunity to apply particle theory in new contexts, and not only to repeat it exactly as learned.

References

but without assigning meaning to them. These are not seen as processes that can be understood and explained, but rather facts, statements of truth.

Perhaps this is the reason why almost all the students use particle ideas to explain changes of state, but have a much harder time doing it for the mixing phenomena. There are many instances during the interviews where it is evident that we are asking the students to do or think about things they had not done before. The position of the students in front of the challenge, the disposition to play with ideas and construct possible explanations turns out to be fundamental for the type of explanation they construct.

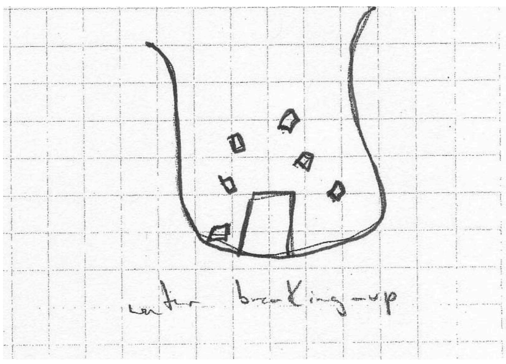
What particles are we talking about?

From some of the interviews it is evident that when students talk about particles, they are actually talking about "small pieces of matter", which is different from the scientific conception, and also poses serious difficulties to understand and explain phenomena. For example, students think that when a mixture of salt and water is evaporated, the salt would be left behind because it is still a solid:

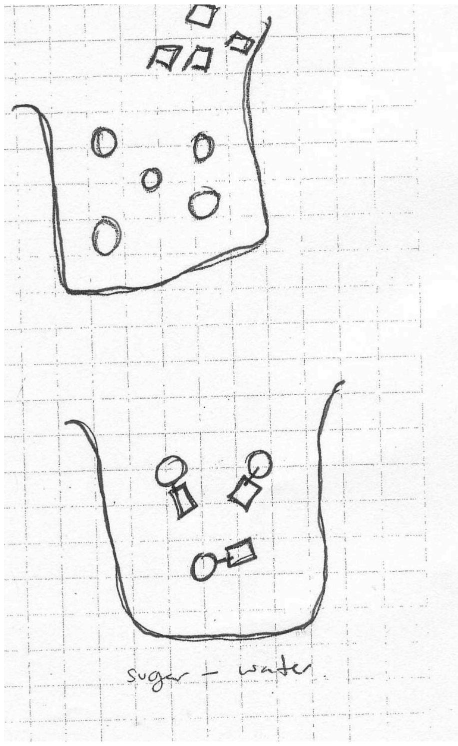
> I: If you wanted the sugar back, what would you do?
> S: leave the water to evaporate. Because the water particles leave but the sugar ones are heavier, they stay behind, they're still kind of solid, except it's just like a really small solid, I guess

I9Y11

In the same way, when students are asked to draw or sketch what they are imagining or saying, sometimes the same conception about particles is used.



A sugar crystal being broken down by water.
I9Y11



knowledge building (being able to hypothesize, being able to see the ideas as a model, rather than pieces of knowledge that apply to any particular phenomena); the kind and amount of cognitive resources available (i.e. notions of interaction), among others.

Commitment to learned "truths"

There seems to be a strong commitment to learnt truths or undisputed knowledge, learnt by heart in school, such as: *"in solids particles are closer together, in liquids particles are closer but not that much, and in gases, particles are really further apart".* When students encounter phenomena which challenges these undisputed truths such as ice floating in water, they make adjustments to the particle model they are using.

In the following extract, it is possible to have a glimpse at the construction of an explanation, where the student seems to be absolutely sure that particles in a solid *have to be* closer together. She comes up with two different explanations, one that states that particles expand, and the other one, that states that there may be more particles (the first one is more strongly alleged). The words shown in **bold** show the strong commitment and reflect voice intonation that can be listened in the recording.

> I: what happens to it [water] when I freeze it? What changes?
> S: well it freezes, obviously after a few hours in the freezer, the particles **obviously** have to come much more closer together to become a solid, so there must be actually touching each other, the particles, from a liquid to a gas, the particles **have to be** more freely and from a liquid to a solid, the particles **have to be tighter together** for it to freeze, if they are loose then it would not freeze
> I: Have you seen how the ice floats in the water, why is that?
> (…)
> S: maybe **the particles obviously have to be together**, to become a solid, they might expand a bit, I'm not sure, cause from a liquid, the particles are not touching and to be a solid, the particles, **there's going to have to be more of them** so they can touch and all of them, so maybe they can expand, they get bigger, but I'm not sure
>
> **I9Y10**

The fact that students think about individual water particles expanding when freezing could be explained more in terms of trying to find an explanation even if it does not follow "the rules" than of attributing macroscopic properties to individual particles, as has been proposed by authors such as Gomez Crespo & Pozo (2004).

Probably, students have learned particle theory as statements of truth and not as a model that can be flexibly used and applied to explain different phenomena. Therefore it seems difficult to uncover the elements of construction that students use for different representations and in different contexts. Students have learned words such as "diffusing", "dissolving", etc., S2: Yeah, I guess (…) Yeah, maybe, I don't know

I4Y10

In this particular case, the students could not apply their knowledge of what happens to the particles upon evaporation to the cases of metal expansion or freezing. Neither could they try to reconcile the different models used, although there is some recognition of the inconsistencies. They rather stick to the conception generated in freezing and metal expansion and changed their conception for evaporation (at least during the interview).

In a different interview (I10Y10), the student applied a consistent model for mixing which relied on substances properties (particularly strength) and she consistently applied a basic particle model to explain changes of state, although attributing macroscopic properties to the particles. When asked to apply the same reasoning she was using for changes of state (using particles) to the mixing phenomena, she was able to extend her reasoning and stated that *"water particles move, forcing up the solid"* (in the case of the sugar), whereas the first time she was asked, the only reason she could state to why sugar dissolves is because it was stronger than the water. Her graphic representation, made at the end of the interview, however, depicted a continuous model of matter. This shows how extraordinarily complex it is to characterize students' representations or expressed models appearing during the course of an interview.

There are also examples of pupils (I5Y10) who are not able to extend the "particle reasoning" beyond the changes of state scenario.

[Students had been talking about changes of state, using a particle model which considered particles, movement and spaces among them]
I: So, these particles you are talking about (…) particles are in there, like in the sugar, in the water, that helps explain why do they dissolve?
S1: Yeah, like mixing (…) Yeah, like (…) water particles (…)
I: These particles you say, they are like (…)
S2: It starts moving more
I: What is that starts moving more?
S1: Starts moving more, I can't think of a word (…) I'm impressed (…)

I5Y10

Even though these students had been talking about particles moving in changes of state, they just couldn't apply the same ideas to the case of sugar being dissolved. It is as if they were two completely different phenomena (which they are) but that could not be explained from the same basic principles (which they can).

In a different interview (I3Y9), when students were asked if they could explain water-dye mixing in the same way they had explained gas diffusion, they said: *"it's different, smell travels"*

The extent to which students can apply the same model to different phenomena could depend on many different reasons: their approach to

Also, it is necessary to make sure that students are asked about phenomena from the different contexts (mixing, changes of state and reactions), so consistency can be analyzed with more confidence.

What if you think about particles?

We've already said that whilst most of the students use some kind of particle model to account for changes of state, this situation changes when we look at the type of explanations proposed for mixing. If we examine the following extract from an interview, it is possible to see how students are able to apply some features of the model they have been using to explain changes of state, in order to explain mixing.

> [After having explained mixing in terms of properties such as density and explaining different phenomena related to changes of state]
> I: How do you explain that the sugar dissolves? Can movement [of particles] help to explain why sugar dissolves?
> S1: I think (…) because you need the sugar particles around, moving it
> S2: It's like stirring it, when you stir it the sugar dissolves quite fast (…)
> **I6Y9**

It could be the case that students have had fewer opportunities (in school experience) to explain mixing in these terms, and think about changes of state and mixing as two totally unrelated sets of phenomena. However, they can apply particle ideas when it is pointed out that they could actually use similar explanations for both of them.

Throughout the interviews, I have asked the pupils to clarify meanings through questions such as: what do you mean by …? Or, are you saying that …? When students express evidently inconsistent models, for example, stating that particles grow bigger on freezing and metal expansion, but not on evaporation, I have asked them, whether they could use the same arguments for both phenomena:

> [In this case, students had explained water evaporation as particles moving more and expanding, and then this fragment occurs later while talking about metal expansion]
> I: OK, but this expansion (…) it doesn't mean the particles get bigger?
> S1: Yeah, and they move as well
> S2: They get bigger as well, so they're gonna (…)
> I: So they move more they are getting more space (…) and the same thing happens when you boil it?
> S2: I don't know, because they don't change when you boil it, so, I don't know.
> I: What do you say? they get bigger when you boil it?
> S1: No, they get smaller because it evaporates
> I: The water particles, they change?
> S1: Yeah, yeah, they are trying to get bigger so that's why when you boil it they find their way up, so anyway.
> I: So what would you say? They change?

twelve) interviews, whereas in the case of gas diffusion, mixing water and dye and mixing water and sugar, particle ideas were used in almost half of the interviews (5 out of 12, 6 out of 12 and 5 out of 13, respectively). There is no evident pattern where we can see whether the interviewees who can explain a specific phenomenon also explain another one. For example, in one of the interviews in which particles ideas were used to explain the mixture of water and oil (I9Y11), particle ideas were not used to explain the mixture of water and dye, and this pupil rather used macroscopic ways of explaining, in particular using density as the main characteristic that determines whether something mixes or not, which seems rather inconsistent.

There are also subtle differences in the ways that these premises are used by the different students. In the case of changes of state, the younger students use mainly a ‘rigid’ particle model (matter is made of particles which have spaces among them). In some interviews, it is rather evident that even if students are talking about particles and spaces, these are not perceived in a dynamic way:

> I: So, when I put sugar in there, what happens with the spaces between the water particles?
> S1: The water will (…) depends on the amount of sugar that you put
> I: So. It’s exactly as if I put a rock in there, you see I put a rock in there, and the water level rises, it is just the same?
> S2: It displaces the water,
> S1: Yeah,
> S2: The rock takes the space up
> I: So, the same thing happens with sugar?
> S2: Yeah

I6Y10

Taking the group of students in Y10 and Y11, in the cases where gases are involved (evaporation, gas compression and expansion), the set of premises used involve movement, and either spaces (4 out of 7), or not. Whereas in the phenomena related to liquids, the set of premises is rather related to spaces between the particles. Explaining freezing, in 4 out of 6 interviews, only premises related to spaces among particles are used. In explaining metal expansion, 3 out of 6 students use only spaces to explain. These could be taken as incomplete models, although they could be used to build further explanations.

In order to extend our understanding of the different ways in which students understand and explain phenomena related to the structure of matter, we would need to continue gathering information from students. Even though some questions about chemical reactions have been asked, it has so far only been in very few interviews which do not allow us to say anything yet about these answers or how do they relate to the explanations of the other phenomena. Another feature that could be really helpful would be to have students draw graphic representations for all the phenomena encountered, since these seem to offer a lot of information regarding the consistency of students in terms of what they are saying and actually imagining or thinking.

4	I10Y10	X – 4	X	X	X – 2	2	3			3
5	E3Y10		5	X	3					4
6	I1Y10	2	2	2	2			3		
7	E5Y10		2		5			2	4	
8	I5Y10	X	X	X	X	4	3	X – 3		
9	I7Y10	4	2	X	X	4				
10	I4Y10	2	2	X – 2	1	2	3	4		
11	I11Y10	4	X	X	2	4	4			4
12	I8Y11	2	2	X – 5	5	4	4			4
13	E1Y11	4	5	6	6					3
14	I9Y11	4	X	5	1	2	3	4		
15	E4Y11							3	4	4

Table 1. Premises of the particle model applied to different phenomena.

X. No reference to particles. 1. Particles; 2. Particles and movement; 3. Particles and spaces; 4. Particles, movement and spaces; 5. Particles, movement, spaces and interaction; 6. Particles, movement and interaction.

In the case where two different models are cited is because students changed after being asked to think in terms of particles.

Where the interview code starts with I, it means it is with English students, whereas if it starts with E, it means it is with Mexican students.

If the phenomena are split in two groups, one of them being the phenomena related to mixing (gas diffusion, water-dye, water-oil, water-sugar), and the other one the phenomena related to changes of state[3] (evaporation, freezing, metal expansion, gas expansion and gas compression), we can find some regularity in students' explanations.

In almost all of the interviews where changes of state were presented (13 out of 14), particle ideas were spontaneously used. In the interview where they were not used (E2Y9), the student, after being asked to specifically think about particles, explained gas compression relating it to particles and their movement. On the other hand, answers that included particle ideas to explain phenomena related to mixing were rarer. Only in one interview (E1Y11), students explained all the mixing phenomena using particle ideas, although not using consistently the same premises.

Looking at the differences between Y9 and Y11 students, it is possible to spot some patterns. In the case of mixing, not one of the younger students used particle ideas spontaneously, whereas all of the older students, used particle ideas, at least in three of the four mixing phenomena. In the case of students in Y10, we find a greater diversity: on two interviews (I10Y10 & I5Y10), particle ideas were not mentioned spontaneously, and only in one interview (I1Y10), a basic set of premises (existence of particles and movement) was used in all the phenomena.

If we take a separate look at the phenomena related to mixing, we can also be aware of some differences. In the case of water–oil, students only used particle ideas to explain why these substances do not mix in three (out of

[3] We are well aware that metal and gas expansion or gas compression, are not changes of state. However, we have included them in this category, since these phenomena involve only one substance, changing in terms of distribution of particles and movement among them.

about particles. Some of the fifteen interviews discussed here were undertaken with pairs of students (10) and some others were individual (5). The interviews lasted from 30 to 50 minutes and different phenomena are asked in each one of them. Given the nature of the approach, it is necessary to try to follow-up students' thinking, which means that if interesting conceptions are elicited, or if the student seems interested, we spend longer considering a particular phenomenon. The interviews are transcribed for further analysis.

Given the nature of the analytical approach, the first set of data has been analyzed, with the intention of finding theoretical categories that could help describe the different representations and how are they constructed. After this first analysis and the construction of working categories, more interviews will be undertaken, informed by the findings and looking to explore features that were not investigated previously. The process of data collection will continue until there is *theoretical saturation*, which means that the new data only adds up to the categories and relations constructed and does not uncover new categories or relations.

Preliminary findings

In this report I will present the preliminary analysis of the first set of interviews. The aim of this part of the research project is to explore the different models students use to explain phenomena, as well as the kind of answers they give, the kind of cognitive and epistemological resources they draw from, and try to describe in detail the elements that configure these models or representations.

I will present, in the first place, an account of the consistency of the explanations given by the students for different phenomena, and then I will describe some other categories that have emerged from students' explanations and that could be used to inform further stages of the research.

Consistency in the use of particle models

From these exploratory interviews, it is evident that students do not use one particle model which is consistently applied to explain every phenomenon presented, as can be seen in Table 1. It is considered that there is consistency when students use the same set of premises from the basic particle model to explain the different phenomena. The 'basic' particle model according to which students' responses are being categorized arises from the kinetic molecular theory as is usually taught in secondary school, and can be synthesized as: "matter is made of particles, which have intrinsic movement, have spaces among them and interact with each other"

		Gas diffusion	Water-dye	Water-oil	Water-sugar	Evaporation	Freezing	Metal Expansion	Gas Expansion	Gas compression
1	I6Y9	X		X	X – X	3	3	3		
2	E2Y9	X – 2	X							X – 2
3	I3Y9	X – 1	X – X	X	X					

particular social environment. Such theory should account for the existence of multiple representations within any individual's mind.

The aims of this study

If we acknowledge that these representations are constructed by the individuals through cognitive mechanisms, and mediated by interaction with the social setting, we would need to determine which features or aspects actually play an important role in the configuration of a given representation. We assume this will give us a better idea of how conceptual change is actually brought about. What we mean by conceptual change within the frame of multiple representations is how, any individual, from this range of representations, comes to use more consistently that one which more closely matches the curriculum models (Kind & Taber, 2005), without discarding the rest of the representations. If school science is related to the way in which students learn scientific content that has already been produced by the scientific community, then understanding how students approach this representation may be a worthy task to pursue.

Why particle theory?

The particulate nature of matter has been one of the most researched topics in the field of science education, from the early studies of Novick and Nussbaum (1981) about the structure of gases, to the more recent ones of Johnson (1998), Tytler (2000), and Gomez-Crespo and Pozo (2004), among many others. The relevance of the subject is also widely acknowledged as being fundamental to understand different concepts in school chemistry, as well as a powerful theory that can illuminate different aspects of the nature of science.

Even though there are many studies regarding the different conceptions that students have for the particulate theory of matter, very few of them have attempted to look to the dynamics of the construction process. My work is intended to provide a "fine grain" analysis trying to uncover different aspects of these representations, such as how they come about, how they relate to each other, and how does an individual chooses among different representations in a particular context.

Methodological approach

This is a qualitative research project which is based on semi-structured interviews with secondary students in English and Mexican secondary schools (Y8-Y11) using for the analysis a grounded theory approach (Glaser & Strauss, 1987; Strauss & Corbin, 1999; Taber, 2000). We are using interviews-about-instances and interviews-about-events as discussed by White & Gunstone, (1992) in three different chemical contexts: mixtures, changes of state, and reactions.

During the interviews, students are asked to describe the phenomena, to explain 'why does it happen that way', and if they do not use particle theory in the construction of their explanation, they are then specifically asked to think

Multiple representations about the structure of matter[1][2]

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Multiple Representations

It is now widely recognized that students have different ways of understanding scientific concepts. Solomon (1983), Linder (1993) and Mortimer (1995), among many others, have acknowledged that an individual approaches problems in different domains and contexts, using different ways of thinking. In this sense, there is not a best conception or representation; rather there are more adequate representations according to the context. The term representation is used to emphasize knowledge constructed in students' thinking, considering the information they already have, their cognitive resources available (Hammer, 2004), as well as the specific features of the situation they are facing.

The existence of these multiple representations as different ways of understanding a phenomenon has been conceptualised in different ways in science education. Mortimer (1995), for example, uses the construct of "epistemological profiles" to account for the different ways in which any individual can understand a given phenomena. This profile is made of all the different representations held by the individual; and learning is seen as the enlargement of some of the profile zones, as well as the decrease of some others. A different approach is the one taken by Petri and Niedderer (1998) regarding conceptual trajectories. These account for the different conceptions that students construct while learning a particular science concept, in terms of a sequence that relates to the development of conceptual understanding. In a similar way, Taber (2001) uses the term manifold conceptions to describe how the same student uses different conceptions to explain different aspects of chemical bonding. Even though some conceptions become more robust with time (are more used, more widely applied, etc.) they basically coexist and are applied in particular contexts.

Representations are considered to be cognitive in nature; however they are the result of an individual's interaction with the environment, through school and social interaction with peers and teachers (Pozo and Rodrigo, 2001). Representations are constructed by the individual within a social setting; they are not idiosyncratic, but rather culturally mediated. This assumption calls for a theory about how knowledge is constructed by an individual inside a

[1] Seminar sponsored by the Chemical Education Research Group of the Royal Society of Chemistry, held at the University of Cambridge, Faculty of Education. July, 11th, 2005.
[2] This seminar was prepared whilst a visiting student in the Faculty of Education, University of Cambridge, under the supervision of Dr. Keith S. Taber to whom I thank for his support, generosity and valuable contribution to this research.