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Postprint / Postprint
Zeitschriftenartikel / journal article

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Empfohlene Zitierung / Suggested Citation:
Löfgren, L., & Helldén, G. (2009). A longitudinal study showing how students use a molecule concept when explaining everyday situations. *International Journal of Science Education*, *31*(12), 1631-1655. https://doi.org/10.1080/09500690802154850

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Journal:	*International Journal of Science Education*
Manuscript ID:	TSED-2008-0018.R1
Manuscript Type:	Research Paper
Keywords:	science education, learning, primary school, secondary school
Keywords (user):	longitudinal study, the particulate nature of matter

Table 1: Overview showing the interviews and interventions that each student has attended.

Year	Interviews and interventions
1997	Interview 7y:1* Interventions Interview 7y:2
1998	Interview 8y started with listening to the 7y:2 interview
1999	Interview 9y:1 Interventions Interview 9y:2
2000	Interview 10y started with listening to the 9y:2 interview
2001	Interview 11y:1 Interventions Interview 11y:2
2002	Interview 12y started with listening to the 11y:2 interview
2003	Interview 13y Interventions
2004	Interview 14y this was a small group interview
2005	Interview 15y started with listening to the 11y:1 interview
2006	Interview 16y this ended with prompting a molecule concept

* Interview [7y:1] means it is the first [1] interview conducted when the student is 7 years old; [7y].

Table 2 shows the outcome of the categorization of the students' answers.

Category	The covered glass of water (Number of answers)	The burning candles (Number of answers)	The fading leaves (Number of answers)	Total for category (Number of answers)	(Percent** of total answers)
A	6	7	8	21	30
B	3	6	5	14	20
C	10	5	7	22	30
D	4	5*	3	12	20
Total	23	23	23	69	100

*As the point of departure in the analysis has been the students' understanding of the situation it is worth noticing that four out of the five students in category D in the situation with the burning candles believe that wax evaporates out into the air and that it is not part of the burning process.

**As the total number is low the percentage has been given with the accuracy of one digit.

A longitudinal study showing how students use a molecule concept when explaining everyday situations

Abstract

In this paper we present results from a 10 year (1997-2006) longitudinal study in which we, by interviews once or twice every year, followed how students, throughout the compulsory school, developed their understanding of three situations in which transformations of matter occur. We believe that students have to meet scientific ideas early in order to gradually, in social cooperation with classmates, friends, teachers, and other grown-ups, elaborate the meaning of a concept. We followed 23 students all born in 1990. 1997 we introduced the idea of the particulate nature of matter. We have conducted interviews allowing students to explain the transformation of matter in fading leaves left lying on the ground, burning candles, and a glass of water with a lid on. In the interview at 16 years of age less than one fifth of the students use molecular ideas in scientifically acceptable ways. The overall conclusion is that most students do not connect the knowledge they gain in school about the particulate nature of matter to these everyday situations. On the other hand the students seem capable of using a simple particle model and the model can help them understand the invisible gas state. The question of how to use this capability in order to develop students' scientific ideas is still not solved and more research is argued for.

Introduction

The results reported in this paper are part of a broader project (Helldén, 2005; Holgersson & Löfgren, 2004; Löfgren & Helldén, 2007) in which we wanted to follow students' development of understanding of transformations of matter in everyday situations. We try to answer the demand of White (2001), where he asks for studies that follow individual students' learning in more detail and over a longer period of time in order to understand the kinds of things that facilitate or obstruct concept development in science.

In the study, reported in this paper, we wanted to know more about students' abilities to use one of the most valuable cognitive tools used in science: the idea of the particulate nature of matter. The intention is to investigate students' relative capability to use particle ideas in different situations, and the extent to which formal teaching in schools of particle ideas impacts on their preferred and possible explanations of the same phenomena, over the years.

Students' difficulties in understanding processes where matter seems to disappear, as in decomposition or burning, or appear out of nothing, as in condensation have been well documented in the science education research literature (e.g. Andersson, 1990; Driver, Guense & Tiberghien, 1985; Krnel, Watson & Glazar, 1998). Whether such processes could be more easily and better understood by an early introduction of the particulate nature of matter has been discussed and examined through the years with some arguing pro (e.g. Novak & Musonda 1991; Papageorgiou & Johnson 2005) and others against (e.g. Fensham 1994; Harrison & Treagust 2002). In the Swedish school the particulate nature of matter is usually introduced in school year 7 (students' age 13-14), the "whole" theory is introduced and the teachers claim it is an important area on which a lot of time is spent through school year 7 to 9 (Oscarsson & Jidesjö, 2005).

Andersson (1990), in a review of published studies of students' conceptions of matter and its transformations, summarizes the findings using four different aspects: chemical reactions, change of state, conservation and atoms, molecules and systems of particles. There are later studies investigating students' understanding of matter (e.g. Nakleh & Samarapungavan, 1999), students' understanding of chemical reactions (e.g. Athee & Varjola, 1998; Johnson, 2000, 2002), and students' understanding of changes of state (e.g. Boz, 2006; Johnson, 1998a, 1998b). There are also studies focused on the development of students' understanding of these concepts (e.g. Johnson, 1998c; Krnel et al, 1998; Liu & Lesniak, 2005). All these studies to a greater or lesser extent investigate the width, depth, or "correctness" of the students' understanding of abstract scientific concepts concerning matter and its transformations more so than investigate students' ability to use these concepts in an everyday context and/or if this use benefits the students' understanding of the phenomena concerned. In a study investigating representational issues in students' learning about evaporation Tytler, Prain and Peterson (2007) claim that even young students can begin to develop an understanding of evaporation explained with a particle model. Selley (2000), in a study concerning dissolution, claims it would be interesting to know more about students' willingness to use the idea of the particulate nature of matter when not being prompted to do so.

Our study contributes to the above findings and questions by investigating if and how students actually use a molecule concept in everyday situations in which different kinds of transformations of matter occur. The study is a longitudinal study that probes students' initial ideas and ability to use particle ideas prior to formal teaching of this concept and through the years when particle ideas are formally taught. The longitudinal design makes it possible to follow the change in the students' use of the concept and most of the data are collected without prompting the molecule concept.

The aims addressed in this paper are

* to investigate how students at the age of 16 at the end of compulsory school use a molecule concept in their explanations of three everyday situations

* to analyse how the individual students' use of a molecule concept throughout the 10 year study can reflect the results at age 16

Methodology

The theoretical framework this study builds upon is Human Constructivism formulated by Joseph Novak (1993). This perspective gets its inspiration from Ausubel's assimilation theory of meaningful learning and underlines the importance of the unique interplay that occurs between thinking, feeling, and acting in human learning and in human construction of new knowledge and also stresses the important role of language in learning processes. This perspective, in our opinion, holds the insights about science concept learning formulated by Scott, Asoko and Leach (2007) as common to social constructivist perspectives, namely

1. Learning scientific knowledge involves a passage from social to personal planes.
2. The process of learning is consequent upon individual sense-making by the learner.
3. Learning is mediated by various semiotic resources, the most important of which is language.
4. Learning science involves learning the social language of the scientific community, which must be introduced to the learner by a teacher or some other knowledgeable person (Scott et al, 2007, p 44)

Building upon this means we believe that students have to meet scientific ideas early in order to gradually elaborate the meaning of concepts. This elaboration is made in social cooperation with classmates, friends, teachers, and other grown-ups. This perspective also makes it possible to use interviews in order to find out about students' ideas.

Design and sample

We have conducted a ten year longitudinal study starting with students aged seven and following them throughout the compulsory school. In the study we have accomplished interviews and interventions shown in Table 1.

Table 1, please insert about here

White and Arzi (2005) make a distinction between studies that are experimental, leading to conclusions and those that are descriptive leading to insights. We would describe our study as descriptive, hopefully, leading to new insights. Concerning the interventions we will emphasize that the role of the interventions is to make it possible to trace a developmental progression of an idea (the particulate nature of matter) that is not usually familiar to students until about 13 years of age. The interventions are not to be seen as a carefully structured program to be tested.

In our study (1997-2006) we have followed 23 students, who started school in a middle-sized Swedish town in August 1996. The students came from three classes in two different schools. In this town, due to a local government decision, all classes up to students aged 12, are age-group integrated; that is they consist of about equal numbers of students aged 6, 7 and 8, or students aged 9, 10 and 11. When the project started in 1997, all 27 students born in 1990 in the three classes were invited into the project, and they all accepted. During the first years, five students left the classes and in 1999 three new students started. When the students were 12 years old, they moved to a new school and were then divided in small groups and mixed with other students from classes of their old schools but also from new schools. They ended up in four age-homogenous classes. The last year two students moved to other schools. This means there were 23 students, 11 girls and 12 boys who participated in the last interview in 2006. These 23 students have taken part of most of the project. The schools are ordinary Swedish schools, and the teaching has been rather traditional. We would argue by this that the

23 students are a good sample of ordinary Swedish school students and not extreme in any sense.

Interventions

The Swedish school curricula and syllabi are goal-driven, which gives a lot of freedom to the teachers to choose both methods and details of content within different subjects. Up to the age of 13, the teaching in science is traditionally mostly in biology. Inspired by the encouraging results from the study by Novak and Musonda (1991), where they introduced a molecule concept early, we decided to introduce the idea of the particulate nature of matter to students during the last of our three interventions in spring 1997 when the students were seven years old. These first interventions lasted for about twenty minutes each. We introduced the idea of the particulate nature of matter by introducing a simple molecule concept to the students. We let the students experience how we can divide different materials into smaller parts. Lastly the students ground a piece of chalk[1]. They studied the tiny bits and we asked if they thought we could go on doing this 'forever'. We told them that there are particles we can divide matter into and that we call these molecules. We also told them that these molecules are so small we cannot see them and that they are in perpetual motion. In spring 1999 we had two interventions lasting for about half an hour each and in 2001 we had one intervention lasting for about forty minutes where we discussed transformations of matter in different situations, but not the situations used in the interviews, using this molecule concept and elaborating it. In 1999 the students for instance dramatized molecules in ice, water and water vapour and in 2001 we presented the idea, for a burning match, that molecules can react with other molecules and turn into other kinds of molecules. More details about these interventions are presented in Holgersson and Löfgren (2004). During these first years of the study the teachers were invited

[1] We are well aware that the way we introduced the molecule is not scientifically correct. Comments on this are placed in the next paragraph.

to demonstrate and discuss similar situations as the ones in our interventions with the students. Some teachers did this and some did not but those teachers who had discussions only used the simple particle model scarcely when explaining the phenomena. In spring 2003 the teachers performed interventions designed by the researchers. In these interventions they were supposed to discuss some situations in which matter transform and in these discussions use the particle idea. Four different teachers were involved and the interventions turned out to vary more than planned and the particle idea was scarcely used in the discussions. From autumn 2003 the students have had ordinary lessons in biology, chemistry and physics with subject specialised teachers and there has been no influence from the researchers. The particulate nature of matter was firstly introduced in physics and this was done in the very beginning of school year 7 (autumn 2003).

The choice to use the word molecule, in the interventions, and not particle or atom was discussed in our research group. We agreed that from our perspective the word particle was not good because, at least in the Swedish language, it would too easily be thought of as a macro-particle. Choosing between molecule and atom, we reasoned that more materials, which we deal with in ordinary life, are made up of molecules than are made up of atoms. We have introduced the molecule as the final link in a division process and this might obstruct the students' understanding of the properties of molecules and atoms (e.g. Andersson, 1990). There are always choices needed to be discussed and decisions forced to be taken and the research group decided to introduce the particulate nature of matter in the way described above which are in line with Novak's and Musonda's (1991) introduction of the particle idea. The purpose of presenting the idea of the particulate nature of matter was to make it possible for students, who wanted to and who found it beneficial, to use the molecule model when thinking of and discussing transformations of matter in different situations.

Interviews

The only possible way to gain information about how students learn and think about different phenomena is through some kind of communication. Like many other researchers (e.g. Duit, Treagust & Mansfield, 1996), we have found that a friendly, semi-structured interview with an individual student about a phenomenon and with concrete things present can give reliable information about his or her ideas. Saying this we are aware of the fact that responses in interviews are co-constructed and dependent of the line of questioning. We have conducted interviews allowing students to explain the transformation of matter in three situations:

- the future of fading leaves left lying on the ground
- the disappearance of the wax of a burning candle
- the appearance of mist on the inside of the cover of a glass of water.

The three situations represent different kinds of transformations of matter. In the situations with the fading leaves and the burning candle chemical reactions occur which change, in the first situation some, and in the second situation all, of the matter into invisible gases. In the situation with the covered glass of water some of the water changes to invisible gas and then again becomes visible water. In this situation there is no chemical reaction changing the matter to other forms of matter but only a change of state. If the students were to meet and discuss the situations in their secondary school education it would be in biology, chemistry, and physics, respectively.

In an earlier project, Hellden (1999) showed that students' ideas about conditions in life, growth, and decomposition also included phenomena such as burning, evaporation, and condensation but also that these phenomena were poorly understood by the students. With the longitudinal design it therefore seemed logical, interesting, and potentially rewarding to choose the three situations above to further investigate how students change their understanding of transformations of matter.

The main structure of the interviews has been as follows: The student is presented with some leaves and asked the question: “These leaves have been lying on the ground all winter. What do you think will happen to them if they are left lying on the ground?” Then two candles, one long and one short, are presented. The interviewer asks, pointing at the candles “What do you think has happened to that piece of the candle?” Lastly a glass with some water and covered with a glass-plate, on which some mist has formed on the inside, is shown and the interviewer asks, “What do you think it is that we can see on the cover and how do you think it could become like this?” In five interviews the students listened to an earlier interview, mostly one from the year before. They were then asked: "Do you have the same ideas today or have they changed?", and "What do think today?"

In the interview 2006 the students, after having explained the situations, were reminded about the early interventions in which we had introduced a molecule concept and also the fact that they in school had learned much more about atoms and molecules. If the students had spontaneously used a molecule concept in their explanations they were asked to elaborate their answers focusing on the molecules in the water, wax and leaf respectively. Those students who had not used a molecule concept were asked to do so.

As could be concluded from Table 1 we have performed interviews 13 times through the years. All these interviews have been tape-recorded and then translated verbatim.

Analysis

In the analysis of this part of the project we start by analysing the interviews of the 16 year olds with respect to how the students use a molecule concept and then with this as a starting point we look back on the students earlier interviews trying to find trends and interesting patterns. Students’ conceptions of matter and particle thinking have been categorized in different models (e.g. Andersson, 1990; Johnson, 1998c) but these models have usually been formed out of students' responses to more arranged situations and more precise questions than in our study. As earlier research has focused on the students' degree of understanding of the scientific concept 'the particle idea of matter' we did not find categories used in earlier research helpful for answering our research questions about how students use a molecule concept. In order to analyse the interviews of the 16 year olds our first question was: "What can be expected?"

We know, from having studied the students' textbooks, that they explain processes such as evaporation, condensation, and burning using the idea of the particulate nature of matter. The textbooks hold a lot of information about molecules and atoms, and different chemical reactions. There are a lot of chemical reactions presented with formulas. The common elements are presented with their symbols and even substances such as wax and cellulose are fully presented with their chemical formulas. We know from experiences as teachers and teacher educators that most teachers follow the textbooks. In our study different teachers are involved but we could not find any difference between the explanations of students from the different classes. We would from this claim that students have been taught about evaporation, condensation, and burning using the idea of the particulate nature of matter. It is clear that both the teachers' and the curriculum designers' (Swedish National Agency for Education, 2007) intentions are that students by the end of the compulsory school should understand and should be able to explain these processes. The intentions are also that students should recognize these processes in everyday situations and thereby be able to understand, describe, and explain everyday situations such as the ones in our interviews using scientific ideas consistent with the taught material.

We know from earlier studies (e.g. Schoultz, Säljö & Wyndhamn, 2001) that students often do not use their scientific knowledge in everyday situations although they have knowledge and are able to use it when confronted with questions in a “scientific situation”. In the last interview at the age of 16 the situations are well-known to the students as we have asked about them throughout the study. Since at the end of the last interview we especially asked the students to explain the processes using a molecule concept they were well informed about the interest of the interviewer and could be expected to use what knowledge they have about molecules.

Some of the students have spontaneously used a simple molecule concept in their explanations of the situations with the covered glass of water and the burning candle now and then during the years (Holgersson & Löfgren, 2004, Löfgren & Helldén, 2007). We have seen that for some students the idea offers a useful tool in explaining how something transforms into invisible things (Löfgren & Helldén). Earlier studies (BouJaoude, 1991; Johnson, 2000; 2002) show that combustion in the situation of a burning candle and decomposition hold particular difficulties as types of chemical change. From the students’ comments over the years we also know that especially the situation with the burning candles has challenged them. Taking all this into consideration we would expect most of the students to recognize the evaporation and condensation processes in the situation with the covered glass of water. We would expect some of the students to recognize the chemical reaction taking place in the situation with the burning candles. We would expect them to talk about these processes using scientific expressions but not necessarily use a molecule concept or the particulate nature of matter in their spontaneous descriptions and/or explanations. Some of the students when especially asked about molecules, we would expect to be able to explain these two situations making some sense of the idea of the particulate nature of matter.

In the situation with the fading leaves the students have not in earlier interviews used a molecule concept and we do not expect them to use it spontaneously in the last interview either. We believe that the students themselves much more have to combine knowledge from different areas to be able to explain the fading process with the help of a molecule model. Our expectations of the students' abilities to use the molecule concept in this situation, even after prompting, are lower and more ambiguous but we would think that some students should make connections to combustion and thereby to a chemical reaction taking place.

Using these spectacles we have formed categories out of how the students use the molecule concept in their responses in the interview at 16 years of age. In the end of this interview we especially prompted the molecules. We have read the answers over and over again trying to find the main ideas used in the answers and out of that we have formed categories. We could discern four different categories of answers, and these are described in the next section. In the process, finding the categories and then categorizing the individual students' answers, we have had discussions within the research group and with an external researcher. It is difficult to categorize a student's answer into just one category as an answer could hold features from different categories. We have read an answer over and over again trying to find the main message of the answer and out of that we have decided the category. We believe that knowing the students as we do from all these interviews have helped in the categorizations but we are also aware of the risk that our knowledge could lead us to wrong conclusions. One student's answers could fall into different categories in the different situations, but there could also be students whose answers fall into the same category in all three situations. We could then use these results and follow a student in a certain category backwards in order to find patterns between spontaneous use of molecules in earlier years and the category at the age of 16, for the three different situations. This was especially interesting as we wanted to explore whether there is any coherent history of use of the particle idea, that might shed light on student explanations at the end of their formal schooling. The presentation and discussion of the longitudinal findings are presented in a later section.

There are two aspects of a methodological nature that need to be addressed before presenting the findings. The first one is the problem of trying to illustrate results with excerpts from interviews. The excerpt only presents part of a whole interview and taken out of its context it might lose meaning that was obvious to us who have listened to and analysed the whole interview. The other aspect needing comment is the follow-up questions. As an interviewer, and probably especially when interviewing young children, one has to decide when a follow-up question is beneficial or not. This means that questions asked were not the same in all interviews. The interviewer had to use her or his judgment in deciding how far to prompt the student in every interview. This is the nature of semi-structured interviews which also gives them a flexibility argued for by Ginsburg (e.g. 1997).

All names used are pseudonyms, and in all excerpts, the first number within brackets is the age of the student and the second indicates whether it was the first or second interview of that year. For example, [9y:2] means that it was the second interview the year the student was 9. The language in the excerpts has of course been translated from Swedish, and changed to be more grammatically correct than the verbatim transcriptions. This was done in order to make the reading easier. In the interviews at age 16 the student first gives an answer without any prompting. Then a section follows where the interviewer especially asks about molecules. In the excerpts there is a line of dots separating the two parts.

Students' use of the molecule concept at the age of 16

Four categories of answers

When analysing the interviews at the age of sixteen we found, as expected, some students who are able to use the molecule concept as a productive tool in understanding and explaining the situations as they understand them. We have in this analysis taken each student's understanding of the situation as the point of departure. This means we have analysed their use of the molecule concept in making sense of the situation irrespective of the correctness. A few of the students, such as Gunnar who is illustrated in the transcript below, are able to ~~both explain the situation in an everyday language and then~~ use the molecule concept as an abstract model making it possible to deepen their understanding and explanation of the situation. We labelled this category 'D'. The selected transcript from Gunnar's interview illustrates this process and the resulting response. As described above the dotted line separates the two excerpts, the first showing Gunnar's answer without the interviewer prompting with the molecule concept and the second showing the interviewer's prompt and Gunnar's response to this prompt.

[Gunnar, 16y about the covered glass of water]

Interviewer: How do you think it could become like this?

Gunnar: It has evaporated from the water in the glass because of the temperature in the room and then it evaporates and then it reaches the lid and is cooled down.

…

Interviewer: If we then imagine a molecule in the water what do you think happens with such a molecule?

Gunnar: When it is heated I thought that the molecules move more and more and are set free from each other and in that way they leave the glass and evaporates out into the air.

Interviewer: If we keep to the situation with the glass and the lid on it?

Gunnar: Then they come up to the lid and it is cold and then the molecules are cooled down and do not move as much and turn into liquid again.

In this D category there are also answers which are short as the next example shows.

[Hedda, 16y about the fading leaves]

Interviewer: What do you think will happen to these leaves if they are left lying on the ground?

Hedda: Either the worms eat them or they are broken down and then they are turned into soil.

…

Interviewer: And now if you imagine a molecule in the leaf, what could happen to it?

Hedda: I think it is the same (as with the candle) it is broken down to atoms and small things and then it can join again and become other substances.

In the D category there are students who can describe the evaporation and condensation processes using the molecule concept in respect of the distribution of water in the air. The students make use of the ideas that molecules are in perpetual movement and that molecules can gain or lose energy and thereby the movement becomes faster and slower, respectively. There are also students who use the idea that new molecules can be formed by rearrangements of atoms.

In the next category, labelled 'C', the students think of the molecule as a very small particle, very often a small part of the substance. This particle is too small to be seen, meaning it is useful in understanding that matter can go out into the air without being seen. It can also change but usually in the same way as the substance. This means these students understand the molecule as a particle with properties the same as the matter concerned. It is also quite common that students think the molecules are formed in the process. Their ideas are strongly tied to the perceptual characteristics of the substance and do not include the abstraction implied by the molecular transformation model. The selected transcript from Jenny's interview, about the burning candles, illustrates the C category. Jenny introduces molecules spontaneously and then tries to elaborate her answer when especially asked about the molecule. When categorizing the 'molecule response' from Jenny we have also considered her spontaneous answer. This has been done for all students who have spontaneously used molecules in the interview responses.

[Jenny, 16y about the burning candles]

Interviewer: What do you think happens to that part of the candle?

Jenny: It becomes hot and in the end it rise up in the air. It becomes hot and rise as small molecules. Some of it runs down there but then it disappears up in the air.

…

Interviewer: If you imagine a wax molecule what do you think happens to it?

Jenny: It rises up in the air. And then I think the air is made up of a lot of different molecules in that case and then I think it disappears up in the air with the heat.

In the C category the students use the molecule in order to describe or explain the situation concerned. As many students, as Jenny, think that the wax evaporates out into the air and is not part of the burning process many students will use the molecule in the same way in the water and candle situations. The simple molecule model used includes molecules too small to be seen and the smallness also enables them to move out into the air. In contrary to the students in the D category the students do not use the idea of molecules in perpetual motion, gaining and loosing energy. A model with the aspect of smallness is, in the students' opinion, rich enough to satisfactory explain the situations. In the situations with the fading leaves and burning candles there are students categorized in the C category who say (without any explanation) that molecules can turn to other molecules.

Then there are students who do not productively use the molecule concept but we have decided to form two different categories out of these answers as it was very obvious that we had one group of students who tried to use scientific facts in their answers and one group who did not. As we wanted to use the categories also in order to follow the students backwards looking for interesting patterns we found it important to make this distinction. Some students, when they are especially asked about the molecule, start talking with scientific expressions and concepts or use facts from the science learned in school but this information is not really of use to explain more about the situation. These answers form our 'B' category. Paul's response to the situation of the fading leaves illustrates this category.

[Paul, 16y about the fading leaves]

Interviewer: What do you think will happen to these leaves if they are left lying on the ground?

Paul: They moulder and they turn into soil.

…

Interviewer: And molecules in the leaf, what do you think happens to them when the leaf moulders?

Paul: They are influenced by the atmospheric humidity, it is like rust. Rust, then it is iron and also copper. If one has a copper plate and an iron screw then the screw will rust because it is less inert. One could say that the leaf is less inert then the soil and is attacked by the atmospheric humidity and it rusts, one could say. The leaves will have small holes and perhaps worms and wood-lice, they are perhaps components of this atmospheric humidity that attacks them, and they disappear into the soil and become small, small things and become part of the soil

We claim these answers hold scientific facts and knowledge but the students do not seem able to connect this knowledge with these everyday situations in a productive way.

The fourth category labelled ‘A’ contains answers in which the students do not use the molecule. Either the students say they do not know what would happen to a molecule in the substance or they tell the same story again but have included the word molecule somewhere in the story. The reason to include these kinds of answers in the same category is that we claim the students are not using the molecule concept, but they have different answering strategies. Excerpts from the interview with Hilda illustrates category A.

[Hilda, 16y about the fading leaves]

Interviewer: What do you think will happen to these leaves if they are left lying on the ground?

Hilda: They are changed by the nature. The nature turns them into soil.

…

Interviewer: A molecule in the leave, what happens to it when the leave turns into soil?

Hilda: It changes and is turned into soil.

To conclude we have found four different categories into which the students' answers, from the interview at the age of 16, could be sorted. We like to remind of the fact that the point of departure in the analysis has been the student's understanding of the situation. The four categories are:

A <u>No distinction between molecule and substance</u>

The answer is the same whether the question is about the situation or about the molecule or there is no answer to the question about the molecule. These answers do not really show any ability to use a molecule concept that is distinct from a more general view of 'substance'.

B <u>Scientific facts used in a non-productive way in relation to the described situation</u>

In few of the answers molecules are spontaneously used when describing and explaining the situation. There is an answer to the question about the molecule whether molecules are used spontaneously or not. These answers show knowledge about scientific facts, including words and expressions but the students are not really able to use this knowledge in a productive way to add to their descriptive views about changes to substances.

C <u>A molecule concept used in a productive way as a small part of the substance</u>

A good half of the answers spontaneously use molecules when describing and explaining the situation. There is an answer to the question about the molecule where the molecule has a function in the explanation. The simple molecule concept used seems to be productive in the way it could, for instance, be used to understand an invisible part of a process, but the molecule concept is undifferentiated from that of a very small portion of the substance.

D A molecule model building on the scientific idea of the particulate nature of matter

In these answers the students show some understanding of the scientific idea of the particulate nature of matter. They can use at least parts of the scientific model of the molecule concept in order to better understand and explain the processes, they believe are involved in the situations.

The outcome of the categorization

As already mentioned when explaining the analysis we could discern four different categories of answers and we have categorised a student's answer into one category per situation. This means there are students whose answers fall into different categories in the different situations but also students whose answers fall into the same category in two or all three situations. ~~It is difficult to categorize a student's answer into just one category as an answer could hold features from different categories. We have read an answer over and over again trying to find the main message of the answer and out of that we have decided the category. In the process, finding the categories and then categorizing the individual students' answers, we have had discussions within the research group and with an external researcher. We believe that knowing the students as we do from all these interviews have helped in the categorizations but we are also aware of the risk that our knowledge could lead us to wrong conclusions.~~ Table 2 shows the outcome of the categorization of the students' answers in the different situations.

Table 2, please insert about here

From Table 2 we see that there are about the same amount of students[2] in the A category in the three different situations. In the water situation there are fewer students in category B and more students in category C compared with the other two situations. In the water situation the students very often talk about a molecule and a water droplet in the same way and they can change between molecule and droplet many times in the same sentence. The everyday language and the scientific language are closer in this situation. This probably makes it easier for the students to use a simple molecule concept as a productive tool in explaining this situation than in the other situations. This sometimes makes it difficult to discern between category C and D. But it probably also explains why the students do not, as often as in the other two situations, use science knowledge not productive to the explanation of the situation. This explains the result of fewer students in category B in the water situation.

Of the five students in category D in the situation with the burning candles it is only one who explains a burning situation, the other four understand the situation as if the wax evaporates (this is obvious both before and after the prompt). All students in the interview at 16 years of age know that oxygen is needed to make the candles burn but none of them can explain why. When asked why oxygen is needed they answer '*because otherwise the candle will go out'* or *'I do not know, it is just needed'*.

In the situation with the fading leaves the students' use of the molecule concept is brief. It is obvious that they are even less accustomed to try to understand and talk about this situation using the scientific model with molecules and atoms than in the other two situations. A few students claim very firmly that molecules in the leaf are of another kind because of leaves being '*living matter and not just matter'* (Inger, 16y) or because of leaves being *'green and then there are more living molecules'* (Jenny, 16y).

[2] In Table 2 the amount of students and answers will be the same within one specific situation but in the column 'Total for category' every student contributes with three answers, one from each situation

From the last column in Table 2, where the answers from the three have situations been summarized, we can gather that in almost one third of the answers the students do not use the molecule idea at all. One fifth of the students' answers hold scientific facts of different kinds but in these answers the students are not capable of using these facts, including the idea of the particulate nature of matter, in a productive way to explain the evaporation and/or condensation processes and/or chemical reactions occurring in these situations. From Table 2 we can also understand that in one third of the answers the students use a simple molecule idea. This molecule concept is possible to use in a productive way as it explains the invisibility and the 'lightness' needed to understand the evaporation process. The concept also contains a possibility that molecules can change from one kind to another and this uncomplicated idea is used in explaining that leaves can turn into soil. We can also gather that in only 12 out of 69 (about 20%) of the explanations the students use molecular ideas in scientifically acceptable ways. This is at the age of 16 after considerable exposure to formal teaching of atomic and molecular ideas and including prompting the molecule in the interview.

From the 23 students attending the study 14 students' answers do not fall into the same category in the three situations. But there are three students whose answers fall into category A, there are two students whose answers fall into category B, there are three students whose answers fall into category C and one student whose answers fall into category D in the three different situations. The nine students whose all answers fall into the same category are in the next section called 'A, B, C and D students' respectively. In the next section we will also mention for example 'a student in the B category'. This means the student's answer in the present situation is categorized in the B category and this student's answers in the other two situations could be categorized in any of the four categories.

Insights from the longitudinal study

In this section we will start by comparing the results in the 16 year interview with the use of the molecule concept through the years comparing the three situations. Then we will shortly comment on the common features of the A to D students. We will present one B, one C and one D student as examples of what is achieved within the circumstances present in this study. Lastly we will show examples of how the students have used a molecule concept before formal teaching occurred and make some comments in connection to these results

Using the molecule concept in the three situations through the years

There are some interesting differences and trends when looking into the spontaneous use in the last interview and the use over the years of the molecule concept in the different situations and analysing this in relation to the different categories. In the situation with the covered glass of water there is a connection between the spontaneous use in the interview at 16 years of age and the category of response to the molecule question. No student in the A category uses the molecule spontaneously. One third of the students in the B category and half of the students in category C and D use the molecule concept spontaneously in this interview. There is also a connection between the earlier use of the concept and the category.

The students from category A and B have used the molecule concept in about a third of the earlier interviews[3]. Students from category C have used the concept in half of the earlier interviews and students from category D in 60% of the interviews. We can then follow a trend through the categories showing more spontaneous use and more use of the molecule through the years as we pass from category A to D. Gunnar from category D does not use the concept

[3] We decided not to include the interviews from age 8, 10, 12 and 15 as the students then first listened to an interview in which molecules were mentioned. We also did not include the first interview 7:1 (nobody used molecules then and had probably not heard the word). The interview at the age of 14 had a different design which does not make it possible to include. The number of earlier interviews appropriate for this analysis is then seven.

spontaneously in the interview at 16 but has frequently used it spontaneously in earlier interviews. We will come back to Gunnar and then also discuss this observation.

In the situation with the burning candle there is a trend showing more spontaneous use and more use in earlier interviews as we pass from category A to C but for the D category both the spontaneous use and the earlier use drops. In this situation the students start later to use the molecule concept than in the water situation. The words and concepts used in talking about burning candles in everyday situations are further apart from the scientific explanation than in the water situation. But this situation has also challenged the students through the years as they have been very aware of not fully understanding the situation. We have seen at least two possibilities to understand the role of the wax in this situation: either it is part of the burning process or it is there to make the wick burn slower and thereby making the candle last longer. In the analysis forming the categories A to D we have, as said before, looked at the students' ability to use a molecule concept out of their own understanding of the situation. Many students, in the last interview, think the wax evaporates out in the air and some of them can out of that, as in the water situation, use the molecule in a productive way.

In the situation with the fading leaves the molecule is not used spontaneously in any interview over the years. To begin with we thought that two students used the molecule concept spontaneously at the age of 16 but after looking more deeply into these students' answers and the interview schedule we think they had been informed about our interview questions and tried to answer in line with our questioning in order to shorten the interview. This judgement is based on our knowledge of the students throughout the longitudinal study.

Features of the students' descriptions in the four categories

As said before most (14) students' answers do not fall into the same category in the three situations but there are three students in A, two in B, three in C and one in D in all situations.

The A students have through the years been less talkative than most other students and they started off with and seem to have gained less knowledge than the others. As the A students have not said very much in the interviews the change through the years is difficult to follow and we decided to not present any A student in more detail. The two B students were very short in their answers and did not seem to have a wide vocabulary to begin with. The C students have been talkative and have through the years used both in and out of school experiences in their descriptions and explanations. The D student is Gunnar mentioned before. In the very first interview he did not have much to say but then he developed fast. He obviously enjoys school and he is in all respects a good learner. We will now present Paul one of the B students, Jenny one of the C students and Gunnar the D student in more detail in order to show what can be learned by following students' explanations over a longer period of time.

Paul a B student

We will now follow Paul in the water situation showing his awareness of learning new words as a part of his learning process. At seven years of age Paul understands the situation through some kind of manipulation with the glass. At the age of nine he says '*It is water from the water in the glass. The heat that has come down there makes the steam water rise.'* From the next excerpt we can notice Paul is explaining more or less in the same way at the age of eleven.

[11y:1]

Paul: It is water, steam water.

Interviewer: Where does it come from?

Paul: From the water.

Interviewer: How does it come from the water?

Paul: When it has been there for many days then it melts in a way and as vapour.

Interviewer: What is needed to have vapour?

Paul: It is hot sometimes.

Interviewer: And if we let this glass stay open in the room for a fortnight or more. What happens with the water then?

Paul: There is no water left.

Interviewer: Well, where is the water then?

Paul: In the air, vapour.

Paul, in the above interview, uses 'melt' instead of 'evaporate' and after having listened to the interview at the age of fifteen Paul goes on in the following way:

[15y]

Paul: Yes, it is good but I know more words now about it. The water condensates and it has nowhere to go and stays in the glass and puts itself on the walls and if one takes the lid off and it stands like that for a fortnight or more than there will be no water left because it has vaporized.

Now he uses new words as condensate (probably mixed with evaporate) and vaporize. By his first comment we can also conclude Paul believes learning new words is important and therefore worth commenting. In the next excerpt from the interview at sixteen years of age we can again notice how he enjoys using new words and showing his knowledge.

[16y]

Interviewer: How do you think it could become like this.

Paul: It is the same (as the candle situation), the thing that is solid is heated and turns to gas. It is water droplets up there.

…

Interviewer: When we started this project we talked about molecules.

Paul: Atoms

Interviewer: Well, we did only talk about molecules in all kind of materials but then you have talked about atoms and molecules in school.

Paul: Molecules are made up of atoms and atoms are made up of particles, electrons, protons and neutrons and such things.

Interviewer: Yes, if we think of a water molecule here in the water could you try to tell me what happens to such a molecule?

Paul: This is worse than school (laughing). Those molecules are made up of oxygen and hydrogen, one hydrogen and two small oxygen, no I do not know. Yes two hydrogen and one oxygen, when it turns warmer one could say those oxygen atoms they move, they sort of pop off and they put themselves on the cover.

From the last part of the interview we can conclude that Paul knows a lot of scientific concepts and that he remembers a lot of what is presented in the school books. The problem is this knowledge is not really productive in understanding the situation in more detail. The result is that he goes on talking and we do not really know if he believes that oxygen atoms can pop off or if this is an answer given 'in the minute' without much thought.

We have seen in the excerpt on page 17 that Paul is 'good' with these kinds of explanations when asked to elaborate his answers. In the situation with the burning candles Paul also mixes correct concepts relevant to the situation with expressions like ' *these molecules they jump off they sort of become smaller and disappears and then they become other parts as their original parts oxygen and nitrogen…'*. We have a feeling this has become an answering style to Paul and that he is rather successful in his schoolwork using this style. The second B student resembles Paul concerning the answering style through the years and in fact students in the B category seem very capable of learning facts from school and elsewhere but not always capable of connecting these new facts with what they already know.

Jenny a C student

Jenny has used the molecule concept now and then in her answers both in the water and the candle situations through the years. As we can see from the excerpts below she has, in the water situation, been focused on the small closed system and she has a strong feeling that this has implications for the process.

[7y:1]

Jenny: It chokes like, just as if you take a glass and put it upside down on top of a candle. It burns out. It cannot breathe then. Then it has become like that up there. It has gone old and so. It has flown away.

Already in the very first interview Jenny uses an experience and makes a connection between this experience and the situation asked about. To make connections between other experiences and the shown situations is more common amongst C students than amongst other students.

[11y:2]

Jenny: It is water vapour. When you choke the air, because the water rises if it just stands (without a lid), but now you choke the air and it becomes hot perhaps and wants to come out then.

Interviewer: If the glass had been left open for say a fortnight what had it been like then?

Jenny: I think there had been less water because it rises up in the air.

Interviewer: Water could rise up in the air then?

Jenny: Yes, small, small, small water molecules, I think.

In this interview sequence we have an example of using the molecule concept to explain why water can rise into the air. This is very common and many students in the interviews at 10-13 years of age use the concept this way.

[16y]

Jenny: It is water vapour or water molecules, type.

Interviewer: And how do you think it has become like that?

Jenny: It is choked or the water is choked and then there is no oxygen and then it tries to get oxygen and then those water molecules come and seek for it and are stuck on the lid.

…

Interviewer: If you imagine a water molecule in the water what do you think happens with such a molecule?

Jenny: I do not know how it happens, or how it rises but I think it has something to do with the fact it wants oxygen. I do not know how it comes up there but it wants oxygen or air and the air is blended, no I do not know, but there is water and then there is air and then it becomes water molecules, then there are atoms and a lot of those things but I do not really know how I think about it, but it wants oxygen and because of that it will move.

As seen from the transcripts Jenny needs a kind of molecule concept to explain the situation but she gives a lot of properties to the molecule and to matter that are not scientifically correct. Jenny is unique mentioning the conditions for living and the role of air or oxygen in all three situations and through the whole study and still in the 16 year interview. When asked about this in the 15 year interview she answered *'well, it is only a way one talks about such things is it not?'*. It is rather common that students in the C category have talked about matter and molecules in the situation with anthropomorphous features but not as consistently as Jenny. In the very first interview we noticed that Jenny made a connection to an experience from another situation. The two other C students and students in the C category very often do this. Through the first years this ability seems to be helpful in their understanding of the processes in situations but perhaps this habit hinders them to by themselves make use of the abstract molecule concept taught in science lessons and textbooks.

Gunnar a D student

We will now follow Gunnar, the only student whose responses fall into the D category in all three situations. Gunnar started early to use the molecule concept in both the candle and water situations and after that in almost all interviews through the years but not spontaneously in the last interview. In the situation with the burning candles Gunnar has not realized that the wax is part of the combustion but he fully explains an evaporation of the wax. In the situation with the fading leaves his answer is very short and close to Hedda's (page 14). From the excerpts below we can see how he has used the concept in the water situation through the years.

[9y:2]

Gunnar: It is water molecules (on the cover) that sort of cannot rise from the glass. Then there is mist all over.

Interviewer: How do you think this happens?

Gunnar: They do not cope to stay in the water and then they try to get out.

[11y:1]

Gunnar: Water has evaporated and become water molecules that are inside the glass and who want to come out. And then they cannot come out and then they are stuck on the lid.

[13y]

Gunnar: It is water, it has evaporated some time and you have put the lid on and then it cannot come out and then it is stuck in there. /Mm/. And then more and more come when it evaporates it becomes some vapour and then it fastens more and more and in the end it is visible again like water.

Interviewer: If I had taken the lid away?

Gunnar: Then it had evaporated after a while it had become water molecules or so round in the air.

[16y]

Interviewer: How do you think it could become like this?

Gunnar: It has evaporated from the water in the glass because of the temperature in the room and then it evaporates and then it reaches the lid and is cooled down.

…

Interviewer: If we then imagine a molecule in the water what do you think happens with such a molecule?

Gunnar: When it is heated I thought that the molecules move more and more and are set free from each other and in that way they leave the glass and evaporates out into the air.

Interviewer: If we stay in this little system with the glass and the lid on it.

Gunnar: Then they come up to the lid and it is cold and then the molecules are cooled down and do not move as much and turn into liquid again.

We can notice that Gunnar uses the molecule concept in a productive way through the years. The molecules seem to serve as an intellectual tool in understanding the situation. He uses expressions such as 'they do not cope' and 'become water molecules' which are of course not scientifically correct. We claim this is of no harm to his possibilities to later understand the concept more scientifically correct, as we can see he does in the interview at 16 years of age. We claim that this possibility to use and elaborate the concept is essential to Gunnar's and all students' absolute conditions in understanding theoretical and abstract models in science. The way Gunnar has talked about the water molecules through the years has been seen and is still seen in the last interview in many students' answers and we agree with Papageorgiou and Johnson (2005) that these are necessary steps to the more scientific understanding of the concept. Gunnar is, in the last interview, able to talk about the situation in an everyday language and then when asked he uses the idea of the particulate nature of matter to convincingly explain evaporation and condensation. This ability has been argued for as important to acknowledge (Eskilsson & Helldén, 2003) and we would argue this ability is an important goal in reaching scientific literacy.

Using a molecule concept before formal teaching

In the above section we have seen Gunnar making sense of and probably needing a simple molecule concept in order to understand and explain the situation with the covered glass of water also in the years before formal teaching of the particulate nature of matter which started in autumn 2003. In the following excerpts we will see two other examples of students in the D category using a simple molecule concept in order to explain the evaporation process.

[Sune, 10y about the covered glass of water]

The water is full of water molecules (he actually uses the word monecules) and then they have very little space and then they try to split and come out and then they are stuck on the lid. If we lift the lid they will rise out into the air.

[Katja, 11y:2 about the covered glass of water after having taken the lid off]

Those molecules had gone up in the air because they just rise and rise and there had not been anything left there. …Because they are very small things that one cannot see or so.

These two students are capable of using the simple molecule concept presented in the short interventions in 1997, 1999, and 2001 in a productive way and especially Sune is doing this very early, already at the age of 10. They have then elaborated the concept to a more scientifically correct concept just as we have earlier seen Gunnar do.

But there are also examples of students in category C in the water and candle situations who have been using the simple molecule concept in this productive way in early interviews. The latest interviews below, when the students are 13 years of age, are from spring 2003, accordingly before formal teaching of the concept.

[Hedda, 11y:2 about the covered glass of water]

It is difficult to explain but I think those water molecules they sort of work together and sort of rise and there are too many and then they are squeezed up in the air.

This answer from Hedda is very close to Sune's. The two students seem to express almost the same idea namely: 'there are too many molecules and they will then rise because of this'. In the next excerpt we notice Inger explaining the invisible water in more or less the same way as Katja did in the excerpt above.

[Inger, 11y:2 about the covered glass of water]

I am not quite sure but water molecules are not visible and then one cannot see when they rise up there either, so then the water molecules rise.

Then we have two examples from the situation with the burning candles where the idea of molecules helps the students to understand the invisibility of the 'disappearing candle'.

[Jenny, 13y about the candle situation]

I do not really know but I think it (the candle) disappears up in the air and becomes small, small molecules, I almost think.

[Katja, 13y about the candle situation]

Well, it melts and then some can run down there but it is much more that disappears so then perhaps it becomes molecules. They can rise up in the air then.

All these examples show an ability to use a simple molecule concept in a productive way just as the students in the D category do but these students have not elaborated the concept into a more scientifically correct concept. Why these students do not develop the concept in the same way as the students in the D category we do not know out of this study. We can only establish this difference and speculate about what could help also these students to a better understanding of the particulate nature of matter. From our experience of this study and the students attending the study, and our experiences as teachers and teacher students' educators we believe the students in the C category could have made progress in the same way as students in the D category if the students had been helped to connect the simple molecule concept with the abstract molecule model taught in school. We believe it is important to ask the same questions as asked by Papageorgiou and Johnson (2005) about what the aim should be when the particle ideas are first introduced and if simpler models are important as steps on the stairs to a deeper scientific understanding of the idea of the particulate nature of matter.

Conclusions, and Implications

We have found four categories of answers – A: No distinction between molecule and substance; B: Scientific facts used in a non-productive way in relation to the described situation; C: A molecule concept used in a productive way as a small part of the substance; D: A molecule model building on the scientific idea of the particulate nature of matter - possible to use in all three situations when sorting the students' answers in the 16 year interview. Only in a fifth of the answers the students use molecular ideas in scientifically acceptable ways (category D). There is almost no difference between the three different situations if we have the student's understanding of the situation as our point of departure in the analysis. This means we could conclude that although a lot of teaching deals with the particulate nature of matter (Oscarsson & Jidesjö, 2005) few students really manages to use the particle model in a way expected and wished for by teachers, curriculum designers and the science community.

One fifth of the student answers show knowledge of scientific facts (category B) that are not used in a productive way in these everyday situations. We would argue the issue expressed by Driver et al (1985) in the following way

> The issue which needs to be considered is not whether students understand the theoretical ideas or models they are exposed to in teaching but whether they can use them or see them as useful and appropriate in interpreting actual events. (Driver et al, 1985 p 168)

is still worth consider and reflect upon. Almost a third of the student answers, especially in the water situation, make use of a simple molecule concept (category C) in explaining the situations. The students in the B category seem to understand more theoretical ideas and models but not to be able to use them whereas the students in the C category seem to find the ideas they hold, although less scientifically developed, useful in understanding and explaining these everyday situations. The question, not answered by this study, is how to help the students in both categories to develop into category D. The thing we would claim is that different strategies are needed to inform about successful teaching for the two groups. Concerning the students in category A we believe much more support is needed and out of knowing the students through the longitudinal study we claim one main issue to handle is motivation.

In the situation with the covered glass of water there are more answers in the C category and less in the B category than in the other two situations. It seems easier to use a simple molecule concept in a productive way in the water situation and we would argue this is not only due to the fact that evaporation might be easier to understand than chemical reactions but also due to the fact that the everyday language is much closer to the scientific language in the water situation than in the other two situations.

We have seen that most students in the interview at sixteen years of age start to explain the everyday situations in an everyday language and without using the scientific idea of the particulate nature of matter. This is of course expected unless we think that our longitudinal study has made the students aware of the science and especially the molecule concept as the special interest to the interviewers. From the answers given in the interviews of the 16 year olds we can in most cases conclude that the longitudinal study has not really had such an impact on the students' answers in the interviews. On the other hand as a researcher the longitudinal study is of great value in analysing the individual answers (Löfgren & Helldén, 2007).

An understanding of scientific models like the idea of the particulate nature of matter and being able to use the model in everyday situations is an essential goal in the compulsory school science. In this study only few students achieve this understanding but we can also conclude out of the longitudinal study that even young students are capable of using a simple particulate model in productive ways in trying to understand and explain transformations of matter in everyday situations. We have seen, in agreement with Tytler et al. (2007) and Papageorgiou and Johnson (2005), that students are able to use the particle idea as a productive tool in understanding evaporation and condensation. To learn to support and develop this ability in young students, in order to achieve more students that, at the age of 16, hold acceptable scientific ideas about the molecule concept and find it beneficial to use these ideas in actual situations, more research is needed.

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