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En longitudinell studie av 10 - 12-åringars förståelse av materiens förändringar

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Abstract

Title	A longitudinal study of 10-12-year-olds´conceptions of the transformations of matter
Language	Swedish, with summary in English
Keywords	Conception, using science knowledge, longitudinal study, categories of description, everyday phenomena, spontaneous explanation, explanation in discussion with others, chemistry learning, matter, molecule, phase concept, chemical reaction, and particulate nature of matter.
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The main aim of this study was to study young people’s ability to use science knowledge when talking about and explaining everyday phenomena involving transformations of matter. Pupils’ individual knowledge was studied both through their spontaneous explanations and through their explanations with appropriate help in discussions with me or with other pupils.

The framework for learning in this study involved both pupils’ individual learning and their learning in a social context. In the project, pupils discussed everyday phenomena with peers and with me. The role of the discourse was stressed in the interviews as well as pupils’ use of parallel models of explanations.

Data were gathered through four interviews with each one of 40 pupils from five classes during a longitudinal study over two years. The pupils were about 10 years old at the first interview. During the study three instructional units were carried out in the five classes. In the first instructional unit a basic particle model was introduced, to be used when discussing experimental situations during the instructional units. The development of the basic particle model was one of the themes during the instructional units. Other recurrent themes were states of matter, gases and chemical reactions. I decided not to introduce the concept of chemical reaction until the last instructional unit. Pupils’ statements in the interviews were categorised from these themes.

The categorizations emanated from presented research on pupils’ conceptions of science but also from the statements of the actual group of pupils. The correctness of the science concepts used was also taken into account in the categorizations. Sometimes I altered a method used before and sometimes I developed a categorization for a special purpose in my study.

An example of the category systems is the combined classification of pupils’ conceptions of the particle nature of matter that contains three perspectives:

A/ the quality of pupils’ particle model as revealed during the interview
B/ the nature of pupils’ use of the concept of molecule during the interview
C/ the number of situations in the interview where pupils use the concept of molecule.

The pupils did not replace their old models; they put for example a new particle model beside their old everyday model. Then they chose which model to use when they met new situations.

Most of the pupils were able to use knowledge of science when talking about known everyday phenomena involving transformations of matter. Almost all of the pupils in the group developed their own thinking models during the project. Pupils’ growing ability to describe features of chemical reactions and the development of their own particle model could help them to understand for example the nature of chemical reactions.

18 Summary

18.1 Background and Aims

In Swedish primary schools, everyday phenomena are often described but usually not explained. Perhaps the children can be helped to use their imagination when building their own models for discussing and explaining phenomena. An elementary particle model of matter is one example of a scientific model that could be a basis for the pupils' own models. A particle model for matter could help pupils to understand and explain phenomena involving transformations of matter.

The aims of this project are to study young people's ability to use science knowledge when talking about and explaining everyday phenomena involving transformations of matter. The development of pupils' explanations is studied on macroscopic and particle levels. Pupils' conceptions are studied from two different perspectives.

18.2 Framework

Frameworks for learning often refer to the works of Piaget and Vygotsky. Those who mean that learning best can be described as an individual activity often refer to Piaget´s work. Von Glasersfeld (1995) summarizes this by saying that learning takes place when a situation leads to a perturbation, and this perturbation leads to an accommodation that maintains or establishes equilibrium. This means that pupils replace their old structures of thinking with new ones. In some studies, where the researchers have the individual's learning as a starting-point, there are some results where the individual learning is not attached to changes of the thinking structures. Kärrqvist (1985, chapter 10), Taber (1998), Tytler (1998), Petri and Niedderer (1998) and Marton (1998) all mean that pupils use different models of thinking when talking about everyday phenomena.

Descriptions of learning in a social context often refer to Vygotsky's work. Pupils meet new ways of talking about phenomena in a social context, and they use these beside their old ones. Pupils' conceptions will be challenged and refined when pupils work together. Schoultz (2000, p 7) means that the discourse of science in science lessons is another discourse than the one you are in when talking about everyday phenomena. Östman (1995, chapter 6) emphasizes the importance the context and the use of language in the discourse have for the understanding. Solomon (1983) and Leach and Scott (1999) describe learning as the pupils' development of their ability to use these new ways of explanations on an individual level, and their reorganisation and reconstruction of the new information on a social level (Solomon, 1983; Leach & Scott, 1999).

Many researchers today have frameworks for learning containing both pupils' individual learning and learning in a social context. Piaget and Vygotsky also have these ideas but they do not make a strong point of the two aspects. Bruner (1990, 1996) completes his framework of learning with the social and cultural aspects of learning.

According to Leach and Scott (1999), learning science as learning to use science language can be understood as a process of internalisation. The learner must interpret, reorganise, and reconstruct his/her experiences from the interaction with others. Leach and Scott put learning in a social context together with learning as an individual activity.

Sfard (1998) and Paulsen (2000) describe learning by means of two metaphors, the acquisition metaphor and the participation metaphor. They mean that teaching must be an appropriate combination of these two metaphors, appropriate for the pupils and the teacher.

18.2.1 Consequences for this study

The framework for learning in this study contains both pupils' individual learning and their learning in a social context. In the project pupils will discuss everyday phenomena with peers and with me. The role of the discourse will also be stressed in the interviews as well as pupils' use of parallel models of explanations.

18.3 Concept of matter

Research on pupils' conceptions of science concepts and how they talk about everyday phenomena is important for me when I design teaching sequences and interviews during my project. I have the following structure of the presentation of such research:

- What is matter?
- Pupils' conceptions of matter.
- Pupils' ideas of the nature of matter.
- Pupils' conceptions of transformations of matter
  - Gases, liquids, and solids
  - Changes of states
  - Physical change or chemical reaction?
- Chemical reaction
- Teaching projects.

18.3.1 Pupils' conceptions of matter

Many studies of pupils' conceptions of matter show the problems pupils have when describing what matter is. Stavy (1990, 1991) finds that pupils do not consider invisible things to be matter. In Lee, Eichinger, Anderson, Berkheimer and Blakeslee (1993), and Stavy (1991) pupils mean that weight is central for matter. Many pupils cannot separate the concepts of matter, material and substance (Stavy, 1991; Krnel, Watson & Glazar, 1998; Johnson, 1996).

18.3.2 Pupils' ideas of the nature of matter.

The research on pupils' conceptions of the structure of matter contains many different conclusions. Piaget (1972) finds a spontaneous development of pupils' atomism when they talk about dissolving sugar in water. They say that the visible grains of sugar will be split into smaller and smaller particles until we cannot see them. Novick and Nussbaum (1978) use magic glasses to challenge pupils' models of gases. They mean that pupils must practice to use and develop their own models. De Vos and Verdonk (1996) mean that the particle model of matter is a good example of the stress between complicated modern theories that are difficult for pupils to accept, and the simplified models that are naive and false.

Renström (1988), Ben-Zvi, Eylon and Silberstein (1988), Griffith and Preston (1992), Whiteley (1993) find in their studies that pupils give the particles macroscopic properties. They talk about continuous matter and that a copper atom is a small piece of copper.

BouJaoude (1991), Claxton (1993) and Solomon (1992, chap 1) state that pupils' descriptions of the particle nature of matter often are unconnected and fragmentary. Others, like Johnson (1998), Lichtfeldt (1996), and Nussbaum (1993), suggest that a basic particle model can be introduced to young pupils.

It is important for pupils to work with models in order to develop their own models of scientific concepts (de Vos & Verdonk, 1996). Many studies have been carried out which address pupils' conceptions of transformations of matter but very few have a longitudinal design. Even young pupils can use a basic particle model to explain everyday phenomena (Johnson, 1998; Novak & Musonda, 1991). Nakhleh and Samarapungavan (1999) state that to understand the microscopic world you have to use your imagination to go from the macroscopic world to the world of particles. They suggest that this points towards an early presentation of the particle nature of matter.

18.3.3 Pupils' conceptions of transformations of matter

Matter can be transformed by physical changes and by chemical reactions. Physical changes can be changes of state and dissolutions. Understanding changes of state involves understanding the phases of matter. Stavy and Stachel (1985) and Krnel (1995) find that 9-13-year-old pupils do not spontaneously sort substances in solids, liquids and gases. They try instead to sort the substances according to what we can do with them. Pupils use water as a prototype for the concept of liquids according to Krnel et al (1998) and Lee et al (1993) and this seems to help them building up this concept. The Swedish concept "fasta ämnen" for solids make pupils think of hard and solid substances. Krnel (1995), Johnson (1996), and Lee et al (1993) also find this. Piaget (1973) finds that many pupils do not know that air is a gas, as also noted by Séré (1985) and Stavy and Stachel (1985).

Many studies about evaporation and condensation of water have been carried out. Zarour (1976), Bar (1989), Brody (1993), and Eskilsson and Lindahl (1996) find the same ideas about clouds and rain as Piaget (1973) Many of them mean that rain is a good everyday situation to use when introducing science concepts as evaporation and change of state. Bar (1989), Helldén (1993), and Eskilsson and Lindahl (1996) find that even young pupils, 9-10-year-olds, use the cycle of water in their explanations. Brody (1993) mean that you cannot reduce the phenomenon of rain to some science concepts but you must also take in aspects from the geosciences about the atmosphere and subsoil water.

18.3.4 Chemical reaction

Andersson (1990) and Johnson (2000a, 2000b) report on pupils' difficulties in explaining transformations that involve chemical reactions. Andersson defines a categorisation of pupils' explanations of situations involving chemical reactions:

- It is just like that
- Displacement
- Modification
- Transmutation
- Chemical interaction

Many researchers have used this categorisation. Often only very few pupils are found to be in the last category, that correspond to the chemists' understanding of chemical reaction. Krnel

(1995) finds that many pupils describe combustion as a modification. He means that if pupils do not know the difference between object and substance they explain chemical reactions as modifications. Johnson (2000a) thinks that using Andersson's categories favours those who have at good concept of matter. You cannot see when a substance changes if you do not know what a substance is. Solsona and Izquierdo (1993) study the verbs used by 16-year-olds when they explain what happens when a nail is rusting and when peeled apples or potatoes are getting darker. They find both chemical concepts and everyday explanations. Holding (1987) and Meheut and Chomat (1990) find that pupils often talk about what happens with one of the substances and say nothing about interaction between the substances involved in the reaction.

18.3.5 Teaching projects.

Many school projects build on the results from research on pupils' conceptions of the concepts of matter and transformation of matter. Lijnse (2000) compare the *Children's Learning in Science project (CLIS-project)* in Leeds and a problem-posing project used by a group from Utrecht. The CLIS-project has three phases: the elicitation phase, the restructuring phase, and the review phase. Lijnse suggests that the evaluation of the CLIS-project shown by Johnston (1990) is no evidence for the CLIS-project being better than ordinary teaching. He finds that the particle models pupils spontaneously use in the CLIS-project are small-scale macroscopic objects. They differ from the particle models used in science. The starting-point for the problem posing approach is that pupils do not have any alternative conceptions that need to be changed. Pupils have to learn to use the scientific models. In this project it is important for pupils to know the background for why a particle model can help us to understand macroscopic phenomena and in what way these particles differ from small-scale macroscopic particles.

Nussbaum (1993) finds a growing awareness of pupils' difficulty in understanding the particular nature of matter by the teachers. He suggests an introduction of a basic particle models at the age of nine. He proposes a teaching project of 15 lessons. These contain questions to discuss and experimental situations. Examples of questions to discuss:

- Is air matter?
- What can you see if you use magic glasses?
- Why can you compress air more than water?
- What smells most of acetone and water?

Tveita (1993, 1996) introduces a kinetic particle model to 12-16-year-olds and finds that these pupils could use a basic kinetic particle model.

18.4 Research questions

I followed 40 pupils for two years from the age of 10 years. During this time I studied how they use science knowledge to explain and talk about everyday phenomena. The project addressed the following questions:

- How does a group of 10-year-olds develop their 'thinking models' of the nature of matter?
- How is the development of the pupils' understanding influenced by the introduction of a basic particle model?
- How does talking with a researcher influence their use of scientific knowledge?

I think pupils' individual knowledge can be described both as their spontaneous explanations and as their explanations with appropriate help in discussions with teachers or with other pupils. The later relates to the Zone of Proximal Development (Vygotsky, 1996). Therefore I study pupils' use of science knowledge from two perspectives:

a/ what pupils spontaneously can perform on their own

b/ what pupils can perform when they talk with me.

18.5 Methods and samples

The present study on learning and development of pupils' thinking builds upon data from a two-year longitudinal study of 40 pupils' explanations of everyday phenomena involving transformations of matter. The sample includes pupils in five classes from two different schools. The pupils in these classes were born between 1986 and 1988. The sample for the interview study includes about 40 pupils born in 1987. Data were collected in four interviews with each pupil from age ten to twelve. After the introductory interview there was one instructional unit of three lessons followed by an interview two months later each term. Knowledge of research on pupils' use of scientific knowledge when talking about everyday phenomena was an important source when I planned the content and implementation of the teaching units and interviews. In this project, I was the teacher as well as the researcher.

In the 1st and 3rd interview the same three situations are discussed: a sealed box with soil, a burning paper/a burning candle and the smell of sweets. In the 2nd and 4th interview, other situations such as burning petrol, rusting iron, rain, and magnesium in citric acid are discussed. I use semi-structured revised clinical interviews. All situations discussed during the interviews are illustrated with real objects. When we discuss smell we have sweets that smell and the burning paper is set on fire during the discussion. I had a list of things to be discussed but my follow-up questions built upon the pupils' answers. One aim of the interview was to present the discourse of science when talking about everyday phenomena.

In the instructional units between interviews some key ideas were presented and the pupils were doing practical work and discussing in groups of four. In the first instructional unit a basic particle model was introduced, to be used when discussing experimental situations during the instructional units. Development of the basic particle model is one of the themes during the instructional units. Pupils have to examine how they can compress water and air in closed containers. They also have to explain why a mixture of 50 ml water and 50 ml alcohol does not become 100 ml. To challenge their thinking about the particle nature of matter they also have to discuss why cylinders of aluminium, wood, and brass have so different weight.

Other recurrent themes are states of matter, gases and chemical reactions. In the first lesson, pupils have to assort substances in groups and argue for their grouping. In the next instructional unit they have to group new substances in solids, liquids and gases. In the third instructional unit the groups have to describe some substances. I want to see if they use the concepts of states of matter.

Examples of tasks about gases are evaporating acetone, sublimating carbon-dioxide snow in a plastic bag, the weight of a football before and after pumping in air.

I decided not to introduce the concept of chemical reaction until the last instructional unit. Nor did I use the particle model when discussing what happens during reactions. To illustrate chemical reactions, pupils mix pairs of substances e.g. citric acid and blueberry, soda and blueberry. We studied what happens and that new substances are formed and sometimes pupils talk about interaction between substances too. Similar tasks come back in the third instructional unit.

All the interviews were recorded on tape and transcribed. The lessons were videotaped and transcribed. The longitudinal design makes it possible to analyse the development of the individuals from different perspectives, e.g. over time, different contexts, and the influence of instructional units. Pupils' conceptions, as shown in the semi-structured interviews, are analysed from their spontaneous explanations as well as from their explanations with appropriate help in discussing with me.

Pedhazur and Pedhazur Schmelkin (1991, p 224-229) state that the researcher must be the greatest critic of the methods used. They give some examples of risks with this type of interviews. Using the same situations in recurrent interviews has an influence on pupils' answers. Different designs of interviews influence the result. Pedhazur and Pedhazur Schmelkin (1991, s 229-230) discuss generalization of the results and mean that this depends on the quality of the data collecting and the data processing.

18.6 The results

The interviews were analysed from different starting-points. The systems of categories are based on pupils' answers and on the scientific concepts. In each system I try to find categories corresponding to an increasing quality of understanding.

I start with an account of the development of pupils' particle models and how they use these models. Then I summarize how they talk about gases and situations involving chemical reactions. In all interviews we discuss what happens when something is burning and this type of chemical reactions has one chapter. Pupils' descriptions of a transformation involving a physical change is shown in a chapter named *Pupils' conceptions of the cycle of water*. One aspect of pupils' knowledge in science is how they relate this knowledge to experiences in everyday life. In *Knowledge and experiences* pupils' use of everyday experiences in the interviews is shown.

In order to illustrate learning situations in the instructional units some examples of these are given. They are only examples and are not used to illustrate the development of pupils' knowledge. The results also contain some examples of the development of individuals from different aspects.

18.6.1 The particle nature of matter

In the project we use a basic particle model. All substances are made up small particles called molecules. There are different types of molecules in different substances.

The description and combined categorisation of pupils' conceptions of the particle nature of matter contains three aspects:

A/ the quality of pupils' particle model showed during the interview

B/ the tendency of pupils using their concept of molecule during the interview

C/ the number of situations in the interview where they use the concept of molecule.

The aspect of the quality of pupils' particle model showed during the interview is based on pupils' explanations from the "talking with me" perspective. It contains pupils spontaneous statements as well as what they say after my follow-up questions. This aspect is categorized in the following categories: recognizing the word molecule, using the word molecule in descriptions, and using the word molecule in explanations. Statements in the explanation category involve talking about molecules as particles.

The A-aspect also is used on pupils' spontaneous explanations. Several pupils have the highest level in many of the three later interviews on the "talking with me" perspective but their spontaneous use of the concept comes later. Sometimes pupils are assigned a lower category in a later interview. I think this is because they have parallel models of explanations and that they use the model they think is best for each situation. When their model with the scientific content is growing stronger I think they choose this in more situations.

Pupils' tendency to use the concept of molecule during the interview is defined as the spontaneity of their use of the concept of molecule. The categories are: use after the influence of my follow-up question, spontaneous use later on in the interview but before my follow-up question, and spontaneous use early in the interview. My motives for this B-aspect of pupils' conceptions are that the use of the concept is related to the quality of the molecule model. If the pupils have a good particle model and see the use of it they also use it more spontaneously.

The third aspect in the combined categorisation is the number of situations in the interview where the pupils use the concept of molecule. If a pupil can see the use of the molecule model in all three situations discussed in the interview I think she/he also builds it on a model of higher quality.

The highest combined category, *spontaneously well,* means that the pupils use their concept of molecule to explain phenomena spontaneously in two of the three situations in the interview, and the category *spontaneously* that they use their concepts of molecule spontaneously in one situation in the interview. The category *stimulated* contains those pupils who use their concept of molecule to describe what happens in the situation only after stimulation from the interviewer. The stimulation can be a follow-up question. Pupils not using the word molecule in their descriptions have the lowest category, *do not mention,* for the interview. Table 74 illustrates the differences in categorization in the 2^{nd} and 4^{th} interview.

Table 1 Combined categorisation of pupils' use of their concept of molecule. Comparison between categorization of the 2nd and the 4th interviews

		Interview 4				
		Do not mention	Stimulated	Spontaneously	Spontaneously well	
Interview 2	Do not mention	4	8		6	**18**
	Stimulated	3	3	3	1	**10**
	Spontaneously		1	1	3	**5**
	Spontaneously well		4		2	**6**
		7	**16**	**4**	**12**	**39**

About 50% of the pupils belong to a higher category in the later interview when comparing the use of their particle model in the second and forth interview. Many of them are in categories two or more steps higher. In the forth interview twelve pupils, 30%, use molecules spontaneously to explain phenomena in more than one context (*spontaneously well*), and more than 80% do this spontaneously or after some assistance (*spontaneously well*, *spontaneously* and *stimulated*). In all comparisons between two interviews the amount of pupils in the higher categories are increasing. About five pupils belong to a lower category in a later interview. This can be due to the fact that this interview does not stimulate those pupils to use their new model.

In the 4th interview pupils are invited to tell me what they know about molecules. The analysis of these answers is based upon how many of the following three components the pupils spontaneously have in their answers: everything is built up from molecules, the molecules are small, and different substances are made up from different molecules. I compare each pupil's answer on this question with the combined category for the pupil. All pupils in *spontaneously well* and *spontaneously* give two or three of the components. None of those giving only one of the components are in these categories. Almost half of the pupils can give two or three of the components but they do not discuss the phenomena in a way, which puts them in any of the spontaneous categories. They do not see the connection between their concept of molecule and their everyday experiences. Perhaps their models are not so strong that they dare to use them.

18.6.2 The concept of gases

When discussing the situations in the interviews the pupils often spontaneously talk about gases. I think this gives information on pupils' knowledge of gases. I did not ask specific questions about gases. In the 1st teaching sequence we work with states of matter and gaseous water. In the second teaching sequence the pupils have to describe what a gas is and we carry out experiments comparing compressing air and water. In the third teaching sequence we focus on the weight of air and steam.

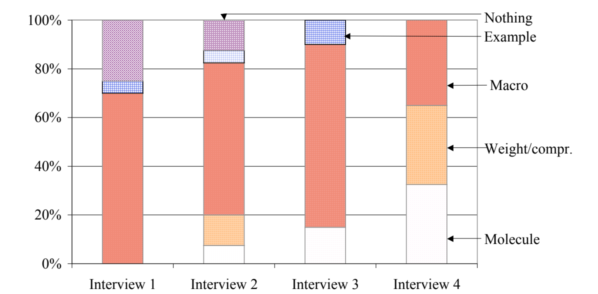

Figure 1 Categorisation of pupils spontaneous talk about gases

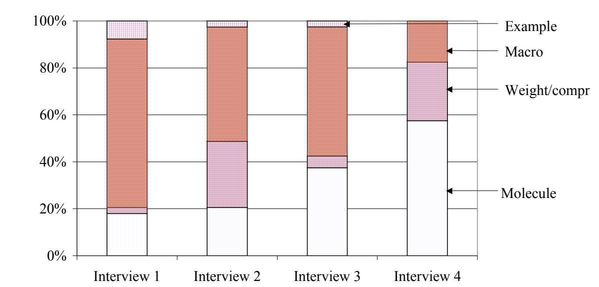

Figure 2 Categorisation of pupils talk with me about gases

The analysis of pupils' conception of gases has the following categories: comparing with air and other gases, talking about gases on the macro level (e.g. evaporation), giving examples of properties: a gas has weight or it can be compressed, and talking about gases on the molecule level. Pupils' talk about gases is analysed from two perspectives: spontaneous talk and talk with me. Many pupils have a higher level when I put follow-up questions than in their spontaneous talk. When we are talking, pupils leave their everyday discourse for a discourse where we use scientific knowledge. Figures 48-49 show the distribution of pupils' categories from these two perspectives.

The gases that pupils are talking about in most cases are steam, air and carbon dioxide. Pupils' talk about gases grows during the project and they use their knowledge about gases more and more spontaneously. In both perspectives the higher category pupils have in the 1st interview the higher category they get in the 4th interview. Pupils' early experiences of using science to talk about everyday phenomena seem to stimulate the development of their understanding science concepts.

18.6.3 The concept of chemical reaction

Many of the situations discussed during the interviews involve chemical reactions. The concept of chemical reaction is introduced in the last instructional unit. In the previous lessons the pupils have to describe what happens when they mix some everyday substances. In the interviews they meet other situations where chemical reactions are involved. Signs of chemical reactions in the descriptions of these situations are studied. The pupils are not asked to explain the concept of chemical reaction. The categorisation is based on Andersson's categories (1990). The categories used are *description*, *a new substance is formed*, *interaction between substances*, and *the use of their particle models*. That categories *new substances are formed* and *interaction* are assigned to statements where pupils talk about signs of chemical reaction. *Interaction* means here that at least one of the substances involved exert an influence on the other. *Interaction* is a higher category than *new substances are formed* because it means that pupils' statements contain explanations to what they see happens when new substances are formed. This analysis is based on pupils' statements in talk with me – not only on what they say spontaneously.

Understanding chemical reactions on a micro level is not the focus in the project. In spite of this 10-20% of the pupils use their molecule model when they talk about chemical reactions. Pupils' explanations of situations involving chemical reactions seem according to my analysis to be very context dependent. 27 of the 40 pupils talk about *interactions* when they talk about the rusting iron but only three when they talk about the burning paper. When talking about rusting iron pupils use verbs as *cannot stand*, and *is corroded*. The number of pupils categorised as *description*, the lowest category, is reduced with 30-40% when they talk about the same context one year later. When comparing the analyses of pupils' explanations on the same or similar situations more pupils always have higher quality in their explanations in the later interviews.

18.6.4 Pupils' conception of combustion

Combustion is a chemical reaction between oxygen and another compound, where mostly gaseous products are formed. All pupils have experience of e.g. burning candles. What happens when something burns will be discussed on a macroscopic level: the role of oxygen/air, where the water formed comes from, and the ashes. In all interviews there is a combustion situation. The main categories used in the analysis are: nothing about oxygen or air, oxygen/air is needed, and interaction with oxygen/air or with the flame. There seem to be similarities between pupils' explanations of burning candle and burning petrol. Only a few pupils do not mean that oxygen or air is needed. In the first interview 12 pupils of 40 do not mean that it is needed for a burning paper. Almost half of the pupils talk in the third and forth interview about some interaction when a candle or some petrol are burning.

In the situations with a burning candle and burning petrol a jar is put over the burning substance. Almost all of the pupils state that the candle will burn out after some seconds because the oxygen/air is running out. Often they do not say anything about what happens with the oxygen/air. Where the water formed on the inside of the jar is coming from is not clear. Many pupils say that it comes from the flame or from the candle or petrol. Some thinking it is coming from the burning material, describe it as formed but others mean that petrol or the candle contain water. Many pupils mean that only solids and hard materials form ashes when they burn.

18.6.5 Pupils' conceptions of the cycle of water

In the interviews there are situations involving transformations of water to steam and the reverse from steam to water. We have soil in a sealed box in the 1st and 3rd interview, evaporating water on the kitchen sink in the 2nd, and discussion of rain in the 4th interview and on the introduction lesson. In the analysis I show the results for the discussion about rain separately.

The categorisation of the first three interviews is based on the categories of Andersson (1990). I have put in an extra category: *a sign of modification*. Statements in this category contain most of the claims for *modification* but are not complete. I do this because I think this will give me more detailed information about the development of pupils' understanding of changes of matter. In the 1st interview *a sign of modification* is the most common category but in the 3rd interviews almost half of the pupils are assigned to the category *modification*. Almost two thirds of the pupils have the categories *a sign of modification* or *modification* in the second and third interview.

In the introduction lesson the pupils have to explain as a paper and pencil task how it will be rain. This question comes back in the forth interview. The categorisation builds on Eskilsson's and Lindahl's (1996) study and it is built on pupils' description of the cycle of water. Almost all pupils talk about cycles of water both in the interview and in the paper and pencil task two years before. About 30% of them say in the 4th interview that the steam will be colder and clouds are formed. More than 50% of the pupils say that the clouds will be filled with water or will be too heavy and then it will rain. For some pupils the clouds are in the air like containers but for most of them clouds are formed.

The pupils have to compare their paper from the introduction lesson with what they just have said to me in the 4th interview. This is not easy for them to do. Many pupils mean that they say the same thing as they have written on the paper two years before. Others say that there is differences but cannot explain them.

18.6.6 Knowledge and experiences

During the interviews pupils often refer to everyday experiences. These comments can be of different quality from details to using overall patterns. An analysis of this can give information about the development of pupils' understanding as well as about how they use science knowledge when talking about everyday phenomena. My category system builds upon a system by Harlen and Symnington (1988). They use it to describe the development of pupils' ability to make observations. I use the following categories: details, similarities and differences, explanations, and patterns. The category *explanation* is added because I want to see how they use their experiences to explain phenomena without talking about pattern or science laws.

Almost all of the pupils often refer to other experiences during the interviews. The number of pupils in the categories *explanations* and *patterns* rises during the project. Almost 75% of them have these categories in the forth interview. 25% give patterns involving other experiences to explain the situations.

18.6.7 Learning situations

The analyses of the pupils' conceptions are based on the interviews. In order to illustrate some learning situations in the instructional units, I describe three examples. The first example concerns pupils' conceptions of the states of matter, the second gases, and the third chemical reactions.

<u>The states of matter</u>

The state of matter is one of the recurrent themes of the study. The first problem for the pupils is to group some substances I have put together in separate plastic cups. The substances include water, toothpaste, sour milk, potato flour, juice, a balloon with air, woollen cloth, wood, aluminium, a piece of chalk, a flower, a straw in a cup with water ('the bubbles'). All groups discuss and compare the substances in the cups and consider different ways of classifying them according to similarities and differences.

After the group work, each group report on what they have come up with and what they have found in common amongst the substances. In the analysis, I look for a structure in the pupils' ideas of similarities between substances, drawing upon an idea used by Krnel (1995) in a study of how pupils aged 9, 11 and 13 classify everyday materials. Overall, there are 24 groups in the classes. None of the groups refer to states of matter in their classifications. However, most of the groups place the two examples of gases in the same group and call it 'air'. This way of classifying is categorised as 'kinds of matter. "Flower and tree needs water and cloth can suck water, these three can suck water" is categorised as 'action or purpose'. "Flower, tree, plants, sour milk, potato flour come from the nature" as 'relation'. "Toothpaste and sour milk are thick" as 'perception' and "Juice is drinkable like water, that contains oxygen and there is oxygen in the balloon" as 'sequence'. Many groups discuss relationships between the substances during the lesson. They often describe this in terms of chains between, e.g. juice and water and then water and flowers. Then they place juice, water and flower in the same group. Most groups discuss the relationship of the substance to water. These discussions are often coded in 'action or purpose' and 'sequences'. This classification of substances is based on pupils' models of matter prior to teaching, pupils' everyday experiences, and discussions in the groups. It will be used as a reference when studying the conceptual development. After this discussion I talk about the concepts of solids, liquids and gases and we use these to sort up the substances.

I use the idea of Bruner (1970) about recurrent work with new concepts. In the second instructional unit the pupils have to sort up new substances and then use the concepts of solids, liquids and gases. This time I use juice, chocolate sauce, a piece of wood, carbonating tablet in water, a piece of cloth, a piece of foam-rubber, flour. Some substances start interesting discussions in the groups. Some pupils mean that e.g. foam rubber and flour contain air and that they therefore can be placed in the group of solids as well as in the group of gases.

During the discussions in the groups pupils build up their concepts and refine them. In the interview two months after this instructional unit the pupils have to tell me what characterize solids, liquids and gases.

How heavy is the football?

In many studies pupils' problems of understanding gases as matter and that gases have weigh are focused. In this study the conceptions of gases are focused in the interviews as well as in the instructional units.

In the third instructional unit we use a football to illustrate the weight of gases. We examine what happens with the weight of the football when it is inflated. Pupils cannot have any experiences from everyday life that a football will be heavier when it is inflated. Therefore this example gives information of pupils' conceptions of gases. Pupils have to tell me what they think will happen. Some pupils think the weight is unchanged because the air has no weight. Many of them think that the ball ought to be lighter. They think that the ball bounces better, when it is inflated. One group of girls tells me that they know that the weight of the football will increase and refer to an experiment with balloons they have seen. In the following interview, pupils have to explain what happens when the football is inflated. When I say that I will pump in as much air as there is in two empty packages for milk, one boy protests. He says that the ball already is full of air and that I cannot pump in so much new air. This gives rise to a discussion about compressing air.

When we see that the football becomes heavier after inflating it pupils try to explain why it is so. Some of them say that there is more air in it and then it will have more weight. One pupil uses her models of molecules to explain why the ball is heavier. She says that the molecules have weight and after inflating the ball the molecules are closer to each other.

In the 4th interview, pupils have to explain why the football becomes heavier. Almost all of them have explanations containing something about that there is more air in it and that air has weight. Jane, Maja and Glen say that the ball is heavier because the air is more compressed. This can also be interpreted as that they mean that the density of the air increases. Maja and some other pupils say that there will be more molecules in the ball and therefore it will be heavier.

Chemical reaction

When studying results and conclusions of studies about pupils' conceptions of chemical reactions I decide to defer introducing the concept of chemical reaction to the third instructional unit. The chemical reaction is one of the recurrent themes of the study. The first step when I work with this phenomenon is that pupils have to mix pairs of substances and to describe what happens. I mostly use everyday substances and reactions involving changes of colour or generation of gas. In one example we mix potassium iodide and lead nitrate. The two white powders give a yellow powder. Some pupils think that the yellow powder is in the grains of one of the substances from the beginning, so we crush the grains of the powders separately to see if that is correct. We find that we need both of the powders to get the yellow powder.

The idea that pupils have to describe signs of chemical reactions and try to explain what happens is followed up in the 3rd instructional unit. Pupils examine what happens when they put a piece of steel wool in a copper sulphate solution. I choose this reaction because they can see the changing colour of the steel wool and the copper sulphate solution and they can notice the raising of the temperature of the water solution. They have access to a thermometer. When the pupils have described what they have seen I introduce the concept 'react with'. We say that the steel wool has reacted with the copper sulphate. Then the groups have to use this concept to describe if there is a reaction or not when they mix some new pairs of substances.

One of these pairs is potassium iodide and lead nitrate. Some potassium iodide and some lead nitrate are put into a beaker containing water. After some minutes the pupils can see a yellow line between the two substances. They can see how this line is built up. Some of them think that one of the substances becomes yellow and is spread out in the beaker. Some pupils are using their molecule models when talking about what happens. They say that the molecules in the two substances change places or that when molecules meet there will be a yellow substance. There are more pupils using their molecule model when talking about chemical reactions in some of the experiments than in the interviews. This can be due to that they see what happens and in the discussions in the peer group they test their models. The experiments with bubbles and the surprising changes of colours also can contribute to their use of their molecular models.

18.7 Case study

Although it is not possible to give a complete account of the development of each individual, the development of some pupils is exemplified in terms of the analysis undertaken in the study.

Alma

Alma does not say anything about molecules or atoms in the 1st interview. This does not necessarily mean that she does not have any model for the particle nature of matter. Her model of molecule develops fast and she uses it in different situations in all the other interviews. The development of her molecular model can be related to the development of how she talks about gases, how she describes phase transformations of water, and how she uses and links her earlier experiences to the situations discussed. The development of how she talks about transformations involving chemical reactions is on the other hand different. This can be due to that conceptions of chemical reactions seem to be very context dependent.

Alma often gives short answers and does not have so many discussions with herself. When I ask follow-up questions she shows more of what she knows. Some of her ideas come back in later interviews. She says that the water formed when a candle or petrol is burning come from the burning substance and vanishes out in the air when it burns.

Disa

Disa knows about molecules in the 1st interview. She uses this many times in the interview. In the later interviews she does not always use it as spontaneously as at the first. Disa has many speculations of her own and she formulates and analyses her hypotheses. The quality of this grows during the project. Perhaps she has used her science knowledge in discussing everyday situations with others before. Disa often asks questions about the situations we are talking about during the interviews.

Elis

Elis often discusses explanations of the situations in the interviews with himself. He uses and builds up his own concepts step by step. This can be the reason why he already in the second interview has the category *spontaneously well* in the combined categorization of the conception of molecules. Sometimes his statements are difficult to categorize. If I look to the scientific content, there often are shortcomings. This can be the reason why his development sometimes is jumping up and down during the study. I think that with his point of view to try out his models, he will develop these models so they get more and more scientific.

Set

Set seems to need many different challenges and examples of the concept of particles and molecules before he uses it. He recognises the word but he does not remember what the small particles forming e.g. water are called. First in the 4th interview he spontaneously talks about molecules in his explanations to many of the situations. He is one of the few pupils that use his molecular model in explanations of chemical reactions. Set often refers to his experiences in all of the interviews.

18.8 Conclusions

18.8.1 Perspectives on knowledge

The pupils' spontaneous use of their models only shows one part of their personal conceptions. When asked follow-up questions, pupils come to a discourse where you use knowledge of science when you talk about everyday situations. This can be described as pupils' ability with appropriate help. Pupils do not replace their old models; they put for example a new particle model beside their old everyday model. Then they choose which model to use when they meet new situations in the interviews. Pupils' explanations of lower quality in a later interview are more common in their spontaneous explanations than in the discussions with me.

Most of the pupils are able to use knowledge of science when talking about known everyday phenomena involving transformations of matter. Almost all of the pupils in the group develop their own molecule model during the project. Pupils' growing ability to describe features of chemical reaction and the development of their particle model can help them to understand the nature of chemical reactions.

18.8.2 Systems of categories

The categories used in the analyses are defined and motivated in each separate part of the chapters presenting the results. The categorizations emanate from presented research on pupils' conceptions of science but also from the statements of the actual group of pupils. The correctness of used science concepts also is a part of the categorizations. Sometimes I alter a method used before and sometimes I develop a categorization for a special purpose in my study. The categorizations originate from the combined perspective on learning and knowing. A central part of the study is to study pupils' use of their concepts. I study e.g. how pupils talk about gases and chemical reactions without my asking them questions of this.

I choose to categorize the pupil with the highest category he/she uses. An alternative could be to give him/her the category where most of the answers given are placed. I choose the one with the highest quality because this shows which is the best explanation the pupil can use. Different situations stimulate the pupil to use the best model of explanation they have. A special situation or question from me could make them use everyday explanations and not to use their science knowledge.

18.8.3 Design

The longitudinal design of the study is used to study the pupils' individual development. Categorization of individuals is based on each one of the four interviews. The interview situation as well as my two roles as teacher and interviewer influence pupils' explanations. I also discuss the same situations in the 1st and the 3rd interview and this fact can influence the result.

A longitudinal study to this extent generates a lot of data. Using computer programs developed for qualitative analysis has made this work easier. It has, for example, been possible to test parallel types of analyses and to keep all the analyses in the same document.

18.8.4 Research questions

The first question of research in this study is "How does a group 10-year-olds develop their 'thinking models' of the nature of matter?". Only a few pupils have a thinking model of matter containing atoms and molecules when the study begins. However, the pupils show preatomic thinking when I ask them to tell me what they can see if they use magic glasses when they look into air with steam. Pupils' descriptions of gases and states of matter develop and become more and more scientific during the project.

The second research question is "How is the development of the pupils' understanding influenced by the introduction of a basic particular model?". More and more pupils use their particle model when talking about the situations in the interviews. When they use their model talking about a phenomenon in one of the interviews, they do not always use the model in the other situations discussed in that interview, and they do not always use it in the following interview. Their use of the model seems in the beginning to be context dependent. Sometimes they use an everyday model of explanation. I use a combined categorisation of pupils' conceptions of the particle nature of matter containing three aspects to describe pupils' particle models. My conclusion of this categorization is that the quality of pupils' molecular models is increasing from interview to interview. Some pupils reach the higher categories already in the second interview but others are not there until in the fourth interview or not even then. About half of the pupils have *spontaneously well*, *spontaneously,* or *stimulated* in the fourth interview. This means that they can use their molecule model when discussing known phenomena and that they do it spontaneously or after influences. The influence of the particle model I also can see in the analyses of how they talk about gases, phase transitions of water, and chemical reactions. I suppose that the introduced particle model not only influences the descriptions on the particle level but also how they use science knowledge when talking about everyday phenomena on a macro level. I see example of this in pupils' descriptions of what happens when something is burning and of the situations involving chemical reactions.

The third question of research is: "How does talking with me influence their use of scientific knowledge?" Comparisons between pupils' spontaneous explanations and what they say in dialogue with me are analysed on pupils' talk about gases and on how they use their concept of molecules. Pupils have an idea about gases but only a few of them have a thinking model of molecules before the study and this may influence the results. Pupils keep their everyday explanations and build up the new thinking models besides these. Some pupils seem to build up their understanding step by step. Pupils first develop their explanations in dialogue with me and then in their spontaneous explanations. The two levels of *spontaneously* and *in dialogue with me* are not two distinct levels. It is two ways to describe pupils' knowing. What they say in dialogue with me they also can use spontaneously but perhaps my questions do not stimulate them to do so or perhaps these models are not so stable that they dare to use them spontaneously. The changes of discourse in the discussions with me make the pupils more ready to use knowledge of science when talking about everyday phenomena. I do not encourage them to use this knowledge but the discussions make them familiar with these kinds of arguing and talking.

18.8.5 Methodical considerations

There are two central areas of validity in this study. Firstly I describe pupils' understanding and secondly I describe the development of their understanding and relate this to a set of teaching units. I talk about pupils knowing as how they use their science knowledge when talking about everyday phenomena and I try to design the categories from this aspect. The categories are defined and motivated in each part of the presentation of the results. The categorisations are discussed with colleges and refined after the co-examination. The development is not connected to a special instructional unit but the development is described as a long-term development during a period with instructional units and interviews. During this period pupils also are influenced by other experiences and this cannot be separated from the influence of the instructional units. The analyses and the descriptions of the development are based on many parallel analyses. There are many examples where results in one analysis are supported by results in another analysis. This can be seen in the analyses of spontaneously and in dialogues with me on gases and use of molecules. The combined categorisation of pupils' use of their molecular models is similar to pupils' talk about molecules.

The results of the study with 40 pupils can be seen as an example of pupils' capacity to use science when talking about everyday phenomena and how using a basic particle model influences this. However it is impossible to quantify this.

The reliability in a study like this is dependent on the validity. My choice to take the category with the highest level according to my categorization systems in all categorizations can be discussed and I have argued for my decision earlier. Sometimes the highest level only is used once and the model used is not so strong.

18.8.6 Implications

There are implications of the findings both for teacher education and for teaching science in primary school. A basic particle model can be introduced early. Pupils need to meet and discuss new examples in order to build up their own conceptions. The development of pupils' conceptions can be followed both from the spontaneous use of their knowledge and from what they show in discussions with others. In the discussions pupils meet a discourse where they use scientific knowledge when talking about everyday phenomena.