EVERYTHING HAS ITS PROCESSES, ONE COULD SAY
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A longitudinal study following students’ ideas about transformations of matter from age 7 to 16

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Malmö University, 2009
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¹ HKr: Högskolan Kristianstad (Kristianstad University College)
² MNA: Institutionen för matematik och naturvetenskap (The department of Science and Mathematics)
ses and single sentences but also thanks for all the good laughs and interesting discussions.

In courses placed in Malmö, Kristianstad and Norrköping I, together with doctoral students and supervisors, have had the opportunity to share different ideas. Thank you all of you, I learnt a lot!

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Jan, without your support this thesis would never have been finished. Thank you for always being there for me whether it is with an endless row of ideas I need to articulate and discuss or more practical matters that need attention!

Åhus, January 2009
Lena Löfgren
ABSTRACT

This thesis concerns students’ learning and meaning-making in science. The theoretical framework builds upon Human Constructivism. This perspective underlines the unique interplay that occurs between thinking, feeling, and acting in human meaning-making and also stresses the important role of language in learning processes.

The aim of the thesis is to learn more about how individual students develop their understanding of processes in which different kinds of transformations of matter occur. This aim is connected to the opinion that such knowledge can help in the development of teaching approaches leading to meaningful learning.

A ten year longitudinal study has been conducted in which 20 students’ conceptions of matter and its transformations have been followed from age 7 to 16. In interviews performed once or twice every year the students described and explained the transformations of matter in three situations: the future of fading leaves left lying on the ground, the disappearance of the wax of a burning candle, and the appearance of mist on the inside of the cover of a glass of water. As part of the study, an early (at the age of 7) introduction of the idea of the particulate nature of matter was made.

The study contributes to earlier studies on students’ ideas about transformations of matter by showing how students develop their ability to explain such processes in everyday situations. The study shows that students develop understanding of phenomena with a strong personal flavour. There is a spread in the students’ capability to use their experiences and the school science in productive
ways to elaborate their ideas into more scientifically acceptable ones. This spread becomes greater during the compulsory school.

The study shows the young students’ competence to use a simple molecule concept in productive ways in their explanations of the situations but it also shows the older students’ difficulties in using the science taught in later school-years. A conclusion is that fundamental concepts, such as the particle model, could be introduced in early school-years but only if the concept is continuously worked on and elaborated.

Because of the longitudinal design the great impact of early experiences, both from family life and school, on students’ ideas is revealed. By following the individual students’ meaning-making over a ten year period and allowing them to comment on their own interview responses it becomes obvious that meaningful learning takes time.

Different kinds of longitudinal studies that can inform us further about students’ meaningful learning in relation to science curricula are asked for as a result of the findings of this study. Longitudinal studies that can reveal how students’ and/or teachers’ ideas about the purpose of schooling change over time are also asked for.

Keywords: longitudinal study, primary education, secondary education, science learning, transformations of matter, the particulate nature of matter
SAMMANFATTNING

Denna avhandling handlar om eleverns lärande och meningsskapan-
de i naturvetenskap. Det teoretiska ramverket bygger på Human
Constructivism. Detta perspektiv framhåller det unika samspel som
äger rum mellan tankar, känslor och handlingar då människor
skapar mening. Perspektivet betonar också språkets viktiga roll i
lärandeprocesser.

Avhandlingens syfte är att få mer kunskap om hur enskilda ele-
ver utvecklar förståelse av processer i vilka olika sorts materie-
omvandlingar sker. Sådan kunskap är värdefull vid utvecklandet av
undervisningsansatser som kan leda till meningsfullt lärande.

En tioårig longitudinell studie har genomförts i vilken 20 elevers
uppfattningar om materie och dess omvandlingar har följts från 7
till 16 år. I intervjuer genomförda en eller två gånger per år beskrev
och förklarade eleverna materieomvandlingarna i tre situationer:
vad händer med vissna löv som ligger kvar på marken, var tvar ste-
arinet från ett brinnande ljus vägen och hur uppstår imman som
syns på insidan av en glasskiva som lagts ovanpå ett glas med vat-
ten. Som en del i studien introducerades redan vid 7 års ålder idén
om materiens partikelnatur.

Denna studie bidrar, i förhållande till tidigare studier om elevers
uppfattningar om materieomvandlingar, med att visa hur elever ut-
vecklar sin förmåga att förklara sådana processer i vardagssitua-
tioner. Studien visar att elever utvecklar förståelse för fenomenen
med en tydligt personlig prägel. Det finns en spridning i elevernas
förmåga att använda sina erfarenheter och skolans naturvetenskap
för att på ett fruktbart sätt utveckla sina idéer i mer vetenskaplig
riktning. Denna spridning ökar under grundskoletiden.
Studien visar de unga elevernas förmåga att använda ett enkelt molekylbegrepp på ett produktivt sätt i sina förklaringar av situationerna men visar också de äldre elevernas svårigheter att använda naturvetenskapen som undervisas de senare skolåren. En slutsats är att viktiga begrepp som partikelmodellen skulle kunna introduceras tidigt i skolan men bara om begreppet kontinuerligt bearbetas och utvecklas.

De tidiga erfarenheternas betydelse för utvecklingen av elevernas idéer har tydliggjorts genom det longitudinella upplägget av studien. Genom att följa individuella elevers meningsskapande under en tioårsperiod och genom att låta dem kommentera de egna intervjuerna har det blivit synligt att meningsfullt lärande tar tid.

Olika typer av longitudinella studier som kan ge oss ytterligare kunskap om elevers meningsfulla lärande i förhållande till läro- och kursplaner efterfrågas som en följd av studiens resultat. Longitudinella studier som kan beskriva hur elever och/eller lärare förändrar sina uppfattningar om meningen med skolan över tid efterfrågas också.
PAPERS INCLUDED IN THE THESIS

This thesis is based on the following papers, which are referred to in the text by their Roman numbers:

**Paper I**

**Paper II**

**Paper III**

**Paper IV**
Löfgren, L. & Helldén, G. (2008). *Following how students from age 7 to 16 use their experiences when developing their ideas about transformations of matter.* Paper presented at the 9th Nordic Re-

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1 According to agreement within the LISMA group the supervisor is regularly a co-author on the papers in the role of supervisor.
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PROLOGUE

About teaching and learning: a personal perspective

In autumn 1971 I stood as a teacher student beside a student in school-year 7 (13 years of age) who did not know how to solve an exercise in mathematics. Rather quickly I realized that it would be of no use to tell him what to do. In that case he had learnt nothing. What I had to do was to try to understand how he looked upon the problem and what it was he did not comprehend or know in order to solve the problem.

After five years of university studies in mathematics and physics I was a teacher student for one year. During the first semester we had periods of practice where auscultations and teaching were mixed. When the students worked individually, I always seemed to meet situations as the one above. It very often took time to understand what the students actually asked about, and what was needed to help them continue their work. With some worry I realized that it would be difficult, as the only teacher in the classroom, to use that much time on individual students.

By coincidence my first teaching post after exam was within the Swedish adult education administered by local authorities (Kommunalk vuxenutbildning). Here the students had very different needs of teaching and scaffolding. I became more and more convinced that every student tried to solve her or his exercises in a way that to her or him was sensible and logical, concerning the knowledge and understanding she or he had. My job was to find out what was understood and what was not and to teach based on that. As time
went by it became more and more interesting and challenging to learn more about why and how we learn or do not learn.

In 1993 I started as a lecturer at Kristianstad University and then met colleagues with a great interest in Science and Mathematics Education and from whom I learnt a lot. The LISMA\(^4\) group was formed in 1994 and as a member of this group I have had the opportunity to read, discuss and meet many researchers within the area from both Sweden and other countries.

Almost at once I came in contact with the work done by Björn Andersson within the EKNA\(^5\) project and although a lot of recognition about students’ ideas became visible I often asked myself what I should have answered if I had been tested. Within the physics domain the supposed correct answers were, at least after some consideration, clear to me but within chemistry and biology I often was not sure. The correct answer could differ depending on the level of explanation asked for and this level was not always made clear.

Conceptual change was a concept I met often in the literature at this time and even if the ideas behind it and the advice to achieve it sounded logical my experiences from adult education made me sceptical as I had the feeling that for most students and in most cases the new ideas took time to develop and the old ones seemed to pop up again even if both the student and I had the feeling the student had ‘understood’ the new concept. Another influence was the famous and often cited words from Ausubel

\[
\text{If I had to reduce all of educational psychology to one principle, I would say this: the most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly. (Ausubel, Novak & Hanesian, 1978, p. IV).}
\]

These words of course directly caught me and conformed with my experiences and opinions from teaching practice, and also were consistent with the pedagogical theories and ideas I had met in courses during my teacher career.

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\(^4\) LISMA: Learning In Science and Mathematics

\(^5\) EKNA: Elevers Kunnande i Naturvetenskap (Students’ knowing in science),
These experiences are to be seen as the point of departure of the project of this thesis.
INTRODUCTION

Why the interest

People in a modern democratic society should have knowledge in order to be able to make decisions in a vast variety of situations. Some of the questions discussed today about environment, energy, and resources deal with our common future. Questions concerning Humankind’s survival on earth often have a connection to where different materials come from and go to in processes in nature and society. Many of these processes include phenomena we cannot apprehend with our senses, such as the burning process transforming solid matter into gas and the evaporation process turning water into vapour.

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, Guesne & Tiberghien, 1985; Knuel, Watson & Glazar, 1998). We still need to know more about how young students develop understanding of processes including transformations of matter.

A research project

My thesis is connected to a broader research project at Kristianstad University. The overall aim of that project is to learn more about how students actually make meaning and come to understand different phenomena in science. The research project ‘A longitudinal study of the conceptual development in science’ was started by
Gustav Helldén in 1997 together with Ingemar Holgersson, Ann-Charlotte Lindner and myself. We have been following, from the beginning, 58 students, born in 1990, through their compulsory schooling. The last empirical data were collected in 2006, ten years after starting the project. We have investigated students’ conceptions of matter and its transformations by interviewing them regularly. We conducted interviews allowing students to explain the transformations 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.

When the project started in 1997 the students attended two different schools and seven different classes. Lindner (2007) has out of the project presented a licentiate’s thesis about seven students’ development of ideas about evaporation. In the beginning I followed nine students all in one class. In 2002 I became a doctoral student in Pedagogic with the direction Science Education at Malmö University, supported financially by Kristianstad University College\(^6\). Gustav Helldén became my supervisor and it was decided that I could use my and his interview data (from 25 students) and the analyses done so far in my doctoral work. These 25 students came from two schools and three different classes.

**Aims of the thesis**

A strong interest in gaining insights in individual students’ ideas and growing understanding of concepts made it easy and beneficial to join the above project and to use the empirical data from it in my thesis. It seemed fascinating and enhancing to be given the opportunity to follow 25 young people’s ideas for such a long period as ten years.

\(^6\) When I became a doctoral student the translation into English of Kristianstad Hogskola was Kristianstad University. Due to a decision 2008 the translation today is Kristianstad University College.
The overall aim of my thesis is to learn more about how individual students develop their understanding of processes in which different kinds of transformations of matter occur. This aim is connected to the opinion that such knowledge can help in the development of teaching approaches that lead to meaningful learning.

Inspired by Novak and Musonda (1991) we, in the project, made an early introduction of the particulate nature of matter. This means that through the years I also have had the possibility to follow if and how individual students use this early introduced concept as an intellectual tool when describing and explaining different phenomena.

**Reading the thesis**

This is a compilation thesis consisting of a “kappa”\(^7\) and four papers. The first paper, written with Ingemar Holgersson as the first author, uses empirical data up to 2001 and from all the students in the broader project. The other three papers only use material from my own 25 students, and Gustav Helldén as the supervisor is the co-author according to an agreement within the LISMA group. The “kappa” consists of a background setting the scene and including a literature review, then follows the research questions, the theoretical and methodological framework and a description of the study. Short presentations of the four papers are given but as papers III and IV more directly deal with two of the research questions the presentations of these papers are more extensive than the other two. Findings in relation to the remaining questions are presented and then an overall discussion follows. Due to the Swedish tradition, the papers are attached in the end and not as chapters in the thesis. It should be possible to read the “kappa” from start to end without reading the papers but for more details concerning analyses and results out of the distinct questions posed within each paper the papers have to be read. This means that some information is given both in the “kappa” and in the papers.

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\(^7\) The Swedish word “kappa” is “coat” or “gown” in English and in this case meaning something that should bring the four papers together to something more elaborated and greater than the sum of the four papers.
BACKGROUND

In this chapter I start by explaining the processes taking place in the three interview situations used in this thesis. Why these three situations were chosen is addressed on page 78 and reflecting comments concerning the situations are given in the discussion on page 122. When in the next section I explain the processes I keep to a level of explanation that to me seems relevant in relation to compulsory school science. After this, short presentations of relevant parts of the Science syllabi of the Swedish compulsory school and the school-books used in the classes involved are given. The chapter ends with a literature review of findings concerning students’ ideas about transformations of matter and the particulate nature of matter relevant to the interest of this thesis.

The three situations

In the three situations – the future of fading leaves left lying on the ground; the disappearance of the wax of a burning candle; and the appearance of mist on the inside of the cover of a glass of water – different kinds of transformations of matter occur. In the situations with the fading leaves and the burning candle chemical reactions take place while in the situation with the covered glass of water phase changes take place. The understanding that matter is conserved in transformations of matter is a basic idea important to have. In the three following paragraphs I will present the processes involved in the situations.
Fading leaves

Fading leaves that have fallen to the ground will perhaps dry and fall into smaller pieces or will be eaten by different animals, such as worms and wood-lice. Animals eating the leaves are of great importance for the decomposition process. The animals fragment and grind the leaves, which make it easier for fungi and bacteria to attack the material and carry through the decomposition. In all organisms, when food is eaten, a respiration process analogical to a combustion process takes place. In this process oxygen is needed to, in a chemical reaction convert the organic material into carbon dioxide, water, and nutrients. The organic material is thereby returned, in inorganic form, to the air and the soil. It is easier to understand that the main end products of decomposition are carbon dioxide and water if one knows that leaves are made up of cellulose and that the elements building up cellulose are carbon, oxygen, and hydrogen.

Soil, which is often seen as the end product of the decaying leaves, consists of remains from dead plants and animals that are in different stages of decay and of material eroded from the bedrock. At the same time as dead organic material is added to the soil, carbon dioxide and water vapour are released from the soil.

The process is easier to understand if one has an image of the whole cycle of the leaves, starting with the photosynthesis and ending up with bacteria breaking down the faded leaves to materials that the plants can take up again. The roles of carbon dioxide and oxygen in this cycle are of course also enlightening to know about.

To conclude: To be able to explain the fate of the fading leaves there is a need to know about the role of different organisms in the decomposition process. The respiration seen as a chemical reaction needing oxygen and converting the organic material into inorganic matter: carbon dioxide, water and nutrients, has to be known. One has to know that air is made up of different gases such as nitrogen, oxygen and carbon dioxide and that air can hold different amounts of water vapour. To understand chemical reactions the idea of the particulate nature of matter is needed.

These small pieces will of course gradually also be part of the decomposition process.
Burning candles

When a candle burns the wax is heated and thereby the wax melts. The melted wax is used, together with the wick, as fuel in the burning process. The wick, usually made of cotton (cellulose), is there to take up the melted wax. Even if the wick burns the main fuel source is the wax which firstly melts and then turns into gas. Combustion takes place where wax, in gas state, from the candle and oxygen from the air convert to carbon dioxide and water vapour. The two gases are released and rise up in the air. In order to understand the chemical reaction taking place in this combustion process the chemical formula of stearin (C_{17}H_{35}COOH), or the elements that build up stearin, has to be known.

The chemical reaction of combustion has to be recognized. That stearin is the fuel in the process and what role oxygen has are to be known. It is again needed to know that air consists of different gases such as nitrogen, oxygen, and carbon dioxide and that air can hold different amounts of water vapour. To understand chemical reactions the idea of the particulate nature of matter is needed.

A covered glass of water

To understand what happens in a covered glass of water we have to realise there are water droplets on the inside of the cover. The water evaporates from the water in the glass and then condenses again when reaching the cover. In this situation there is no chemical reaction but two phase changes: evaporation and condensation. In a phase change the substance is the same but the substance turns from, for instance solid into liquid or from gas to liquid. Matter can be found in three different phases, namely gas, liquid, and solid. When water evaporates the liquid ‘water’ turns into the gas ‘water vapour’. In condensation the opposite happens, that is the gas ‘water vapour’ turns into the liquid ‘water’. To understand the

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9 From an early point we have used the word ‘wax’ when ‘stearin’ had been the proper term to use. This was done from an advice that students were more likely to use wax when talking about the material candle consists of.

10 There is a fourth phase; plasma, but the temperature needed for this phase is not normally found on earth.
evaporation and condensation processes and especially these processes at room temperature the idea of the particulate nature of matter is needed (Johnson, 1998c).

To conclude: In the situation with the covered glass of water evaporation and condensation at room temperature take place. To understand these processes a particle model is needed.

A summary of relevant science knowledge when explaining the interview situations

From the above presentations of the three situations the science content concerned in the situations can be summarized in the following way:

- Processes: chemical reactions such as respiration and combustion and phase changes such as evaporation and condensation.
- Basic understanding: conservation of matter.
- Intellectual tool: the particulate nature of matter.
- Concepts or expressions often used when talking about the processes: leaf, fade, mould, moulder, rot, decay, decompose, turn into soil, animals, decomposers, bugs, bacteria, wax (stearin), burn, melt, oxygen, air, smoke, water, steam, mist, vapour, dew, evaporate, and condensate.
- Knowledge that could support understanding the processes: a leaf is made up of cellulose; a candle is made up of stearin, and the chemical formula of cellulose and stearin or the elements they consist of.

The Swedish syllabi in science

The Swedish curriculum and syllabi are goal driven and a lot of freedom is given to the teachers. In the syllabi there are goals to aim for through the nine years of the compulsory school but there are also goals that the students should have attained by the end of the fifth and by the end of the ninth school year. In 1994 the compulsory school received a new curriculum and new syllabi in the
different subjects. In 2000 the syllabi were revised. As the students in this study started the compulsory school in 1998 (in 1997 they attended pre-school) the syllabi presented here are from 2000 (Skolverket, 2007).

In the syllabi from 2000 there are a common syllabus for Science studies and separate syllabi for the subjects Biology, Chemistry, and Physics. Both the goals to aim for and the goals to attain are given under three different headings: ‘concerning nature and Man’, ‘concerning scientific activity’, and ‘concerning use of knowledge’. The three headings are meant to deal with ‘the knowledge in science’, ‘the knowledge about science’, and ‘the use of science knowledge’. In the syllabi from 2000, issues concerning value and environment are stressed in comparison to the syllabi from 1994. There is also a stronger focus on the use of the science knowledge in everyday situations and in issues concerning society. There has been an ambition to construct syllabi which lead to school teaching that engages students. The basic idea is to move the main focus of the studies from learning facts to a more nuanced view of science knowledge and science activity (Skolverket, 2000).

I will now present the Swedish syllabi in Science for the compulsory school that I find relevant in relation to this thesis. I will first present the goals to aim for. I have chosen to present more than half of these goals in order to give a fair picture of the intentions of the syllabi in relation to the knowledge and abilities I will later discuss. As already said there are both a syllabus for Science studies and one syllabus for each subject but I now present the goals heading by heading. The letter at the end of each goal indicates from which syllabi it is taken (S = Science studies; B = Biology; C = Chemistry; P = Physics). I will then present the goals to be attained. Here I have been more restrictive and only taken those with a strong impact on the content within the thesis. As I found the goals to be attained under the two later headings to be in strong accordance with the goals to aim for I decided to just present goals to be attained from the first heading, ‘nature and Man’.
Goals to aim for

The school in its teaching of science studies, biology, chemistry, and physics should aim to ensure that pupils concerning nature and Man believe in and develop their ability to see patterns and structures which make the world understandable, as well as strengthen this ability through oral, written and investigatory activities, S. Develop their knowledge of different forms and conditions for life, B. Develop their knowledge of the interaction between organisms and their environment, B. Develop their knowledge of elements, chemical compounds and chemico-technical products of importance to daily life, C. Develop their knowledge of transformation in chemical reactions, C. Develop their knowledge of the structure of atoms and chemical bonding as explanatory models for chemical processes, C. Develop an understanding of the indestructibility of matter, transformation, recycling and dispersion, C. Develop their knowledge of fundamental concepts in physics in the areas of mechanics, electricity and magnetism, optics, acoustics, heat, as well as atomic and nuclear physics, P. Develop their knowledge of energy and energy forms, their transformation and properties, as well as society’s supply of energy, P (Skolverket, 2007).

These goals and the science content summarized above coincide enough to conclude that the science content needed to understand the three interview situations is within the aim of the compulsory school. In the beginning of the syllabus of Science studies it is pointed out that the world is understandable. This should be interpreted in the way that the world is possible for all people to under-
stand and not just persons with expert knowledge (Skolverket, 2000). Transformation in chemical reactions is mentioned and also interactions between organisms and the environment. These are two important areas for understanding the processes in the interview situations.

The school in its teaching of science studies, biology, chemistry, and physics should aim to ensure that pupils concerning scientific activity

- develop the ability to see inter-relationships between their observations and theoretical models, S
- develop a knowledge of different working methods in biology, such as field observations and laboratory work, as well as a knowledge of how these interact with theoretical models, B
- develop their knowledge of how experiments in chemistry are based on concepts and models, and how these can develop through experiments, C
- develop a knowledge of the interaction between investigations and experiments on the one hand, and the development of concepts, models and theories on the other, P

(Skolverket, 2007)

These goals imply that an important object of learning expressed in all the syllabi is the understanding of scientific models and the role of such models. To introduce and work with the idea of the particulate nature of matter seems to be fully in line with these goals.

The school in its teaching of science studies, biology, chemistry, and physics should aim to ensure that pupils concerning use of knowledge

- develop the ability to use scientific knowledge and experiences as a basis for examining their views, S
- develop their concern and responsibility when using nature, S/B
- develop their ability to use a knowledge of chemistry/physics, as well as ethical and aesthetic arguments in discussions and consequences of the application of chemistry/physics in society, C/P
- develop a critical and constructive attitude to reasoning of their own and others, showing respect and sensitivity to the views of others, S (Skolverket, 2007)

These goals are more difficult to relate to the science content described above. When reading these goals it is obvious that the issues concerning value and environment are expressed clearly. The focus on the use of science knowledge in everyday situations written about in Skolverket (2000) is not, in my opinion, as clearly seen under this heading.

These goals lead to the question: “Are students at the end of the compulsory school expected to be able to explain processes in everyday situations, as the ones in the interview situations, with help of the idea of the particulate nature of matter?” The question could also be expressed more openly in the following way: “Which theoretical models are expected to be used in everyday situations at the end of the compulsory school?”

Goals that pupils should have attained by the end of the fifth year in school

Pupils should concerning nature and Man

- be able to give examples of the life cycle of some plants and animals and their different growth processes, B
- have a knowledge of the concepts of solids, liquids, gases and boiling, evaporation, condensation and solidification, C (Skolverket, 2007)

The life cycle of some plants could include, on some level of explanation, the decomposition of fading leaves. It is also clearly said that the students should have knowledge of evaporation and condensation. This means that at the end of the fifth school-year all
students should be familiar with the fate of fading leaves and the processes of evaporation and condensation. The level of explanation asked for is not clear.

Goals that pupils should have attained by the end of the ninth year in school

Pupils should concerning nature and Man

- have an insight into how matter and life is studied in different levels of organisation, S
- have a knowledge of the cycles of nature and flow of energy through different natural and technical systems on the earth, S
- have an insight into photosynthesis and combustion, as well as the importance of water for life on earth, B
- have a knowledge of some of the elements, chemical compounds and chemico-technical products, C
- have a knowledge of the most important cycles in nature, and be able to describe some dispersion processes of matter by air, water and the ground, C
- have a knowledge of the properties of water and be able to describe its role as a solvent, and as a means of transport over earth and by plants, C
- have a knowledge of the properties of air and its importance for chemical processes, such as corrosion and combustion, C
- have a knowledge of pressure, heat and temperature in relation to different forms of matter, P
- have an insight into how matter is built up out of elementary particles and atoms, P (Skolverket, 2007)

The goals in chemistry are all the goals that are there while in biology and physics there are many fields of knowledge that are not at all relevant to the three interview situations. When examining the goals it is sometimes only parts of the goals that take up the knowledge needed in order to explain the situations. The students
should have an insight in how matter can be studied in different levels of organisation. Together with the insights of how matter is built up and the role of oxygen in combustion I conclude there is an intention in the syllabi that students should be able to use the idea of the particulate nature of matter when explaining chemical processes such as respiration and combustion. If they should also recognize such processes in everyday situations is not clearly expressed. This ability is probably implicit as there is an overall intention in the syllabi that the ability to use the knowledge in everyday situations is important.

It is also said that the students should know about heat and temperature in relation to different forms of matter. Together with the aim from the fifth year in school about evaporation and condensation and as water is mentioned in many of the different goals it seems that the students should deepen their understanding of these processes during the last years of the compulsory school.

The questions asked about the level of explanation or which theoretical models students should be expected to be able to use are not fully answered but it seems there is an intention that students should be able to use scientific models, including the idea of the particulate nature of matter, when explaining processes such as those present in the interview situations.

**Teaching material**

In this overview I look into the teaching material used in the classes of the interviewed students. I decided to restrict this overview to the last three years of the compulsory school as it is then the material introduces more abstract concepts and relations between concepts. It is also at this time the students are presented with special books in biology, chemistry and physics. I have not had the intention or the possibility to follow the teaching. This overview does not show what is taught but shows what the authors of the text-books think should be dealt with during the last three years of compulsory schooling. My experience, as a teacher and a teacher educator, is that most teachers in these years use the text-books in their teaching and that the content in the book often becomes the
sylabus. I present the material in relation to the content needed in order to explain the situations used in the interviews. The presentation is made subject by subject without comments. This section ends with integrated comments on the material used in the three subjects.

Biology

The course material in Biology is covering the last three years of schooling in one book. It is called ‘Biologiboken för grundskolans senare årskurser’ (The Biology book for the later years of the compulsory school) (Linnman, Linnman, Wennerberg, Carlsten, & Magnusson, 1995). It was written in 1995 and the preface says that it has taken the new curriculum from 1994 into account. This means the book follows the syllabus in Biology from 1994 and not the one from 2000.

One of the first things said is that most living organisms breathe. The organisms take up oxygen from the air or from the water and the oxygen is needed to burn the nourishment. In this process the organisms get the energy needed to live. In a chapter about plants the very first thing said is that all plants have chlorophyll and that it is the chlorophyll that makes it possible for the plants to use energy from the sun in order to by themselves make nourishment. The nourishment is made out of substances in air and water. The chapter about animals starts by saying that animals cannot as the green plants use the sun-light to by themselves produce energy but instead they are dependent on the green plants in order to receive their required energy. It is said that all animals have to breathe to receive oxygen needed in the burning of food. In a chapter named ‘Ecology’ is said that the most important principles of an ecosystem are:

The sun is the driving force of all eco-systems, […]

The substances circulate in a cycle (all substances as for instance water, oxygen, carbon dioxide and nitrogen circulate in the nature – they never cease! When a hare dies every atom land somewhere, perhaps in a human being, bacteria, fox or pine-
Nothing disappears (When burning a fire nothing disappears although the wood is gone. The substances just convert and are somewhere else, as for instance in the ashes or gases in the air. [...]"

Everything is spread. [...] (Linnman et al., 1995, pp. 102-103).

In the same chapter decomposers are named as mushrooms, bacteria and small animals such as worms, beetles or mites. The decomposers live from the energy of dead material such as faded leaves, cones, skeletons, branches, faeces and urine. They ‘break down’ the material to such substances that the plants can take up again. It is said that photosynthesis can be summarized in the following way:

\[
\text{Carbon dioxide} + \text{water} + \text{light energy} \rightarrow \text{dextrose} + \text{oxygen} \\
\text{(Linnman et al., 1995, p. 148).}
\]

It is also said that today the air consists of about 21% oxygen and that all of that oxygen comes from photosynthesis. Then after explaining what is produced in the green leaf the question about where the carbon dioxide comes from is pronounced and as an answer one can read:

All substances that are formed by the photosynthesis contain carbon. Carbon comes from the carbon dioxide in the atmosphere. The amount of carbon dioxide in the air is very small – just about 0.03%.

As carbon dioxide all the time is used in the photosynthesis one could ask why the carbon dioxide in the air does not cease. Carbon dioxide is all the time formed by all burning of substances that contains carbon. It happens for instance in our own body. Dextrose (grape-sugar) is burned in our cells. Then carbon dioxide is formed, which we breathe out through our lungs.

Carbon dioxide is also formed in combustion in engines, boilers, factories, volcanoes etc. (Linnman et al., 1995, p. 149).
Chemistry

The course material in chemistry for the last three years is also covered with one book. This is called ‘Kemi, åk 7-9’ (Chemistry, school year 7-9) (Sandin, 1989). This book was written in 1989, which is before the new curriculum. The book is still (September, 2008) possible to buy which probably means ‘schools’ and teachers think that the book covers the new syllabi in Science studies and Chemistry.

In a chapter about burning it is said that three conditions must be there to get a fire: a burnable material, enough heat and oxygen. The illustration to these lines is a candle and a sparkler. In another chapter about air the composition of air is written in detail and then oxygen, nitrogen, carbon dioxide and the inert gases are shortly described and some properties are mentioned. There is also a short chapter about chemical reactions with the main message that in a chemical reaction new substances are formed. These new substances have other properties than the substances to start with.

There is a comprehensive chapter about compounds containing carbon. This chapter starts by saying that carbon is an element that is everywhere in nature and that this element is part of a continuous cycle in nature. The plants use carbon dioxide to produce carbon compounds such as sugar and starch. These substances are eaten by humans and animals. When plants and animals die the carbon will be transformed to new carbon compounds such as peat and coal. When these substances are used as fuel we get back the carbon as carbon dioxide.

When talking about organic acids, stearin acid is mentioned and the formula is given and the text also informs that this acid is white, solid and is part of candles. The text is illustrated with a picture of a box of candles.

Under the heading ‘Carbohydrates’ one can read about photosynthesis. It is said that in this process green plants are able to use the energy from the sun to form substances called carbohydrates. Sugar, starch, and cellulose are carbohydrates. The photosynthesis is summarized in the following way:

\[
\text{Carbon dioxide} + \text{water} + \text{energy} \rightarrow \text{carbohydrates} + \text{oxygen}
\]
It is then said that animals, humans and some plants, e.g. fungi, need the nourishment that the green plants produce. They use the energy content in carbohydrates that is formed in the burning in the cells. The burning or the cell breathing is described as

$$\text{Carbohydrates + oxygen \rightarrow carbon dioxide + water + energy}$$

(Sandin, p. 127)

Cellulose is described as a carbohydrate that is used in the plants’ cells and is called the ‘skeleton’ of the plants.

Complementing the books in biology and chemistry are special booklets with exercises, laboratory experiments and field work.

Physics

The teaching material in physics for school-year 7 to 9 consists of three books which include both facts, exercises, and laboratory experiments. The books were written in 1996, 1997 and 1998 respectively (Paulsson, 1996, 1997, 1998). They are called 'Fysik Lpo för grundskolans senare del, bok 1; bok 2 respektive bok 3' (Physics Lpo for the later part of compulsory school, book 1, book 2, and book 3, respectively). The books are used one each year starting with book 1 in school year 7 and so on. Book 1 starts with ‘matter’ saying that all materials consists of matter. It is a Latin word and means ‘substance’. Everything that can be weighed is matter; for instance candles and light bulbs consist of matter but the light they send out is not matter. There is one page with the heading 'Atoms and molecules’ saying that all matter is built up of atoms. The text continues saying: substances that are made up of one kind of atoms are called elements. Atoms are unbelievably small. A molecule consists of two or more atoms. Air is a mixture of mainly nitrogen and oxygen. Oxygen molecules are mentioned. All substances that are not elements are called chemical compounds. Water is given as an

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example where every water molecule consists of two hydrogen atoms and one oxygen atom joined together.

On the next page solids, liquids and gases are shortly presented through the example of water. It is said that water boils at 100 degree Celsius but also said that water can disappear (for instance from a bowl of water). Water evaporates and forms water vapour. Also condensation is mentioned. It is also stressed that matter is undestroyable. In the very beginning of the chapter dealing with the basis of electricity the atom is presented a bit more. All atoms have a nucleus consisting of protons and neutrons and around the nucleus there are electrons. The atom is neutral, the proton has a positive charge, the electron has a negative charge and the neutron has no charge.

In the second book less than half a page deals with the concepts of evaporation and condensation. The main message is that when a liquid evaporates it takes up heat while when a gas condenses it gives away heat. The fridge, illustrated with a picture, is given as example of a compressor in which the processes of evaporation and condensation all the time makes liquid turn to vapour and then the opposite. In the third book there is a chapter about atom and nuclear physics but the new things mentioned in this chapter do not, in my opinion, have any impact on the interview situations.

Comments in relation to the teaching material and the interview situations

I will here comment on the above presented material in relation to the science content needed in the three interview situations. The point of departure is the summary on page 32.

The process of respiration (burning) in organisms is mentioned both in biology and chemistry text-books. The need for oxygen and the end product carbon dioxide in this process are clearly expressed in the chemistry book. The books do not express that matter is conserved but say that nothing disappears. Burning is in the biology book used as a concrete example of this idea. In the chemistry book the three conditions for burning are mentioned. It is also
mentioned that in a chemical reaction new substances are formed with other properties than the substances to begin with.

Water evaporation and condensation are talked about in the first book of physics. In the second book these processes are dealt with more generally in relation to heat transfer. The molecule model is not used in the descriptions.

That matter is undestroyable – in science mostly named ‘conservation of matter’ – is stressed in the biology and physics books.

The idea of the particulate nature of matter is presented in the books of chemistry and physics but not as if it is a model but as the fact that matter is built up of atoms. Out of this different kinds of substances are presented, especially in chemistry. The different parts of an atom are presented, in both chemistry and physics. In biology this kind of knowledge is used when for instance talking about photosynthesis.

All the concepts mentioned in the summary are to be found in the books. The chemical formulae of cellulose and stearin acid are given. Cellulose is said to be an important part of plants and that candles consist of stearin acid is clearly said.

Out of this could be concluded that the knowledge needed to explain the three interview situations on a scientific level is in the books. Photosynthesis and the cycle of carbon are dealt with in both the biology and chemistry books and an understanding of these processes is probably helpful when making meaning of the interview situations. But the notion of model is not at any point made obvious. The ideas are not presented as theoretical constructions built on and confirmed by experiments.

**Literature review**

My study concerns transformations of matter, both changes of state as in evaporation and condensation and chemical reactions as in decomposition and burning. The study also deals with the particulate nature of matter. The study concentrates on three everyday situations, fading leaves, burning candles and water evaporation and condensation in a small system (a glass of water with a lid on).
The idea of the particulate nature of matter is introduced to the students in this study at an early age.

I have therefore restricted this literature review to papers written within the domains of students’ understanding of evaporation, condensation and chemical change. The first part of the literature review concentrates on papers within this area that in some way also connect to discussions or findings of the particulate nature of matter. Another restriction is the level of depth or abstraction within the area. I have concentrated on papers that are relevant in comparison with the content of the Swedish syllabi in science studies, biology, chemistry, and physics for the compulsory school.

In science education research a lot of emphasis has been laid on finding out about students’ conceptions of different concepts especially during the 1970s and 1980s. This was done within the framework of Piaget’s developmental stages and/or constructivism and conceptual change. The students’ conceptions were talked about as students’ misconceptions, alternative conceptions, naïve conceptions, or ideas. I will present some of these findings as they have had a great impact on later research. Before continuing this review it seems important to raise the difficulty of presenting a literature review when dealing with a longitudinal study of this length. Some of what is presented in this review was published before the study started and has had an impact on the study from the beginning. There are also findings and discussions which were presented during the study. Some of those have had impact on the study and some of those are presented here in order to be able to discuss those findings in relation to my findings.

Transformations of matter and the particulate nature of matter

As there are two seminal papers, Andersson (1990) and Krnel, Watson and Glazer (1998), which are often cited and which are surveys of the research within the area of students’ understanding of matter and its transformations as well as students’ development within the area, I have taken these papers as a point of departure in this part of the review. Andersson (1990) summarizes the research up to the late 1980s sorting out what we then knew. The purposes
of the paper by Krnel et al. (1998) are to, out of results of earlier studies, find paths of development of the matter concept.

Andersson (1990) claims that students’ everyday understanding of matter can be distinguished into the same five categories out of their understanding of both phenomena known as chemical reactions and those known as changes of state to scientists. These five categories are:

- Disappearance, a substance can disappear into nothing
- Displacement, a substance in a given place disappears from there just because it is displaced
- Modification, a substance retains its identity while some of its properties are changed
- Transmutation, includes a number of transformations that are forbidden in chemistry
- Chemical reaction, this idea can also be used wrongly for instance to explain a phase change.

It is also shown out of earlier research that students’ answers concerning conservation problems are influenced by their above conceptions of how matter is transformed.

Andersson (1990) also concludes from earlier studies where students’ conceptions of atoms and molecules have been studied that the picture is scattered but some lines can be distinguished.

- If you see the atom as the primary building block or if you see it as the final link of division could influence your further understanding.
- Macro properties are often transferred to the micro world. The first four models seen above are also used on atoms and molecules.
- Concerning systems of many particles the results “may in general be interpreted as indications of a conflict between, or a mixture of, the ‘continuous, static, no vacuum’ conception and the ‘particulate, dynamic, vacuum’ one” (p. 69).
Andersson (1990) argues that "the presentation in text-books is incomplete and sometimes probably confusing for a person with no scientific training" (p. 71) and he summarizes that “the analysis based on recent research results demonstrates that there is room for specific improvements in textbooks (and probably also teaching practice) when it is a question of illustrations, language and the model-observation relationship” (p. 75). He also concludes out of earlier research that there probably ought to be more discussions about conservation of mass in connection to different experiments and more effort laid on developing students’ understanding of the gas state in school education.

Krnel et al. (1998) use a theoretical framework based on Piaget’s statement of children’s development of the matter concept via ‘action’. Using this framework in the analysis of earlier research the authors come to some conclusions. Krnel et al. (ibid) stress the importance of creating learning situations in which children can differentiate objects from matter by dealing explicitly with extensive and intensive properties. The development of the concept of matter starts in understanding objects (macro level), then matter on a macro level, and from there objects on a micro level. The authors mean that this necessary development makes the expression ‘conservation of matter’ problematic for children to understand. It is also stressed that the concept of matter can not be understood only through experience but also involves mental operations.

How have then these surveys influenced later research and what kind of implications could the results presented in these surveys and later papers have on my research? There are a lot of studies (e.g. Nakleh & Samarapungavan, 1999; Hatzinikita, Kouldaidis & Hatzinikitas, 2005) in which students have been asked questions about the above phenomena with the researchers categorizing the answers in different ways. In these studies the students are in different ways asked to use the particle theory. Selley (2000) investigates how 12 to 14 years olds spontaneously use the particle idea in explanations concerning solutions. The conclusion is that the simplest model that matter is composed of tiny pieces, is usable to many children but the kinetic-molecular model is quite demanding. Results from a study with 13, 15 and 17 year old Turkish students indicate that, despite science teaching, even the older students have
difficulties in using the particulate theory to explain phase changes (Boz, 2006). One conclusion was that students of all age groups were reluctant to use the particulate theory although they had some correct ideas. The author then argues for the importance of helping students to link the theory to different events by encouraging them to use the idea in their explanations. Another conclusion is the need to present the similarities and differences between the model and the reality (Boz, 2006). In a paper concerning students studying chemistry in grade 11, Harrison and Treagust (2000) discuss the necessity and the difficulties in using models in science education. They assert that being able to use different models in different situations shows a high intellectual position. Gómez Crespo and Pozo (2004), who examined students’ understanding of phase changes, solutions, expansions, and chemical reactions, establish students’ difficulties in connecting the theories learned in school with the reality around them. This includes the difficulty to understand when models are used and when we are talking about the real world. De Vos and Verdoonk (1996) claim that we probably have to explicitly teach about the features of science explanations in order to help students understand the fundamentals of the particle theory. There are also studies concentrating on special issues in order to inform about possibilities to reach more successful learning situations. Solomonidou and Stavridou (2000), as an example, suggest that introducing chemistry by working especially with the concept of substance could improve students’ understanding.

There is an underlying discussion going on dealing with the questions: “When should the particulate nature of matter be introduced?” and “How can it be introduced?” Ahtee and Varjola (1998) asked students in the secondary school aged 13 and 14, students in the first year in gymnasium (age 16) and students in a first year university course in chemistry to describe a chemical reaction. They concluded that the idea of the particulate nature of matter should not be introduced early because the students have difficulties in understanding it. In a study building on results from TIMSS\textsuperscript{12}, Liu and Lesniak (2005) claim it is too difficult for stu-
dents to understand the scientific particle concept and suggest one should not introduce it to students other than those attending special programs in the upper secondary school. Fensham (1994) has also argued against an early introduction, asserting that it is too difficult for young students to grasp the idea and an early introduction could thereby hinder further understanding of the concept and/or further interest in science.

There are other studies (Novak & Musonda, 1991; Johnson 1998a, b, c, 2000, 2002; Eskilsson & Helldén, 2003; Papageorgiou & Johnson, 2005; Tytler, Prain & Peterson, 2007) arguing in favour of an early introduction of the particulate nature of matter. Novak and Musonda (1991) report a 12-year longitudinal study in which they used audio tutorial science instructional sequences to introduce in grade one and two science concepts that are usually introduced much later. One of these concepts was the idea of the particulate nature of matter. The students’ conceptual understandings in science were traced over a period of twelve years and compared with a control group. The data clearly show a positive impact of the early science instructions on the students’ cognitive development in science. In a later report on the same study Novak (2005) stresses that the data also indicate the importance of not underestimating primary students’ learning abilities.

Johnson (1998a, b, c, 2000, 2002) reports a longitudinal study following students from 11 to 14 years of age. In interviews students were asked about some situations but they were also directly asked about particles. Johnson (1998a) found four different models used by the students, namely:

X: Continuous substance.
A: Particles in the continuous substance.
B: Particles are the substance, but with macroscopic character.
C: Particles are the substance, properties of state are collective (p. 399).

These models were discussed and compared with what is taught by textbooks and teachers. The paper ends by asking if perhaps model A and B are necessary steps in understanding the idea of the particulate nature of matter. Johnson also suggests that perhaps
model B is a good model when starting teaching about the particulate nature of matter but he also stresses that this should be an active choice and has to be consequently built upon in later teaching. In the following papers Johnson especially discusses boiling water (1998b), evaporation and condensation below boiling point (1998c), recognizing chemical change (2000) and explaining chemical change (2002). The results and discussions presented in these papers all draw on the longitudinal study and the models presented above.

Johnson argues that the gas phase is of importance for students’ understanding of the situation (Johnson 1998b; 1998c). Johnson (1998b) emphasises the difficulty of knowing what the students mean when talking about oxygen, air or gas. In both studies Johnson claims students’ understanding of the gas phase will be supported by a simple particle model B in comparison with having no model to work with. Johnson (1998c) argues for the need of a particle model in order to understand water in the air and discusses the science curricula in which teachers are supposed to teach about evaporation below boiling point much before the particulate nature of matter is supposed to be introduced. Johnson (1998c) also argues for the importance of comparing boiling and evaporation below boiling point. Tytler et al. (2007), also in a longitudinal study, introduced a particle concept in school-year five and emphasise the importance of letting teachers and students use many different representations. In the study they let students explain different situations in which evaporation occurs and they show possible advantages with an early introduction.

Johnson (2000) asserts that Andersson (1990) assumes that students understand what a substance is in the same way as the scientific definition but claims this is not the case. In a study of Norwegian teacher students Håland (2008) shows that only 4 out of 31 students have “reasonably good notions of substances” (p. 3) in relation to evaporation, burning candles, and formation of dew. Johnson (2000) emphasises the difficulty in understanding the chemical reaction taking place in a burning candle. He asserts that scientists use the notion that matter is composed of atoms to explain chemical reactions. In the next paper Johnson (2002) shows that students have to have a well developed particle concept in or-
der to understand chemical reactions. Papageorgiou and Johnson (2005) introduced the particulate nature of matter to one group of ten year olds through situations where melting occurred and then these ideas were used throughout a teaching sequence. Another group of students went through the same teaching session but now only with explanations on a macro level. They claim the model B presented above is a good starting point. This model is easy enough for young students to understand and it is good enough to explain a lot of those phenomena supposed to be explained rather early in school and which, in the authors’ opinion, cannot be understood and explained without a particle model.

Decomposition

There are not many studies that examine students’ ideas about decomposition. In decomposition, matter that could be seen, as in the leaf, will be converted to the gases carbon dioxide and water vapour which cannot be seen. Some of the matter is converted to nutrients in the soil. Earlier studies, a lot of them mentioned and summarized in Driver, Guesne and Tiberghien (1985) and Driver, Squires, Rushworth and Wood-Robinson (1994), have shown that especially young students are not aware of the material character of air and other gases and that they often take for granted that everything they cannot observe does not exist. Helldén (1995) confirmed these results in a longitudinal study following 25 Swedish students from age 8 to 15. In this study it was obvious that many students thought that soil was the end product in decomposition. Helldén claims that “Pupils’ ideas about the transformations of matter can be explained by their limited conception of the gaseous state” (p. 267).

In a study of ecological understandings of students aged 5 to 16 years, Leach, Driver, Scott and Wood-Robinson (1996) examined the students’ ideas about a decaying apple. This study confirmed earlier results. Leach et al. claim that a vast majority of the students up to the age of 16 did not see any need to explain where all the matter goes in the decaying process. The study also showed that there is an increase with age in making suggestions about cau-
sation. The students mentioned micro-organisms, visible organisms, and physical factors as the cause of decay but many responses also suggested that the students saw decay as related to age. For instance they would say that when the apple was removed from the tree it did not have any food and this would result in decay. Younger students tended to suggest just one reason for the decay whereas older students offered more reasons. Leach et al. also stress that the use of scientific words such as ‘rot’ or ‘decompose’ does not necessarily mean that the student has the same conceptual understanding of the process as a scientist.

Burning

Students’ ideas about burning have been investigated in many studies. From Driver et al. (1985) and Driver et al. (1994) we know that students are fully aware of the need for air or oxygen in a burning process but that the function is unclear. Even most students in secondary school do not think that “the oxygen has an active role in the process” (Driver et al., 1985 p. 159). When a candle is burning, the wax is often seen as not part of the burning process, but just melting because of the heat and then evaporating out into the air.

In a study with 13 year old students BouJaoude (1991) used, among other things, a burning candle in order to find out about students’ ideas of burning. The students seemed to think that processes such as evaporation and melting just happened, no explanation was needed. He also asserts that the students did not seem to be concerned about the conservation of matter. It was not an issue to be dealt with. BouJaoude concludes that the students’ understandings of the burning process are “fragmented, inconsistent, and based on the visible aspects of events that they observed” (p. 700).

Watson, Prieto and Dillon (1997), in a study with 14 to 16 year olds, found that many students seem to confuse changes in state with burning. Again many students thought the wax of the candle just melts. The idea that the flame would consume oxygen was rare. Rahayu and Tytler (1999), however in a study of students in primary school years, noticed a progression of the students’ ability
to think of a substance as defined by its properties rather than its history. This means a growing confidence with the idea of transformation of substances. As in BouJaoude’s study with 13 year olds the students in this study paid no attention to conservation of matter.

Rahayu and Tytler (1999) found a high proportion of ‘simple descriptions’ in the situation with a burning candle compared with other situations presented. They suggest that this is because the candle is familiar to the students who therefore describe the object and not the wick, wax or process. Johnson (2000 & 2002) claims that the burning candle is an especially difficult example of chemical reaction as it involves the gaseous state in both reactants and products, and decomposition as well as synthesis. Tsaparlis (2001) claims students’ difficulties in understanding chemical reactions have the consequence that students will not notice these reactions in common phenomena.

Evaporation and Condensation

Students’ understandings of the water cycle, phase changes, evaporation and condensation, and how and when learning challenges might be met, have been frequently investigated over the last 25 years. Many of these studies build upon the Piagetian framework of developmental stages or the idea of conceptual change that sprung out of the constructivist framework (Bar, 1989; Bar & Travis, 1991; Bar & Galili, 1994; Osborne & Cosgrove 1983; Russell, Harlen & Watt; 1989; Stavy, 1990). Coherent with Piaget’s idea that young children cannot understand the idea of conservation of matter, many of the studies explored the age when this idea was realised by the students. If a student answers, in interviews or questionnaires, that water in a situation disappears, the interpretation has often been that the student so far is not aware of the conservation principle. This interpretation has later been questioned (e.g. Johnson, 1998b; Tytler, 2000). But even if some of the results of these studies have been questioned in later studies, the studies show the difficulties students have in understanding phase changes such as evaporation and condensation.
The gas stage is problematic to students. Water vapour is for instance often thought of (even by adults) to be the condensed water seen in the air when water boils. When the vapour is not seen it has become air (Osborne & Cosgrove 1983). Russell et al. (1989) found the following categories among 5 to 11 year olds when asked about evaporation from an open water tank:

- No necessary conservation
- Change of location with no physical change in the nature of water; and to the following sub categories
  - Relocation of water by human or animal agent
  - Relocation of water to the site of the agent
  - Relocation of water to a site other than the agent
- Physical change in the nature of water associated with change of location; and the following sub categories
  - Conservation and transformation in perceptible form
  - Conservation and transformation in imperceptible form.

The final sub category is said to probably be “as far as children’s descriptions of the phenomenon of evaporation might be expected to reach without the support of a particle model of matter” (p. 572). According to Bar and Travis (1991) boiling is understood and possible to explain earlier than evaporation below boiling point. They also claim that the understanding of condensation is parallel with the understanding of evaporation. To understand condensation on a cold surface, it is necessary to know that the air holds water vapour.

Johnson (1998b), from a 3 year longitudinal study of 11 to 14 year olds, questions Bar and Travis (1991) when they say young children understand that during boiling liquid is changed into gas. Johnson (1998b) claims that understanding that water (vapour) rises up into an already existing amount of gas is not the same as understanding the gas phase. Out of this he means it is extremely important to get the students to understand that the bubbles in boiling water consist of water vapour. This could be a clue to understanding the properties of a gas. Concerning evaporation and condensation below boiling point, Johnson (1998c) claims that
students know there will be less water in an open container if the container is left for some days. The students in his study did not mean that water was transformed into air (as claimed by for instance Andersson, 1990), but they use the word air for anything in the gaseous state. Johnson (1998c) concludes that in order to understand condensation and evaporation students have to understand the gaseous state both in the way of seeing water vapour as a gas of its own and as seeing water vapour as a part of air.

Osborne and Cosgrove (1983) make the observation that students’ understanding of scientific terms such as condensation and evaporation are frequently superficial. Even many older students (age 16-17) in their study did not have “sound scientific concepts underpinning these labels” (p. 836). The difficulty of interpreting the understanding behind the use of words is obvious in presentations of two different students ‘using’ the same conception but understood in quite different ways (Tytler & Peterson. 2004). Johnson (1998a) also emphasises the importance of not too readily interpreting students’ ways of using words as their understanding of a phenomenon. In his opinion we have often in research studies been too harsh in our interpretations of students’ answers.

In a cross-sectional study of 6 and 11 year olds about students’ understanding of evaporation and condensation phenomena Tytler (2000) found that many students pronounced more than one conception when they described and talked about situations. Most of the younger students seemed to concentrate on the perceptual elements of the phenomena. But many young students’ thinking seemed to be in advance of that suggested in previous studies. Tytler (2000) claims that ”previous work has to a varying extent underestimated the conceptual sophistication of children considering evaporation phenomena” (p. 462). Tytler and Peterson (2004) claim that the idea that water changes state and becomes part of the air agrees with earlier studies (e.g. Bar and Galili, 1994) but the gradual development of this idea and the age when this development is possible to start oppose earlier findings. Canpolat (2006), on the other hand, in a study of undergraduates claims that the students in his study (becoming primary teachers) believe that water has to be heated by its surrounding in order to evaporate. If the water has a higher temperature than the surrounding it will just
transfer heat and thereby change temperature, but no evaporation takes place.

Summary and implications for my study

I will now sum up those findings of the studies above that have influenced my thesis.

- Many studies show students’ difficulties in understanding matter and its transformations.
- Many studies show that students find it difficult to understand the idea of the particulate nature of matter.
- There are few studies concerning decomposition in comparison to studies concerning burning and evaporation and condensation.
- Many studies categorize students’ answers in order to find students’ conceptions about matter, its transformations and/or the particulate nature of matter.
- The gas state is shown to be difficult for students to understand.
- Effort is laid on finding out when students are able to apprehend conservation of matter.
- There are studies trying to find solutions to these difficulties, that suggest more effort be laid on special concepts, later/earlier introduction of the particle theory, improvement of text-books or improvement/changes in teaching.
- There are studies suggesting that teaching should follow specific lines because students develop understanding following these lines.
- In most studies the analyses are made in comparison to the “complete” and “correct” scientific idea.
- In most studies the particle concept is prompted in order to learn as much as possible about the students’ ideas about the scientific concept.
- Few studies look at students’ ability to use the particle idea in everyday situations.
- Some of the later studies emphasize students’ difficulties
in understanding models and scientific explanations and especially stresses the importance of explicitly in teaching situations deal with these matters (Andersson (2000) also made remarks in this direction).

- In some of the later studies there are suggestions about the importance of explicitly, in teaching, helping students to connect the theoretical science learned in school with situations in the students’ ordinary lives.
- There are some (mostly) later studies that recommend an introduction of the particulate nature of matter through models that are not scientifically correct (or “complete”) but good enough to be starting points and possible to elaborate later into more scientifically correct models.
- If emphasis is laid on correct scientific concepts a late introduction of the particle concept is argued for. On the other hand if, in understanding common phenomena, the focus is laid on possible explanation advantages by using a particle concept an early introduction is argued for.
- There are very few longitudinal studies following the same students over a longer period of time.

My study has the intention to complement the studies summarized by studying individual students’ development of understanding and their ability to explain the processes decomposition, burning, evaporation, and condensation in some everyday situations. Either chemical reactions or phase changes occur in the situations chosen. Students’ understanding of decomposition has been the interest but in only a few studies. The development of this understanding is studied, in my research together with burning, evaporation, and condensation. An early introduction of a simple particle concept is discussed with reference to those arguing pro and others against. An early introduction of a molecule concept is made in this study, which makes it possible to examine and follow if and how students make use of such an intellectual tool when explaining everyday situations. In this study the students can be followed before, during, and after the more formal introduction of the particle concept is made in school. The longitudinal design makes it possible to fol-
low individual students’ development but also to trace communal-
ities within the group.
From the overall aim of my thesis - to learn more about how individual students develop their understanding of processes in which different kinds of transformations of matter occur – and the background described above the following research questions have been formulated:

1. How do students, aged 7 to 16, change their ideas about the concepts decomposition, burning, evaporation, and condensation involved in the three situations presented above?
2. How do students, aged 7 to 16, use the molecule concept in their descriptions and explanations of the three situations?
3. How do students, aged 7 to 16, use experiences from both out and in school when describing and explaining the three situations?
4. How can we make sense of individual students’ learning pathways?

Question 1 is addressed and the results up to age 11 and age 13 are presented and discussed in paper I and paper II, respectively. This question is further dealt with in “Following students’ ideas”.

Question 2 is addressed and the results are presented and discussed in paper II. The main results and the conclusions made are presented in “The four papers”.
Question 3 is addressed and the results are presented and discussed in paper IV. The main results and the conclusions made are presented in “The four papers”.

Question 4 is addressed and results presented and discussed in paper II up to the age of 13. This question is further dealt with in “Following students’ ideas”.
THEORETICAL AND METHODOLOGICAL FRAMEWORK

A few years before this study was planned and the first data were gathered, the first handbook on science education edited by Gabel (1994) was published. Since then two more handbooks on science – “International Handbook of Science Education”, edited by Fraser and Tobin (1998) and “Handbook of Research on Science Education”, edited by Abell and Lederman (2007) – and one general handbook – “Handbook of Research on Teaching” edited by Richardson (2001) have been published. The reason to mention these handbooks is to elucidate the amount of research that has been accomplished within the area of science education during the last decades and which have had or could have had impact on this study. The first chapter about learning in Fraser and Tobin (1998) is named “Learning in Science – From Behaviourism Towards Social Constructivism and Beyond” (Duit & Treagust, 1998) showing the width of perspectives that could be addressed. Abell and Lederman (2007) write that the trend of change over time from quantitative to qualitative methodologies corresponds to the move from behaviourism to cognitive theories about learning. They claim that science education is “influenced by the prevailing learning theory of the day” (p. xii) but also that “Few would argue that perspectives of learning have changed drastically over the past 100 years” (p. xii). In the first chapter about science learning, in this latest handbook, Anderson (2007) claims that the science learning literature is diverse and holds different methods and viewpoints that could make the reading demanding and sometimes frustrating. In
the next sections I will explain the theoretical and methodological framework of this thesis.

**Human Constructivism – my interpretation**

The theoretical framework of this study builds upon Human Constructivism formulated by Joseph Novak (1993). This perspective gets its inspiration from Ausubel’s assimilation theory of meaningful learning (Ausubel, Novak & Hansenian, 1978). The assimilation theory explains acquisition, retention and forgetting of knowledge but also how knowledge is organised in the cognitive structure of the learner. The theory deals with school learning in the form of meaningful reception learning but even so I think the theory can help us understand the development of students’ learning that occurs from lots of different experiences within as well as outside school and over a longer period of time. The opposite of meaningful learning is rote learning.

The core of the assimilation theory (Ausubel, 2000\(^\text{13}\)) is the idea that new meaning is gained by the interaction of new potentially meaningful ideas and earlier learned concepts\(^\text{14}\) and propositions\(^\text{15}\). An idea is potentially meaningful to a learner if it is relatatable to the learner’s knowledge structure on a nonarbitrary and nonverbatim basis. The new idea is subsumed into an established idea. Both ideas are then modified and interact through retention and could become more complicated and greater than the sum of the two ideas. This process of assimilating new meanings results in progressive differentiation of concepts and propositions by consequently elaborated understanding and it also gives a readiness to anchor further new meanings to the newly built ideational concepts and

\(^{13}\) Concerning the concepts and aspects that are treated in the following there are, to my view, no important differences in Ausubel et al. (1978) and Ausubel (2000). As I am more familiar with Ausubel (2000) I have used that reference although this book was written later than when Novak (1993) formulated ‘Human Constructivism’ the first time.

\(^{14}\) “Concepts may be defined as objects, events, situations, or properties that possess common criterial attributes and are designated by the same sign or symbol” (Ausubel, 2000, p. 2).

\(^{15}\) Propositions are, due to Novak (1993, p 171) “two or more concepts linked to form a meaningful statement”. Ausubel et al. (1978, p 629) defines propositional learning as “learning the meaning of a new composite idea expressed in sentence form; acquisition of a specific meaning derived from two or more concepts, but constituting more than the sum of the latter because of the ‘semantic’ properties of word order and inflection (syntax)”
propositions. When concepts and propositions are elaborated by successive new learning processes new and different understandings can occur and conflicting understandings can be resolved by a process of integrative reconciliation. When the assimilation process goes on the understanding of the different components in concepts and propositions cannot be dissociated from the anchoring ideas and oblitative subsumption occurs. In the cognitive structure there are anchorage ideas or subsumers (Ausubel, ibid). These are ideas, thoughts or concepts to which one can link the new learning material. The cognitive structure consists of superordinate and subordinate segments structured in a hierarchical system. The main organisation principle is progressive differentiation and the second subsuming principle is oblitative subsumption.

Ausubel (2000) distinguishes between three kinds of meaningful learning: representational learning, concept learning, and propositional learning. Representational learning takes place in naming, defining, and labelling activities if the learning of single words also includes the meaning of them, that is to say what they represent. Concept learning is learning what the concept itself means, what critical attributes it holds. Learning the word of the concept is representational learning. Propositional learning is to learn the meaning of new ideas expressed in propositional form. A new idea is more than the sum of the meanings of the individual words in the proposition, which also means that before one can learn the meaning of the idea expressed in the proposition one must first know the meanings of the different words/concepts or what they represent.

Ausubel et al. (1978) argue that for meaningful learning the following conditions must be fulfilled:

- The subject matter to be learnt must be potentially meaningful to the learner.
- The learner must know the meaning of concepts that relate to the new information to be learnt.
- The learner must choose to learn meaningfully.

Meaningful learning is in principle impossible without a language. The language plays an integrative and operative role in thinking.
and thereby in the learning process. The language does not only play a communicative role as proposed by Piaget. To make meaningful learning easier to obtain advance organisers are proposed to be introduced. The advance organisers will help students to link new knowledge to already existing relevant concepts and propositions (Ausubel, 2000).

Novak (1993) claims that when a person, a researcher, creates new knowledge, it is to that person (researcher) a form of meaningful learning. In the creation process new regularities could be recognized, new concepts could be defined, old concepts could be extended, new relationships between concepts could be recognized, and sometimes new structures could be seen. Novak (ibid) tries to “confl ate issues that deal with the nature of knowledge construction into the issues that deal with the psychology of meaning making” (p. 190). The importance of the unique interplay that occurs between thinking, feeling, and acting in human learning and in human construction of new knowledge is underlined. Novak (ibid) claims that “all human beings have an enormous capacity to make meaning” (p 190) and he also stresses the important role of language in this meaning making process. The capacity for meaning making is referred to as Human Constructivism.

From a Human Constructivist perspective (Mintzes & Wandersee, 1998) knowledge is a framework of concepts related to one another in a hierarchical structure. Students build up their individual and unique frameworks in an active process and over time. Even if every framework is unique there is enough commonality that sharing meanings is possible. This also means that the individual concept structures can be changed and enlarged and makes education (and new science creation in the science community) possible. The learner’s mind is viewed “as a unique and intricate framework (a hierarchical web) of interrelated concepts” (p. 53). To meaningfully learn new things requires much time and effort from an active learner. The frameworks provide both a rational and an emotional base for problem solving and learning.

Constructivism is often closely connected to Piaget. The idea of age-related general stages of cognitive development proposed by Piaget (e.g. Piaget, 1972) is rejected by Novak (1993). Human constructivism instead builds on the idea that it is the comparably low
quantity and quality of relevant concepts and propositional frameworks due to fewer experiences that limits new learning and problem solving in young children and not their developmental abilities. This could be seen as more in line with Vygotsky’s views of learning (1986) where he stresses the importance of social factors in learning. One could say that Piaget claims that development is crucial for learning while Vygotsky and Novak claim learning is crucial for development.

Constructivism could also in teaching environments mean that the student has to learn all by herself or himself with the result that the teacher is ‘setting the scene’ and not actively supporting the learning process. The result is a kind of discovery learning in which the student altogether constructs its own knowledge. This is an idea rejected by both Ausubel and Novak and not in any way included in the Human Constructivist perspectives. The idea of the teacher as a transmitter of knowledge is also rejected in consequence of what is already said about meaningful learning and active students. A ‘Human Constructivist teacher’ is one that structures the content that should be learnt, who takes into consideration what the students already know and who, in harmony with Vygotsky’s idea of the zone of proximal development (1986), stretches the intellectual demand of thinking.

In my opinion, the Human Constructivist perspective 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)
Human Constructivism stresses the significant role of cognitive processes and the role of prior knowledge more than most social constructivist perspectives. The individual meaning making is crucial, the teacher who introduces the knowledge of the scientific community and who stretches the student’s bounds is important and the important role of the language in meaning making is stressed. These later issues coincide with Social Constructivist perspectives formulated by Scott et al. (2007).

Both the Human Constructivism and Social Constructivism presented above hold the idea that the models and theories that build up the Science Knowledge are created and built up by human beings (e.g. Aikenhead, 1996; Sjöberg, 2000). This means Science is a social construction but not just any human construction is possible. The theories and models have to be tested in relation to the world around us. Looking at the result of meaningful learning, as meaningful learning is advocated by Human Constructivist perspectives, it would coincide with Marton’s and Booth’s (1997) ideas that by learning, our view of the world becomes more differentiated and more integrated. The world will look a bit different to us as a result of new knowledge!

In my opinion, building on this interpretation of Human Constructivism means 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.

**Learning about students’ ideas.**

The only possible way to gain information about how an individual student learns and thinks about different phenomena is either through some kind of communication with the student or through observing the student when she or he communicates with others. The perspective described in the latest section makes it possible to use interviews to find out about students’ ideas. Although learning and understanding are often situated, students also show enough consistency over situations in different contexts to make it mean-
ingful to use individual interview situations to learn more about their conceptions of a particular phenomenon (Ginsburg, 1997).

Like many other researchers (e.g. Duit, Treagust & Mansfield, 1996), I 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. Having concrete things present that the student could look at but also sometimes feel and manipulate in different ways is natural and quite generative when interviewing about phenomena in natural sciences. The design also provides flexibility, allowing the possibility to follow up different themes raised during the interview (Ginsburg, 1997). If the aim is to, from the interview, learn as much as possible about the student’s ideas about a phenomenon the follow-up questions are crucial. They have to be dependent on the student’s response and they are supposed to give new or deeper information about the student’s ideas (Rossman & Rallis, 1998). The interviewer has to have a sensitive ear both to what is said and what is not. When interviewing young students it is important to put forward follow-up questions also because we do not always use words with the same understanding (Ginsburg, 1997). This kind of interview will then often have the same features as a conversation in which one really wants to understand the other person’s ideas about a situation or phenomenon. From a methodological perspective one has to be aware of the fact that responses in interviews are co-constructed and dependent on the line of questioning.

With the opinion that learning is a gradual process and that students have to gradually elaborate the meaning of important scientific concepts it becomes necessary to follow these processes if the aim is to learn more about how students change and elaborate their ideas. A study that follows the same group of students by collecting data at least twice, at different points of time over a time span of at least one school year is by Arzi (2004) defined as longitudinal. Longitudinal studies, where individual students are followed over time, have been asked for by Arzi (1988) and White (2001). Longitudinal studies have been rare but during the last years the longitudinal design has gained more interest and two special issues on longitudinal studies have been presented by two in-
ternational journals in science education (Shapiro, 2004a; Tytler, Arzi & White, 2005).

In the issue edited by Shapiro (2004a) different studies are presented, some concerning students' development within different concept areas. Such are light (Shapiro, 2004b), ecology (Helldén, 2004a), evaporation (Tytler & Peterson, 2004), and transformations of matter (Holgersson & Löfgren, 2004). Other papers deal with more general developmental issues, namely students' attitudes (Reiss, 2004) and the advantage of human constructivist views and concept maps in order to achieve meaningful learning (Novak, 2004).

The papers in the issue edited by Tytler et al. (2005) report on the insights that longitudinal studies can give on general developmental issues. Johnson (2005) claims for instance that students in his three year longitudinal study changed their responses and this is not in line with the resistance to change reported in many other studies. With the longitudinal design individual changes could be tracked. Adey (2005) reports on long-term effects of cognitive development only possible to trace within a longitudinal design. Tytler and Peterson (2005) show the change in conceptual knowledge and scientific reasoning of 12 students followed from age 5 to age 10 and discuss the insights gained through the longitudinal design. Novak (2005), out of the longitudinal study (Novak & Musonda, 1991) and combined with studies that have followed, argues the importance of early introduction of important scientific ideas such as the particulate nature of matter. White and Arzi (2005) from the papers presented in the issue discuss advantages and obstacles with longitudinal studies and they end by concluding:

It might seem that concentration on individuals in descriptive studies could not lead to insights that apply generally to learning or teaching. The insights offered by the descriptive studies in the present volume show that this is not so, as they do tell us about the idiosyncrasies of individuals, but they also yield general principles. Similarly, the experimental studies go well beyond mere numbers and simplistic conclusions. If we wish to understand important long-term changes and how they occur, our
research must stretch over time and include different styles and methods. (p. 148).

In the next chapter I will present my study: in consequence with my opinions about how students’ expressed ideas reflecting their learning could be followed, the study is longitudinal with interviews.
THE STUDY

It is essential to know more about how individual students develop their understanding of transformations of matter to understand what supports learning and thereby be able to develop science teaching within the area. To accomplish this, long-term or longitudinal studies have been called for in the literature (Arzi, 1988; White, 2001).

Table 1: Overview showing the interviews and teaching sessions that each student has attended

<table>
<thead>
<tr>
<th>Year</th>
<th>Interviews and teaching sessions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>Interview 7y:1; Teaching sessions; Interview 7y:2</td>
</tr>
<tr>
<td>1998</td>
<td>Interview 8y, started with listening to the 7y:2 interview</td>
</tr>
<tr>
<td>1999</td>
<td>Interview 9y:1; Teaching sessions; Interview 9y:2</td>
</tr>
<tr>
<td>2000</td>
<td>Interview 10y, started with listening to the 9y:2 interview</td>
</tr>
<tr>
<td>2001</td>
<td>Interview 11y:1; Teaching sessions; Interview 11y:2</td>
</tr>
<tr>
<td></td>
<td>Interview 11y:3, started with listening to the 7y:2 interview</td>
</tr>
<tr>
<td>2002</td>
<td>Interview 12y, started with listening to the 11y:2 interview</td>
</tr>
<tr>
<td>2003</td>
<td>Interview 13y; Teaching sessions performed by the teachers</td>
</tr>
<tr>
<td>2004</td>
<td>Interview 14y, this was a small group interview</td>
</tr>
<tr>
<td>2005</td>
<td>Interview 15y, started with listening to the 11y:1 interview</td>
</tr>
<tr>
<td>2006</td>
<td>Interview 16y, this ended with prompting a molecule concept</td>
</tr>
</tbody>
</table>

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

This study tries to meet this need by studying individual students in detail and over a longer period of time. White and Arzi (2005) make a distinction between studies that are experimental, leading
to conclusions, and those that are descriptive leading to insights. I would describe my study as descriptive leading to new insights.

In order to answer the research questions I have used empirical data from a ten year longitudinal study starting with students aged seven and following them throughout the compulsory school. In the study I have conducted interviews and teaching sessions shown in table 1.

The sample

As said in the introduction this study is part of a broader project involving to begin with 58 students. My part of the study began with 27 students. These 27 students came from three classes in two different schools. They had started school in a middle-sized Swedish town in August 1996. 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 study started in 1997, all 27 students born in 1990 in the three classes were invited to participate in the study, and they all accepted. During the first years, five students left the classes and in 1999 three new students started. In August 2002, when the students were 12 years old, the 25 students moved to a new school. They were divided into small groups and mixed with students from other classes. The students were distributed into 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 in most of the project. There are 20 students who have been in the study from the first year up to the last year. The schools are ordinary Swedish schools, and the teaching has been rather traditional. I would argue that the students are a good sample of ordinary Swedish school students and not extreme in any sense.

In Sweden the students start the compulsory school the autumn the year the students become 7 years old. Almost all children attend the so-called pre-school class which starts the autumn the year the children become 6.
Teaching sessions

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. To support the regular teaching in the classes, members of the research team carried out some teaching sessions presented further in the next paragraph. The teachers of the different classes were invited to perform sessions at different occasions. These sessions are presented in a later paragraph.

Before presenting the teaching sessions I will emphasize that the role of these sessions was 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 teaching sessions are not to be seen as a carefully structured program to be tested. To stress this point, in the short presentations of the design in the papers, these teaching sessions are mostly named interventions. In this richer and more detailed presentation I have decided to name them ‘teaching sessions’, since I want to make clear, that I also look upon the interviews as interventions.

Teaching sessions performed by the research team

1997

In 1997 three teaching sessions with a length of about 20 minutes each were performed. During the first session we discussed different kinds of matter. The students were asked to feel and describe what they felt, when examining different materials. We used solid materials such as stone, wood, iron, and chalk. We also looked at and discussed water and air, and different ways of making air perceptible. As one example we opened a plastic bag and just made a knot on it. Then suddenly some air is trapped in the bag and you can feel, if not the air, at least that there is something in the bag that is taken from the ‘perceptible empty space’ around us. Together with the students we described and emphasised what characterizes different materials.
The theme of the next session was how to divide different kinds of matter into smaller parts. The students crumbled leaves, filed wood and iron, and ground stones against each other and looked at the resulting small parts both with their own eyes and with a magnifying glass. With water they used differently sized pins to bring up water droplets of different sizes. To show that also air could be divided into different sized amounts, soap bubbles were used. The students shook concentrated soapy water in a small bottle and looked at the small bubbles formed. Lastly they were allowed to grind a piece of chalk into as small pieces as they could. Then we discussed the possibility of continuing this process of tearing matter apart into smaller and smaller parts, and claimed that this is not possible. There is always a limit. Everything consists of very small parts that cannot be divided with ordinary means and we call them molecules. This means that there are different kinds of molecules and we can for example speak of stone molecules, wood molecules, water molecules and air molecules. An important thing however is that the molecules are so tiny we cannot see them.

To introduce a molecule concept this early and in this way was inspired by the encouraging results from the study by Novak and Musonda (1991). The choice to use the word molecule, in the teaching sessions, 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 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’s decision to introduce the particulate nature of matter in the way described above is 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.
In the last session in 1997 we came back to the theme that all matter consists of molecules. After that, the students were allowed to smell ground coffee and a perfumed soap from a distance, and we discussed how we could sense those smells. We also heated concentrated black currant lemonade and registered that the smell became more intense when the lemonade got warmer. We explained these observations with molecules leaving the coffee, the soap, or the lemonade, and travelling through the air reaching our noses and producing the smells that we feel. We made connections to the smell we can feel when food is cooked and we emphasized that the molecules are in perpetual motion and the speed of this motion can differ.

These three teaching sessions were performed during the spring term and were documented by video-tapes.

1999

In spring 1999 we performed two teaching sessions lasting for about half an hour each. At the first session, the students studied leaves in different stages of decomposition. In the material there were also a few wood-lice and worms and we talked about how these together with other animals and bacteria took part in the decomposition process. We also discussed how the molecules of the leaves during this process convert to other kinds of molecules and where some of them rise into the air. Another theme was to study what happens when a match burns. Every student was allowed to light a match, let it burn a short time and then blow it out. They put the match in front of them and studied it carefully. We noticed that the black part of the match is thinner than the not burned part and out of this we discussed about burning, that air is needed, new molecules are formed and some of them rise into the air.

During the second intervention the students were allowed to study what happens to an ice cube and boiling water respectively. We then discussed what happens to water molecules in either case. Then they studied a cold bottle, which we took out from the refrigerator. We also studied and discussed what happens when we exhale on a mirror. Where does the water in the mist come from? At the end of the session we dramatised the life of water molecules together with the students. At first we squeezed them into a corner of
the room. The students could hardly move and this symbolized the condition of molecules in ice. Then we released a little bit so they could just move about each other with some effort. This was to symbolize water. Eventually they were allowed to ‘evaporate’ one by one and move freely about in the room as water molecules in the gaseous state.

As in 1997 these sessions were carried through in the spring term and were video-taped.

2001
One teaching session, lasting about 40 minutes, was conducted in 2001. The students discussed the water circle in light of what happens when you breathe upon a cold glass. Then they were allowed to cut up spruce twigs and we discussed how we smell the strong emerging scent from the spruce. The students also lit log-fire matches and we discussed the role of oxygen and the formation of carbon dioxide and water vapour as the results of the burning process. Eventually the students studied wood-lice, worms and other animals. We discussed their role in the decomposition of different plant material lying on the ground. As in 1997 and 1999, this session was performed in the spring term and was video-taped.

Teaching sessions performed by the regular teachers

During these first years of the study the teachers were invited to demonstrate and discuss similar situations as the ones in our interventions with the students.

In January and February 1998 the teachers included a few of our themes in their ordinary teaching. They talked to the students about all matter consisting of molecules. The teachers allowed the students to put a plate or an open jar with some water (or melting snow) in the classroom for several days, so that the students could see that the water disappeared. The teachers explained this saying that some of the water now was up in the air as water molecules among the other air molecules. They also talked about the reasons why we for instance sometimes can smell food in the corridors or at home. This teaching was done after some informal in-service training performed by the members of the research team.
In the very end of the spring term in 1999 the teachers performed a few experiments in their classes. They had a jar with leaves, worms and wood-lice standing in the class-room for some time. Two jars with water, one with and one without a lid were studied day by day. The teachers were also encouraged to discuss how we can perceive the smell from scenting flowers.

These sessions have not been documented further and we can assume that the discussions have been rather different in the different classes. To use this simple particle model in discussing and explaining every-day phenomena is not familiar to the teachers and this also surely made the interventions differ from class to class dependent on the teachers’ confidence in using this newly presented idea.

As mentioned before the students were moved to a new school in the autumn term 2002. The research team met the new teachers in early spring 2003 and informed about the project so far and asked if the teachers would perform teaching sessions during the spring term designed by the researchers. In these sessions the teachers were asked to discuss some situations in which matter transforms. In these discussions they should use the particle idea in a way similar to earlier in the project. Four different teachers were involved and the sessions turned out to vary more than planned and the particle idea was scarcely used in the discussions. It seems these teachers, who had more science in their education than the teachers earlier involved in the project, were less confident and more reluctant to use this simple molecule concept in discussions with the students.

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 teaching material used has been presented in the background chapter.
Interviews

I 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.

In an earlier project, Helldén (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 investigate further how students change their understanding of transformations of matter.

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 kinds 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.

From 1997 to 2002 I interviewed 9 students who have participated in the whole project; one new student joined my interview group in 2001. During these years Gustav Helldén interviewed the rest of the students. They were to begin with 18 students and in 2002 the number had changed to 15. In the interview in 2003 and onwards I conducted interviews with all the students.

In the beginning of April 1997 I met the students for the first time in individual interviews. After a short presentation, where the intention was to make a positive contact with the student, I told
her or him a little of what was going to happen and why I had this interview. I told the student that I and my colleagues, who performed similar interviews with students in other classes, were interested in students’ ideas about different things. I was deeply interested in her or his ideas and thoughts about some situations that I would present. In an earlier study Helldén (1992) had the experience that starting questions by saying “What kind of ideas have you got...” or “What do you think happens ...” are productive in order for students to tell about their ideas. I therefore used the same technique. During the interview I now and then emphasized my interest in their ideas and not in “correct answers”. Helldén (1992) claims questions starting with “what do you think” can make students engage in thinking and can avoid students only trying to find the correct answer.

The student was presented with some brown 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?” Depending on the student’s response further questions or comments followed.

Then two candles, one long and one short, were presented. I pointed at the short candle and said: “This candle has been as long as the other one but it has burned and become this size.” I lit the short candle and asked: “What do you think has happened to that piece of candle?” Also in this case the student’s comments were followed up; both in order to make the student feel comfortable but also in order to sort things out or receive more information.

Lastly a glass with some water and covered with a glass-plate, on which some mist had formed on the inside, was shown and I asked, “What do you think it is on the inside of the cover?” Follow up questions to this were: “Where do you think it comes from?” and “How do you think it could become like this?” Other follow-up questions formed out of the student’s response were of course asked also in this situation.

Together with one of the members of the research team, Ingemar Holgersson, I then performed the teaching sessions already presented and after that in the middle of May I had new interviews with the students. These were as the ones described above.
Helldén (2003) has shown that students often can shed light on their own statements by being allowed to comment on them at a later time. Therefore in 1998 a more metacognitive approach was used. The student was presented with the same equipment and listened to the last interview from the year before, one part of the interview at a time. I then asked: “What do you say about what you said last year?”, “Do you have the same ideas today or have they changed?”, and “What do you think today?” Also in this interview, different follow up questions were asked depending on the student’s answers.

This pattern was repeated in 1999 and 2000 and then in 2001 and 2002. In 2001, I decided to extend the interviews in the following way. In the first situation I presented the students both with leaves, dry grass and a peg, all of which I had brought in from the woods. I then asked them about what happens to all of these things. I also presented them with a sample of soil and asked: “How is soil formed?” In the next situation I changed the long candles for tea lights, one new and one nearly burned out. After asking the same question as above I supplemented it with the following question: “What do you think happens in the flame?” In the third situation I continued the interview by taking off the cover and laying it on the table. Then I asked: “What do you think will happen if the glass is left for a fortnight without a cover?” and “What do you think will happen to that thing (the mist) on the cover, if it is left like this for a fortnight?”

In the autumn term 2001 I also had interviews where the students listened to the second interview from 1997.

In the spring term 2003 I used long candles again but apart from that used the extension from 2001. As the students had now moved to a new school and a new situation, for instance with age homogenous classes and subject rooms instead of ‘home rooms’, I started the interview by commenting and asking a bit about their experiences of this new situation. This spring I also had my first interviews with the 15 students that Gustav Helldén had earlier interviewed. These were performed in the same way as the others. I started them with explaining why I was the interviewer. Especially with these new students the chat about their new situation was valuable in creating a natural communicating situation and not an
interview situation asking for the correct answer. These interviews were conducted before the teaching sessions performed by their regular teachers. Originally the research team had planned to have new interviews after the sessions just as in 1997, 1999 and 2001 but because of both practical and pedagogical reasons I decided to make a change of the design. The practical problem was due to the difficulty to find space both in the students’ timetables and in mine at the end of the term. The students were also at this time ‘new-born’ teenagers and not as keen as before to tell about their thoughts. I felt it was not worth perhaps losing their confidence by having two interviews this very spring.

In the spring term 2004 I arranged small group discussions in the following way. Out of the previous responses I created concept cartoons of the three interview situations. I met a group of three to four students in a small room in the school and presented the concept cartoons to the students, one at a time. I told them that the claims made on the concept cartoon were responses from them or other interviewed students through the years. They were asked to discuss the claims and together make a new balloon with their ideas of today. This was done for each one of the situations. Also this time I had brought the same material as in earlier interviews. The group discussions were tape-recorded but also video-recorded in order to be able to safely decide who the speaker was.

In spring 2005 I had interviews with the metacognitive approach described earlier. The student listened to the first interview from 2001 and was then asked to comment in the same way as earlier. After having commented one part of the interview I presented the concept cartoon made by the student’s group the previous year and asked her or him to comment also on this statement. In the end of the whole interview I asked: “Have you any ideas about what it is that, during the years, has changed your way of describing and explaining about the situations we have now discussed?”

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. Before the interview started I asked all the students about their choice of program for upper secondary school.

There have been comments now and then when I have, in different situations, presented the study. The comments have been about the effect of asking the same students the same questions over such a long time. Most students have not seemed to be aware of what they exactly said in previous interviews until being reminded through the metacognitive approach. I decided after the last interviews in 2006 that it would be interesting to gain an insight in how students not participating in the project would answer the same questions. Therefore I interviewed three new students from one of the classes in the same school: These interviews were performed in the way described for 2006. These three students answered similarly to the students who had attended the whole project. The reason for just three students is purely practical. The idea to interview students who had not attended the project came up after the last interviews in spring 2006. I interviewed three students who quickly accepted to be interviewed and who the teacher thought of as representative. I found that their ideas about the three situations were very similar to the ideas of the interviewed students. I had no intention to use this as a control group and receiving the same kind of descriptions and explanations from these three students was enough to satisfy my curiosity.

All the interviews, apart from 2004, were performed individually, tape-recorded and transcribed verbatim. As could be concluded from table 1 I have performed interviews 14 times through the years.

**Methodological issues**

Before presenting the results of the study the ethical aspects that have been taken into consideration will be addressed and also some quality criteria.
Ethical aspects

The ethical principles for research within the disciplines of Humanity and Society have been followed (Vetenskapsrådet, 2002). Before the collection of data started in 1997 the parents gave their consent to students attending the research project. As the study went on for such a long time this procedure was repeated in 2003. Parents whose children joined the project in between because of moving into the schools also gave their consent to participation before the child’s first interview. All names are pseudonyms and when presenting students and their interview responses effort has been taken to not ruin confidentiality.

In addition to following these basic principles it is also important in interview situations to make the students feel comfortable with the situation. The student has to know she or he is allowed to keep silent and not have to answer all questions. That she or he can decide to discontinue the interview at any moment is also important to know. When interviewing young students during school time it is especially important to make these conditions clear to the students. This was done in an encouraging way and I tried to be sensitive to the student’s mood throughout the interview. This means that an interview with one student on one occasion could be elaborated and giving a lot of information while on another occasion I had to be satisfied with short and straightforward responses.

Generality, Trustworthiness, and Importance

There has been discussion among qualitative researchers whether the concepts reliability and validity have relevance in evaluating so-called qualitative research (e.g. Bryman, 2008a). Other criteria have been suggested by for instance Guba and Lincoln (1994), Larsson (1993), and Schoenfeldt (2002). Schoenfeldt (ibid) presents a three-dimensional box with the following three attributes by which a study could be judged: Generality, Trustworthiness, and Importance. I will use the first two attributes when commenting on my thesis here. In the discussion I will say something about Trustworthiness. According to Schoenfeldt (ibid) Importance is “To put things bluntly, how much should readers care about the results?”
I of course find this study important and want readers to care about the results.

I follow individuals, and the insights about science learning that I will present in the next chapters are dependent on the students I follow. I do not claim any generality in the individual students’ learning pathways but as these students can be looked upon as common Swedish students both in respect of their own abilities and family situations and in respect of their school experiences I claim that the insights (if trustworthy) presented can be applied in a wider range than just this study.

In order for a reader to be able to judge the trustworthiness of the insights I have presented my earlier experiences, the theoretical framework, and the design of the study. Due to White and Arzi (2005) it is important when reporting on descriptive studies to “provide readers with sufficient detail of procedures for them to judge whether the insights are well founded” (p. 144). Details about the analyses are presented in “The four papers” and in the different papers. Both in the papers and in the next two chapters the results and insights are illustrated with a lot of examples and excerpts from the interviews in order to make possible a thick description (Geertz, 1973, see Bryman, 2008b). There is a problem of trying to illustrate results with excerpts from interviews as has been pointed out in papers II and III. The excerpt only presents a part of the whole interview, and taken out of its context it might lose meaning even though that meaning was obvious to me, who had listened to and analysed the whole interview.

Another thing to take into consideration when reading the excerpts is the follow-up questions. As an interviewer one has to decide when a follow-up question is beneficial or not. This means that questions asked are not the same in all interviews. I had to use my judgement in deciding how far to prompt the student in every interview and actually after each statement. This is the nature of semi-structured interviews, which also gives them the flexibility argued for by Ginsburg (e.g., 1997). With these issues of methodological nature in mind I hope the reader can appreciate and judge the results and insights presented in the following chapters.

17 The sample is presented on page 72
THE FOUR PAPERS

In this chapter I will present the four papers included in this thesis. As this is a longitudinal study all four papers are about the same study described earlier. The papers were written during a time span of about 6 years. Most of the work on paper I was done during 2002. Papers III and IV were worked on mostly after spring 2006. It was not until then that all the empirical data were gathered and possible to analyse. The papers will thereby on the one hand give a picture of the development of the study; the questions and predictions made as the study proceeds, and on the other hand probably give a hint of the process going on within the researcher when trying to understand the individual students’ pathways and the group story which slowly developed.

In table 2 an overview of the four papers is presented. In the first paper the student sample consists of all students that attended the larger project out of which this thesis is a part. The sample in paper II and onwards is about half of the original sample and then with a few leaving and a few joining the project. All these changes are due to students changing schools. In table 2 it is also shown how the papers connect with the research questions.

I will now for each paper present its ‘history’, the focus and analysis, and some of the main findings, conclusions and implications. As papers III and IV directly deal with research questions 2 and 3 respectively, the presentations of these papers are more comprehensive than the presentations of papers I and II.
Table 2: Overview of the papers, the research questions, the sample and the age of the students

<table>
<thead>
<tr>
<th>Paper: number</th>
<th>The research question dealt with</th>
<th>Sample: number of students*</th>
<th>Students’ age</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Question 1 → up to age 11.</td>
<td>58 → 43</td>
<td>7 - 11</td>
</tr>
<tr>
<td>II</td>
<td>Question 1 &amp; 4 → up to age 13</td>
<td>27 – 5 + 3 = 25</td>
<td>7 - 13</td>
</tr>
<tr>
<td>III</td>
<td>Question 2 →</td>
<td>27 – 5 + 3 – 2 = 23</td>
<td>7 - 16</td>
</tr>
<tr>
<td>IV</td>
<td>Question 3 → and partly question 4</td>
<td>27 – 5 + 3 – 2 = 23</td>
<td>7 - 16</td>
</tr>
</tbody>
</table>


When I present the findings of research questions 1 and 4 in “Following students’ ideas” I will present more from papers I and II. As the four papers concern the same study there are interview excerpts in the papers relevant to more than one research question.

**Paper I: A long-term study of students’ explanations of transformations of matter**

As already said most of the work for paper I was done in 2002. Some of the results were presented in a conference in Kristiansand, Norway in 2002 (Helldén, 2004b; Holgersson, 2004; Löfgren, 2002).

Every phenomenon was analysed by categorizing the conceptions the students expressed. In this analysis all the members of the research team were involved. The students expressed 5 to 6 different conceptions in every situation. These conceptions are presented

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18 Question 1: How do students, aged 7 to 16, change their ideas about the concepts decaying, burning, evaporation, and condensation involved in the three situations presented above?
19 Question 4: How can we make sense of individual students’ learning pathways?
20 Question 2: How do students, aged 7 to 16, use the molecule concept in their descriptions and explanations of the three situations?
21 Question 3: How do students, aged 7 to 16, use experiences from both out and in school when describing and explaining the three situations?
and illustrated by three students’ responses on page 83, the fading leaves; on page 86, the burning candle; and on page 89, the covered glass of water.

Findings that are especially stressed are:

- The longitudinal approach allowed us to see trends in explanations – trends common to the group and trends of personal approaches.
- Across the years, explanations were most often framed in a personal setting relating directly to some experience.
- For some students the molecule concept became a convenient tool for understanding evaporation, for others it did not.

**Paper II: Following young students’ understanding of three phenomena in which transformations of matter occur**

Most of the work with paper II was done during 2003 and 2004. The results have been partly presented in conferences in Noordwijkerhout, the Netherlands in 2003 (Löfgren & Helldén, 2003) and in Lublin, Poland in 2004 (Löfgren & Helldén, 2004). The questions addressed in this paper are:

- How does students’ understanding of three different phenomena in which transformations of matter take place change from the age of 7 to 13?
- How can we make sense of individual students’ learning pathways?

I went on with the analysis of student’s conceptions presented in paper I. Conceptions vs. time diagrams for each individual and each phenomenon were made and I analysed the diagrams on an individual and on a group level. As the group of students grew older they changed their ideas about the situations following more or less a common path or track. The group tracks are illustrated by interview excerpts from one student in every situation (pp. 491, 493 & 495).
In the analysis of the students’ change of understanding of the transformations of matter in the three situations I used the Ausubelian framework of meaningful learning and looked for occasions where meaningful learning in the forms of subordinate, superordinate, and combinatorial learning were seen. In the analyses I had discussions with different researchers.

Conclusions and implications are:

- The students at the age of 13 explained, in some way, the invisible part of the phenomena in the candle and water situations but not in the situation with leaves.
- The student increased her or his domain-specific knowledge and was able to use this knowledge to build up a narrative that became increasingly rich in content.
- A student very often has a personal idea that is used as an anchorage idea.
- In the later interviews, the students seemed less satisfied with just a description of the situation but seemed to demand more of an explanation in order to be satisfied with their own interview statements.

**Paper III: A longitudinal study showing how students use a molecule concept when explaining everyday situations**

Paper III was mostly worked on during 2007 and in August that year parts of the results were presented in a conference in Malmö, Sweden (Löfgren & Helldén, 2007). Results from the earlier parts of the study were also presented in Ålborg, Denmark in 2005 (Löfgren & Helldén, 2006a). The sample in this paper is the 23 students interviewed in the last interview in 2006. The paper answers the second research question:

- How do the students use the molecule concept in their descriptions and explanations of the three situations?

In the last interview at the age of 16 I prompted the molecule concept in the last part of the interview. This interview was performed
at the very end of the compulsory school when the students had had teaching on the particulate nature of matter. According to Oscarsson and Jidesjö (2005) science teachers in Swedish schools claim this is an important area on which a lot of time is spent through school years 7-9.

From analysing how the students used the molecule concept in this last interview four categories were formed, namely:

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 (for more information see paper III, page 12)

The categories are illustrated by interview excerpts from Hilda (category A, page 12), Paul (category B, page 11), Jenny (category C, page 11), and Gunnar and Hedda (category D, page 10).

Table 2 on page 13 presents the outcome of the categorisation of the students’ answers in the different situations. It is only in 12 out of 69 explanations that the students use molecular ideas building on the scientific idea of the particulate nature of matter (category D). 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. In one third of the student answers, the students use the molecule concept in productive ways but as if a molecule is a small part of the substance (category C).

Most students’ responses fall into different categories in the different situations but there are three students whose answers fall into category A, two in category B, three in category C and one in category D in all three situations.\(^{22}\)

The results in the 16 year interview are compared with the use of the molecule concept through the years in the different situations. In the situation with the covered glass of water there is a connec-

\(^{22}\) These students are later referred to as A, B, C and D students respectively.
tion between the spontaneous use in the interview at 16 years of age, the earlier use and the category of response to the molecule question. In the situation with the burning candle there is a connection up to the C category but for the D category both the spontaneous use and earlier use drops (see page 15).

The D student, Gunnar, has used the molecule concept in many of the interviews in the candle and water situation. In the earlier interviews he used the concept as an intellectual tool to understand and describe the situations but the way of using it was of course not in all means scientifically correct. The use was often in line with the answers in the interview at 16 years of age categorized in category C. I claim that the possibility to use and elaborate the concept during a rather long time span is essential to Gunnar’s and to all students’ absolute conditions in understanding theoretical and abstract models in science.

More examples of students’ ability to use a simple molecule concept before formal teaching are presented. These examples are from students whose answers in the last interview fall into D or C category. But when the students use the concept early they use it in the same way. I suggest that students in the C category could have made progress in the same way as students in the D category if they had been helped to connect the simple molecule concept with the abstract molecule model taught in school.

To conclude:

- At the age of 16 only in one-fifth of the answers do the students use molecular ideas in scientifically acceptable ways and 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.
- At the age of 16 one-fifth of the answers show knowledge of scientific facts that are not used in a productive way in these everyday situations.
- At the age of 16 one-third of the students answers show ability to use a simple molecule concept in a productive way.

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23 The formal teaching introducing the particulate nature of matter started in the autumn of 2003.
24 With a simple molecule concept I mean the concept we introduced to the students the very first year of the study.
• 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.

• In the situation with the fading leaves molecules are, across all the interviews, never spontaneously mentioned by any student neither is the idea of the particulate nature of matter spontaneously made visible in any interview responses.

• In the situations with the burning candle and the covered glass of water some students use the molecule concept to explain the invisible parts of the phenomena. Some of these students start doing this already at the age of 9 to 10 and then usually in the water situation.

• Out of the longitudinal study we can conclude that many young students are capable of using a simple particulate model in productive ways in everyday situations.

• 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.

**Paper IV: Following how students from age 7 to 16 use their experiences when developing their ideas about transformations of matter.**

The work on paper IV started in the later parts of 2004 and some results were presented in conferences in 2005 first in Leeds, Great Britain (Löfgren & Helldén, 2006b) and then in Barcelona, Spain (Löfgren & Helldén, 2005). I was at this time disappointed in the outcome of the interviews in 2005 where I used the metacognitive approach. I had hoped to get more insights in the students’ own ideas of their learning processes than was the case. When I in late
2007 looked back on the material and combined it with the analyses made in the work with paper III some very interesting trends and features came up. I continued working on the paper in 2008 and I presented it in a conference in Reykjavik, Iceland in June 2008 (paper IV). The aims in the paper are to investigate:

- How students use previous experiences when they develop and express their ideas about decomposition, burning, evaporation, and condensation
- How students talk about their own learning when given the opportunity to listen to earlier interviews.

In the analysis for this paper I decided to concentrate on the experiences, both those from school and out of school, that the students express in the different interviews. I have also especially examined how they talk about their own learning and made comparisons between that and the way they use the molecule concept at the age of 16 (paper III).

The first aim above coincides in meaning with the third research question of this thesis:

- How do students, aged 7 to 16, use experiences from both out and in school when describing and explaining the three situations?

I will now describe and discuss the results of this research question using paper IV. I will come back to the second aim in the next chapter when I present results concerning research question 4.

When analysing the data a group story out of the expressed experiences in the situation with the fading leaves was found. Also the essence from the ideas expressed in the last interview is the same in all interviews even if the interview responses are differently elaborated depending on the student’s language resources and willingness to express her or his ideas.

The students came to school with different experiences depending on for instance how they lived and how much they were out in the woods. The first years the students were divided in three different age-integrated classes, called K, L and M in paper IV. In classes
K and L the teachers in 1998 did some experiments and discussed with the students what happens when leaves fade. In class M the students had the same experiences in 1999. These early school experiences had a great impact on the students’ ideas in this situation. All the teachers talked about animals eating the leaves, in class K the teacher only talked about worms whereas in the other classes more animals were mentioned. This had an impact on the students’ responses at the age of 16 (paper IV, pages 5 & 8). Almost all students from class K in the interview at 16 years of age only mention worms whereas there is greater variety of animals mentioned from students from class L and M. It is interesting to notice the heavy and forthgoing impact of these early experiences.

In the other two situations there is more diversity both in the experiences mentioned through the years and in the ideas expressed in the last interview. Sune is an example of a student who struggles with making sense of an early experience. His early experience of making candles has obviously had impact on his ideas concerning the situation with the burning candle (pages 9-10). Sune, and many other students, mention water in connection with the burning candle. To some students the melted wax is probably thought of as becoming water meaning a transmutation (Andersson, 1990) of matter. This observation has been made in earlier research (e.g. Johnson, 2002). In Sune’s case, I make the interpretation that he actually thinks a lot of the candle is made up of water and that this conviction is connected to his early experience of making candles. It is possible that he thought the melted wax was water and that this has influenced his ideas. However at the age of 16 he seems convinced that the candle is made up of a lot of water.

Inger’s development of responses is followed in the situation with the covered glass of water and her ability to refer to everyday situations is demonstrated (paper IV, pages 13-14). Up to the age of 13 Inger used these experiences in a productive way to elaborate her ideas and integrate new knowledge. As seen from the excerpts in paper IV she goes on referring to relevant experiences from daily life, but now she is not able to connect the science taught in school year 7 to 9 to these experiences. This also means she cannot use the school science to elaborate and deepen her understanding of the processes in the interview situations.
I conclude:

- The early experiences, both from family life and school, have great impact on the students’ ideas through the years.
- Some students explicitly refer to their experiences when describing and explaining the situations and some do not.
- Up to school-year 5 or 6 (students’ age 12 to 13) most students who refer to experiences are capable of using them together with science learnt in school to productive elaborate their ideas about the processes involved in the interview situations.
- During school-year 7 to 9 many of the students who have been able to use experiences and school science in productive ways seem to have problems going on doing this.
- There is a spread in the students’ capability to use their experiences and the school science in productive ways to elaborate their ideas into more scientifically acceptable ones. This spread becomes greater during the compulsory school.
- It seems difficult for most students to connect the science taught in the later years of the compulsory school to the knowledge they have gained in earlier years and to their own experiences from daily life. Some students seem to solve the problem by rote learning and some seem to decide that science is of no concern to them.
FOLLOWING STUDENTS’ IDEAS

In this chapter I will present the findings of the first and the fourth research question presented on page 59. The findings and conclusions of research questions two and three are presented in the earlier chapter under the headings “Paper III” and “Paper IV”, respectively.

I will present the findings and also discuss the findings in connection to this. The questions and thereby the findings are of course in a way intertwined, also with the ones dealt with in the previous chapter, which will mean that some things will turn up more than once. In the different papers the results are confirmed by giving examples in the form of excerpts from different student interviews. In the presentation below I will now and then refer to such examples from the papers but I will also sometimes use new excerpts from a girl called Hedda.

Hedda has attended all interviews and I have been the interviewer. Hedda is rather talkative although she did not say very much in the first interviews. Her ideas about the three situations did not stick out as special in any way during the first years. In the later interviews she expressed herself with confidence and in the last interview when asked specifically about the molecule she showed an ability to explain the situations with the help of the molecule concept building on the scientific idea of the particulate nature of matter in the situation with the fading leaves and in the situation with the burning candle. In the situation with the covered glass of water she did not elaborate her explanation very much when specifically asked about the molecule. Hedda’s way of talk-
ing about her own learning shows awareness compared with the other students.

**How students’ ideas about decomposition, burning, evaporation, and condensation change**

In this section I will present findings answering the first research question:

- How do students aged 7 to 16 change their ideas about the concepts decomposition, burning, evaporation, and condensation involved in the three situations presented above?

In this section I will concentrate on the findings concerning the students’ ideas about the different phenomena involved in the three situations. There are other aspects on the students’ change of ideas that will be presented and discussed in the section dealing with the fourth research question.

**Decomposition**

The process of decomposition to the students at the age of 16 is seen either as animals eating the organic material or as organic material rotting or mouldering. In both cases the organic material turns into soil. That the process of decomposition includes chemical reactions in which gradually the organic material is converted into carbon dioxide, water, and nutrients have not been recognized. The students focus on and are satisfied with the end product, soil.

The students’ conceptions about the fading leaves up to the age of 11 are presented in paper I and the conceptions are illustrated by giving examples from the transcripts of three students; Ida, Lars, and Jenny (for these illustrations see page 84-86). Jenny has been interviewed by me but not Ida and Lars. The conceptions about the fading leaves are presented in table 3.
Table 3: Student conceptions in explaining what happens to leaves left on the ground.

<table>
<thead>
<tr>
<th>Nr</th>
<th>Conception</th>
<th>Citations characteristic of the conception</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Just disappears</td>
<td>- <em>It is nothing left.</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- <em>Mmm, they have blown away during the autumn.</em></td>
</tr>
<tr>
<td>2</td>
<td>Change due to human activity</td>
<td>- <em>They have perhaps been kicked away.</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- <em>...they have become a hut of leaves that somebody has built over there.</em></td>
</tr>
<tr>
<td>3</td>
<td>Become soil</td>
<td>- <em>They could have turned into soil.</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- <em>That it becomes very, very small and then it turns into soil.</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- <em>When you throw them on the compost then they turn into soil.</em></td>
</tr>
<tr>
<td>4</td>
<td>Breaking up</td>
<td>- <em>They become small pieces.</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- <em>If someone trots on them … they become small pieces.</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- <em>They blow away and they get crushed.</em></td>
</tr>
<tr>
<td>5</td>
<td>Rot</td>
<td>- <em>Then they rot and get old.</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- <em>I think it would moulder away …</em></td>
</tr>
<tr>
<td>6</td>
<td>Animals eat them</td>
<td>- <em>Then the worms would eat them and then they come out and it turns into soil.</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- <em>They moulder and then the worms eat them and do a poo-poo and they have turned into soil.</em></td>
</tr>
</tbody>
</table>

Students usually mention more than one conception during an interview. The concrete experiences of leaves just disappearing or changing due to human activity that could be the only conceptions mentioned in the very first interviews were gradually combined with the other conceptions shown in table 3. Hedda (11y:3) claims that talking about a hut of leaves (which she mentions in 1997) is not what she was asked about. This shows a growing awareness of focusing on the process of fading leaves rather than just describing concrete experiences. In paper II group tracks of the students’ change of understanding are presented showing the group direction of all students’ pathways up to the age of 13. The group track of the situation with the fading leaves is presented in figure 1. In paper II this group track is illustrated by excerpts from interviews with Nils (page 491).
Break to pieces, rot or trodden on.

→ Add animals eat the leaves and/or they turn into soil.

→ Continue to broaden the idea, focusing on transformation into soil

Figure 1: Showing the group track of the fading leaves

The decrease of descriptive explanations in favour of more science oriented explanations that had been seen in the very first year (paper I, page 94) slowly went on up to the age of 13 as can be imagined from the group track presented above. From the data up to this age it was also seen that a few students in the later interviews seemed to wonder what happens in the animal when the leaf turns into soil or what happens in the rotting or mouldering process (paper II, Nils 13y, page 491; Astrid 13y, page 499).

What happens concerning students’ ideas after this age? Not very much one could say. Hedda (16y) for instance said “Either the worms eat them or they are broken down and then they are turned into soil” (paper III, page 10) More examples are given in paper III (Paul 16y, page 11; Hilda 16y, page 12) and in paper IV (Jenny 16y, page 8). The expressed ideas have not changed much from those expressed from the age of 9 to 11. Most students are happy with the end product soil and even Gunnar (see paper IV, page 6), who has shown to be a very reflective and able student (see paper III, page 19-20), is satisfied with the explanation that fading leaves either in some way break down or are eaten by animals and thereby turn into soil. Also when challenged by the interviewer (paper IV, page 6) he does not seem to even imagine other end products. For more details see paper IV, page 5-10.

The need for further explanations that has been seen up to the age of 13 does not seem to develop as was expected. Most students instead seem satisfied with the leaves turning into soil because of animals eating the leaves or just because of rotting or mouldering. And when asked to elaborate for instance what happens when leaves moulder they usually answer by saying it is almost as rotting or that they do not know. There are a few students who express ideas that seem more focused on the “inside” of the process than
the end product. Jenny (16y) for instance says: “it probably has to do with air and water and the sun and then the photosynthesis which changes everything” (paper IV, page 8). Hedda (14y) expresses the idea that perhaps the leaves can mould into soil inside the worm. She by this statement seems to focus on some kind of process inside the worm. In this situation there is no student in any interview who spontaneously uses the molecule concept when explaining what happens to the leaves.

The words used by the students, and the meanings of the words used, change over time. To begin with the word ‘rot’ often just means changing colour but later could mean the process, or part of the process, that turns leaves into soil (for example look at Nils in paper II, page 491). ‘Break down’ is in the same way changing from just meaning going to pieces to referring to some kind of process. Moulder, decompose and decay are words that are more frequently used in the later interviews. As can be seen from Ruben (16y) in paper IV, page 6 the students often use these words and rot and break down as synonyms.

Most students mention animals (worms, larvae or wood-lice) eating the leaves as one of the causes to fading leaves turning into soil. It is very rare that bacteria or germs are mentioned and there is no increase as the students grow older.

Comparing the ideas expressed by the students and the change of their ideas with the results from earlier research presented on pages 51 to 52, I would say most of the earlier results are confirmed. Helldén’s (1995) result - that the students thought of soil as the end product in decomposition - is confirmed. I can out of this study claim just as Leach et al. (1996) do that a vast majority of the students up to the age of 16 do not see the need to explain where all matter goes in the process. There is also, as in Leach et al., an increase in explanations (including causation) with age. Younger students in the study of Leach et al. tended to suggest just one reason for the decay. This is not obvious in my study. Even in the first interviews the students offered more than one possibility. The possibilities or reasons usually include human activities and/or situations in which the leaves break to pieces. The different results

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25 The word process now used even if the student only focuses the end product.
in the studies could of course be explained by the fact that the students in my study are 6-7 years old in the beginning and in the study of Leach et al. students aged 5-6 are also included.

In the study of Leach et al. (1996) the decaying object is an apple and in my study the decaying objects are leaves (through the whole study), grass, and pegs (from 2001). Bacteria are mentioned occasionally by one or two students in my study and no other microorganisms are mentioned at all. In the study of Leach et al. 10% of the 5-7-year-olds mentioned germs. This is suggested to depend on the students’ familiarity with being told not to eat food dropped on the floor with the reason there could be germs on it. The difference in the findings leads to interesting suggestions. One reason for the difference could be the different objects – in one case it is food and in the other case it is organic material – and we tend to talk about these things in different ways in everyday situations. Another reason could be that we talk about fading material in different ways in Sweden and in the UK. Or it could be a combination of both. In Sweden I would say most people say that food dropped on the floor should not be eaten because it might be dirty (with the underlying meaning, dirt is not good for you, dirt can make you sick). I claim we, in Sweden, do not have a word as ‘germs’ used in everyday speaking that could be characterized as a micro-organism. Therefore in Sweden younger students will probably not mention micro-organisms when talking about the decomposition of apples either. I remember that when I was a child we were told not to walk in dry leaves lying on the ground and especially not kick around with them as this could cause falling ill with polio. This raises the question whether such everyday talk could have been seen in the results from a study performed 50 years ago. The latter investigation is not possible to carry out but an investigation in Sweden with 5 to 9 year-olds about fading apples would be rather easily performed.

As seen above the students in my study have used words as ‘rot’, ‘break down’, and ‘decompose’. This was also seen in the study of Leach et al. (1996) but they stress and I will agree that – also taking the above discussion into consideration – a student’s use of scientific words does not necessarily mean the student has the same understanding of the concept concerned as a scientist has.
Burning

Concerning the students’ ideas about burning it could be concluded that the burning of course is seen by the students but the roles of wax and oxygen are unclear. To many students the wax is not taking part in the burning process but is just heated by the fire and ‘evaporates’ up in the air. Most students are not aware of a chemical reaction taking place, and certainly not a chemical reaction in which oxygen reacts with the wax in such a way that the resulting products are carbon dioxide and water vapour.

Table 4: Student conceptions in explaining the burning candle.

<table>
<thead>
<tr>
<th>Nr</th>
<th>Conception</th>
<th>Citations characteristic of the conception</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A description instead of an explanation is given</td>
<td>− You’ve burnt more on that candle.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>− It has been burning longer …</td>
</tr>
<tr>
<td>2</td>
<td>Wax runs down</td>
<td>− It runs down, and then it gets a bit thicker down here.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>− It melts down and get here. Then you take it away.</td>
</tr>
<tr>
<td>3</td>
<td>Wax melts</td>
<td>− It melts … and it is burned in the end.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>− It melts … and dries up again.</td>
</tr>
<tr>
<td>4</td>
<td>Wax gets out into the air</td>
<td>− … then it becomes smoke and flies away …</td>
</tr>
<tr>
<td></td>
<td></td>
<td>− … it gets up into the air too …</td>
</tr>
<tr>
<td>5</td>
<td>Signs of chemical reaction</td>
<td>− The wick absorbs the wax, then the wax goes up and then it burns …</td>
</tr>
</tbody>
</table>

The students’ conceptions in the situation with the burning candle up to the age of 11 are presented in paper I and illustrated by the same students as in the situation of the fading leaves (page 87-88). The conceptions are presented in table 4.

Also in this situation it is common that students mention more than one conception during an interview. The concrete experiences of having seen candles burn, melt, and run which are mostly de-
scribed in the very first interviews change to explanations including these features but also the idea of wax rising into the air. In paper II group tracks of the students’ change of understanding are presented showing the group direction of all students’ pathways up to the age of 13. The group track of the situation with the burning candles is presented in figure 2 below. This group track is in paper II illustrated by excerpts from Inger (page 493).

Run down and/or melt. → Burn up in the air as smoke or gas. → Transformation supported by a molecule idea and/or by an idea of matter changing from one kind to another.

Figure 2: Showing the group track of the burning candle

In the group track shown above this move for the whole group from descriptions of the concrete experiences to explanations holding the idea of something invisible rising into the air is confirmed. The move from focusing on the visible melting and running candle to focusing on the ‘process’ of ‘missing’ matter is seen in most students up to the age of 13 (examples: Ida paper I page 87; Inger paper II page 493).

What happens concerning students’ explanations in this situation after the age of 13? The above mentioned move goes on and all students in the later interviews focus on explaining the ‘missing’ wax. The missing wax rises up into the air in some way. Students explain this rising with an evaporating idea; that is, melted wax evaporating into the air, (e.g. Inger 11y:1, paper II, page 493). Gunnar at the age of 16 says that the wax disappears up in the air and evaporates. When he is prompted with the molecule concept Gunnar continues: “The wax molecules, they move more and more because of the flame and in the end they are set free (separate) from each other and evaporate”. In this statement Gunnar clearly shows an idea of evaporating wax. He can combine the notion of evaporation with the molecule idea.
There are also students who in the evaporating idea include the idea that some of the wax is water and that this water of course evaporates when heated. Sune presented in paper IV, page 9 is an extreme example of a student holding this idea and confirming it to himself, interview by interview. He expresses clearly the idea that most of the wax or candle is made up of water. Hedda (11y:1) mentions water vapour by saying: “the wax melts like water vapour sort of”. In this statement it is rather clear that Hedda makes an association with water vapour. This does not mean that she really thinks it is water or water vapour. In many students’ responses it is less clear than in Sune’s case, even after follow-up questions, if the students actually mean water or talk about the melted wax as water.

In this situation there are students who use the idea of molecules, able to invisibly rise into the air, in their explanations (e.g. Jenny 16y, paper III, page 11). For more details about this see the section concerning research question 2 and paper III.

Both among the students who use the molecule idea and among those who do not use it there are students who focus a process that changes the wax to something else (e.g. Inger 13y paper II p 493). Hedda (14y) claims that the wax must turn into different things and that the things that build up the wax must turn into gas. A problem for Hedda, which she notices and expresses, is that she does not know what wax consists of. She claims this to be one of the reasons why she does not know what happens in the burning situation. In the later interviews there are also other students who claim that not knowing what substances\(^\text{26}\) wax consists of reduces their ideas about what will become of the wax.

When we analysed the interviews up to the age of 11 we saw that few students gave explanations in which wax had an active role in the fire and it is still like this in the last interview. All students in the last interview know that oxygen is needed for burning to take place and most of them mentioned it in earlier interviews. They either answer they do not know what role oxygen plays or just answer it is needed to keep the fire alive without making connections to the idea of a chemical reaction taking place. It is worth

\(^{26}\) Substance is the word mostly used by the students but as they mean they need to know what the candle or leaf is made off the correct chemical term should be element.
noting that out of the five students who in the last interview could use the molecule model building on the scientific idea of the concept four students used it to explain an evaporation situation but not a burning situation. Hedda is the exception showing an awareness of some kind of chemical reaction as she says that the wax molecule will become elements and/or atoms again.

The findings above confirm many of the findings from earlier studies. The students in this study are early aware of the need for oxygen but the function is still unclear at the age of 16. This is fully in line with the findings from Driver et al. (1985, 1994) and from Watson et al. (1997). In this study it is also obvious that very few students know what wax is, what elements wax is made of, or its chemical formula. This and the very vague idea of the role of oxygen probably make it almost impossible to imagine any important attributes of this special burning process even if a chemical reaction is sensed by the student. This confirms the claim from Johnson (2002) that the burning candle is an especially difficult example of a chemical reaction and also Tsaparlis’ (2001) claim that students will not notice chemical reactions in everyday phenomena because of their difficulties in understanding chemical reactions.

Evaporation and Condensation

Out of the situation of the covered glass of water a conclusion about the students’ ideas about evaporation is that the process of evaporation is well known to the students from the age of about 11 in an everyday meaning – water or water vapour is going out into the air, but even in the last interview it is rare with a more scientifically elaborated explanation. Concerning the students’ ideas about condensation it could be said that the result of the process of condensation is of course observed by all students. The need to explain why the water on the lid is seen again is more frequently expressed as the students grow older. Most students are satisfied with the explanation that the cover stops the water. In the last interview it is only two students who describe condensation as a process in which water vapour is cooled down to liquid. The students’ use of
the word condensation is rare and often mixed up with evaporation.

The students’ conceptions up to the age of 11 are presented in paper I and here below in table 5. The conceptions are illustrated, also in this situation, by Ida, Lars and Jenny in paper I, page 89-92.

Table 5: Student conceptions in explaining the mist on the covered glass of water.

<table>
<thead>
<tr>
<th>Nr</th>
<th>Conception</th>
<th>Citations characteristic of the conception</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>External or anthropomorphic focus</td>
<td>- <em>I think you’ve used some magic.</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- <em>I think it has been sucked up.</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- <em>... it goes up to the cover and sticks to it, because it wants to get out ...</em></td>
</tr>
<tr>
<td>2</td>
<td>Air focus</td>
<td>- <em>... and no air has come in there.</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- <em>... then there is no air, so such molecules can appear.</em></td>
</tr>
<tr>
<td>3</td>
<td>Heat focus</td>
<td>- <em>It will be warm, the water, and then there will be rising mist.</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- <em>... then it will be a bit warm, so there will come some steam.</em></td>
</tr>
<tr>
<td>4</td>
<td>Evaporation focus</td>
<td>- <em>... then the water evaporates, I think.</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- <em>... then the water evaporates and goes out into the air ...</em></td>
</tr>
<tr>
<td>5</td>
<td>Particle focus</td>
<td>- <em>There are tiny water droplets that fly up and stick to the glass.</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- *... water molecules ... they can get up in the air ... stick to the glass ... then there will be some mist ...</td>
</tr>
</tbody>
</table>

In this situation, again, most students expressed more than one conception during one interview. Explanations with external causes are the only ones that are not found more than very early. The group track up to the age of 13 in this situation is presented below in figure 3 and in paper II. This group track is in paper II illustrated by excerpts from Sune (page 495-496).
In the group track shown above there is a move to using evaporation and molecules in the explanations and then elaborating these ideas. What then happens after the age of 13? In this situation the students go on elaborating their ideas of evaporation, some use the molecule concept and some do not. The focus on heat and air is still there in the later interviews but this is intertwined with the students’ ideas about evaporation and/or molecules.

The idea that hot water will rise is expressed by many students already in the first interviews. Inger (7y:1) for instance says: “If the water is warm then the water rises upwards” (see paper IV, page 12). From the age of 10 to 11 the word ‘evaporate’ is used by many students and to most of them this is a process that only takes place if the water is hot. This is in contradiction to the findings by Canpolat (2006). In his study undergraduate students claim that if the water has a high temperature it will just transfer heat to the surrounding but no evaporation will take place.

The closed situation with the covered glass of water is to some students confusing and makes them unsure if one can talk about evaporation (see Inger 16y paper IV, page 14). They have the idea that ‘evaporate’ must result in matter disappearing up in the air. To other students ‘evaporate’ seem to be enough to explain both the evaporation and the condensation.

The students’ focus on air in the earlier interviews has often been connected to the closed situation (e.g. Jenny paper I, page 91; Sune paper II, page 495). But as evaporating to the students means that water or water vapour rise up in the air, air is mentioned also in the later interviews. Many earlier studies (e.g. Driver et al. 1985; Osborne & Cosgrove, 1983; Bar, 1989; Bar & Galili 1994) show that students have difficulties with the difference between water
vapour and air. There have been claims from for instance Andersson (1990) that students think water transforms into air in the evaporating process. Johnson (1998b) claims the interpretation of the students’ use of the word ‘air’ should instead be that they use ‘air’ for any gas. In my study the students talk about water vapour rising up in the air but also expressions as ‘the water becomes air’ are rather frequently used. When especially asking Julia (15y) about this after she has listened to her interview when she was 11 years old and in which she said “vapour rises and then it becomes air” Julia answers:

Well, vapour comes when water boils, water vapour that is.
And that is water molecules and they then mix with the air.
They become part of the air. (Julia, 15y)

Julia’s idea at the age of 11 is not obvious but at least at the age of 15 she does not mean that water becomes air but that the water vapour becomes part of the air as water molecules. This is again an example of the difficulty to interpret what the students exactly mean when they use different words. This difficulty and the risk of wrong interpretations have been reported and discussed by for instance Osborne and Cosgrove (1983), Tytler and Peterson (2004), and Johnson (1998a).

When explaining the situation with the covered glass of water the students use the idea of matter made up of molecules more often than in any of the other situations. More details of how they use the concept have been presented and discussed in the previous chapter and in paper III. The students very often use both evaporation and molecules in the same interview as can be seen from the excerpts from Sune in paper II, page 456. Some students move from using the molecule concept to using ‘evaporate’ when they learn to explain the situation with this word/concept. In paper III Gunnar is seen both being able to talk about the process without and with the help of the molecule concept.

Although the students have shown a greater need to explain why the water is seen again on the lid as they grow older it is only Gunnar (see paper III, page 10) and Hedda that in the last interview express an awareness of the process including a change in tempera-
ture. The rest of the students explain the water on the lid by saying the evaporated water is stuck by the cover and therefore visible again. Some students claim there are many molecules or water droplets and therefore the water is seen again. The word ‘condensation’ has been scarcely used by the students. One example of using it with the correct meaning is Inger in the interview at 15 years of age; see paper IV, page 14. ‘Condensation’ is used by five students in the last interview but then naming the process of evaporation.

I would out of the findings in this study argue that almost all students at the age of 16 and many of them earlier understand the evaporation process in an open system “with both conserving the physical material of the missing water and suggesting a transformation associated with the change of location” (Russell et al., 1989, p. 570). Most of the students say that the water rises up in the air in an imperceptible form as water vapour. This is due to Russell et al. (ibid) the most advanced understanding that could be expected without a molecule concept. On the other hand there are only a few students who explain the condensation with the same accuracy which contradicts the finding from Bar and Travis (1991) that the understanding of evaporation and condensation follow each other.

**Similarities and Differences between the Different Situations**

In this section I will present and sum up some findings with respect to similarities and differences between the different situations. I will start by presenting and commenting on some excerpts from the last interview with Hedda. The reason to do so is to show a possible difference between the situation with the burning candle and the situations with the fading leaves for a student who in my opinion has recognized a chemical reaction taking place in both cases. In the situation with the burning candle Hedda says:

> The wax it turns into gas, all the different substances that the candle is made up from, they turn into gas.

She also expresses a lack of knowledge as she claims she does not know what substances the candle is made of. Hedda also mentions
that oxygen is needed but that she does not know why it is needed. When a little later she is asked especially about the molecule she answers:

I think it splits into different parts. It becomes elements again and yes atoms.

I claim Hedda is aware of a substance, wax, that in the burning process decomposes into its ‘original’ substances. Johnson (2002) has pointed out that the chemical reaction in a burning candle is especially difficult as it involves the gaseous state both in reactants and products, and that it also involves both decomposition and synthesis. The idea of decomposition is recognized by Hedda. She does not know the role of oxygen and she does not express the idea that it is part of the process. Perhaps because of this she does not express the idea of synthesis. On the other hand, when comparing Hedda’s claims in the situation with the fading leaves another suggestion is possible. When talking about the fading leaves Hedda says to begin with:

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

When in this situation asked about the molecule Hedda continues:

It is broken down to atoms and small things and then it can join again and become other substances.

Hedda’s way of using the words substance, element and atom is not fully scientifically correct. In the situation with the fading leaves the idea of decomposition is seen (breaks down to atoms), as in the situation with the burning candle, but the idea of synthesis is also seen (they join again and become new substances). No new substance, such as oxygen in the burning situation, is mentioned but Hedda anyway has the impression new substances could be formed. Why is this then more likely in this situation? The visible end product ‘soil’ perhaps makes it easier to imagine that the process includes creating new substances whereas in the situation with
the burning candle it is easy to imagine that the end products of the decomposition rise directly into the air.

In the situation with the fading leaves the students early come to understand soil as the end product of the process of decomposition. Most students are satisfied with this explanation and very few students seem motivated to by themselves challenge or elaborate this idea.

In the situation of the burning candle all students learn at about the age of 11 that oxygen or air is needed to maintain a burning process but no student can explain why the oxygen or air is needed. In this situation most students are aware of some lack of knowledge and they are not satisfied with their explanations.

With the covered glass of water there are students who are puzzled about how to use the evaporation concept but most students seem satisfied with knowing this is how you can explain the situation.

Out of this we can conclude that most students are satisfied with their explanations in the situation with the leaves and in the water situation. But in the situation with the burning candle they are not satisfied with their explanations.

The students become aware of and explain, in some way, the invisible part of the phenomena in the candle and water situations but not in the situation with the leaves. To the students there is no, or they do not focus on any, invisible part in the situation of the fading leaves.

In all situations there is a change from conceptions more descriptive and more concrete to conceptions more advanced and more reflective of scientifically correct ideas as the students grow older. There is also in all situations new words/concepts that are learnt and which the students elaborate the meaning of through the study.

Tytler (1998) has shown that students only gradually see that a general principle, in his studies air pressure, can explain different phenomena. Most students in my study do not come to apprehend either the relations or the non-relations between the phenomena in the three interview situations. For instance, they do not see that chemical reactions take place in the situations with the burning
Making sense of individual pathways

This section presents the findings to the fourth research question with reflections and discussions. The question is:

- How can we make sense of individual students’ learning pathways?

In paper II this question is addressed with the data collected from when the students were 7 up to when they were 13 years old. Findings stressed in paper II are firstly, the strong personal flavour of the way students develop understandings of the phenomena; secondly, students often have an anchorage idea which they elaborate; thirdly, some students use everyday experiences in productive ways when elaborating their ideas others do not; and fourthly, to some students, there seems to be a growing awareness about not having enough knowledge and a need to understand more deeply what happens in the processes involved.

When the analysis of the individual students’ responses to the interview questions is continued through the last three years the strong personal flavour stressed in paper II is confirmed. In paper IV it is said that there is a group story in the situation of the fading leaves both concerning the kind of experiences expressed and the understanding of the situation in the last interview. This could be seen as a contradiction to the above statement but it is not. In paper IV a group story is found in the situation with the fading leaves when compared with results from the other two situations. Within the group story there are still individual differences. The unique individual changes in understanding are still seen. These changes are dependent on what the student focuses and on the student’s personal experiences, language resources and ability to reason.

I will now remind of the four categories formed from analysing how the students used the molecule concept in the last interview as
these categories will be the point of departure in the following part of this chapter.

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 (for more information see paper III, page 12)

By following some students backwards, whose responses in two or three situations fall into the same category, personal and/or ‘small group’ features will be highlighted and discussed.

**Category A students**

Hilda’s response illustrates, in the situation of the fading leaves, category A (paper III, page 12). She is a so called A student which means her answers from the three different situations all fall into category A. Hilda is not very expressive in any of the interviews but in the later interviews she is more focused on the processes in the situations than in the earlier interviews. But she is not interested or able to explain the processes. To her they just happen. She seems to be satisfied knowing they take place and she is not much interested in or curious about finding out more details. Nancy who in paper II (page 498) exemplifies a student who is not capable of using her experiences in productive ways is found to be an A student. In the last interview Nancy focuses on the concrete situation and begins answering out of that. In the situation of the fading leaves she, as one of very few students, suggests that someone could have been taken away the leaves. The A students and those students who have two answers falling into category A are often, still in the later interviews, focusing on the concrete situations and describing those. They often show low ability to use their experiences in productive ways during the first years of the study when
this is rather common to many of the other students. Even if they focus on the process this does not seem to challenge them to ask questions and answer these using their own experiences and/or new knowledge. This pattern seems to remain through the study. These students do not usually comment on their learning or school results, but Nancy, who does, obviously sees herself as an underachiever.

Category B students

Paul (paper III, page 11 & 16-17) and Nils (paper II, page 491) have answers that fall into category B in all situations in the last interview, meaning they are so called B students. As commented on in paper III the B students and many of the students whose answers fall into the category B often are capable of learning facts from school and elsewhere but rarely capable of connecting these facts with what they already know. In paper IV there is also seen a trend that these students do not, as much as some of the others, express ideas about their learning showing own reflections but showing up an interest in new words (Paul, paper III, page 17) and/or an expectation that things should be learnt in school (Nils, paper IV, page 16).

Sune’s (paper II, page 495-496, paper III, page 20, & paper IV, pages 9-10 ) answers in two of the situations fall into category B. Sune and Nils are examples of students following the group tracks presented in paper II. During the first years of the study, Sune, Nils and Paul elaborate their ideas, they learn new words and they seem rather keen to use these in explaining the situations. When doing so they do not always show an understanding of the meaning of the words. This is seen in all students and did not stick out as unusual. When looking at all data and comparing these students’ answers with C and D students’ answers there is a slight but noticeable difference that I will come back to when presenting features of these students.

In the water situation Sune’s answer falls in category D and he is an early user of the molecule concept in this situation. Sune, in paper IV, page 9, illustrates a student building his ideas on an early
experience but where the experience is not helping him to actually understand the situation. Sune seems keeping almost rigidly to his first idea and even if he is reflecting and logically builds on this first idea he does not seem to question it. Paul is using his knowledge in a parallel way in his explanations at 16 years of age shown in paper III (page 11, 16-17).

These three students learn a lot from school but are not usually in the later years capable of using their new knowledge in productive ways to explain the phenomena in the three situations used in the interviews. They though seem to have learnt to use this knowledge in school situations in ways that perhaps cheat both themselves and their teachers. Paul is an expert in talking and using scientific words as seen in paper III. He makes a confident impression when talking and there is a risk teachers assume he knows and understand more than he really does. Even if the other two are not as ‘good’ as Paul they too talk very confidently and use scientific words that they probably do not understand. All three give the impression they think of themselves as overachievers.

**Category C students**

Inger (paper II, page 493, 497; paper III, page 21; paper IV, pages 12-14, 15, & 16), Jenny (paper I, page 85-86, 88, 91; paper II, page 499; paper III, page 11, 18, 21; paper IV, page 8), and Ruben (paper II, page 497, paper IV, page 15) are C students. These students express, quite early, ideas and knowledge that help them understand and explain the situations. They make associations and bring in experiences both from everyday life and school when describing and explaining the situations. All three also have a rather broad vocabulary already in the first interviews. Inger and Jenny have shown awareness of not knowing and therefore not being able to explain more. Jenny and Ruben early and rather frequently have used a simple molecule concept in the situations with the burning candle and the covered glass of water. Inger has only scarcely used the molecule concept and then in the water situation. Inger though is the expert of bringing in adequate experiences and associations in her explanations. To begin with this ability seems to
help her elaborate and change her ideas but in later years (as seen in paper IV, page 12-14) she is not capable of connecting the science taught in school with her everyday experiences. These students elaborate their ideas very successfully up to about the age of 13 but as said the science taught in the last years does not seem to have much impact on their ideas.

In contrast to Sune, Nils and Paul especially Inger has shown a struggle with the meaning of certain words. In the first interview when she is 11 years old she says when talking about the burning candle: “I do not really know what it is called because evaporate that is water, is it not” (paper II, page 493). Even in the last interview she is not sure about the meaning of evaporate and she says about the water situation: “it evaporates but I do not really know because if it evaporates I think it should go away completely” (paper IV, page 14).

These students although reflective and aware of lack of knowledge do not seem capable of using the more abstract science taught in the later school years in order to deepen their understanding of the processes taking place in the interview situations. When commenting their learning they usually refer to family situations and as is seen in paper IV Inger even stresses that they have not talked about “these things in school” and she also says she does not know much about molecules and she has not quite cared about them. The school science does not seem to have influenced or motivated these students to take the content into reflective consideration. I have the impression they think of themselves as average students in science but also in most other subjects.

Category D students

There is only one D student, Gunnar, and he is presented in the water situation in paper III, page 19-20. There are short interview excerpts from Gunnar in paper II, page 497 and 498, and also in paper IV, page 6. Hedda (paper II, page 497; paper III, page 10 & 21; paper IV, page 8) and Simon (paper IV, page 8 & 15) are students who have answers that in two situations fall into category D. Hedda was also mentioned in the previous sections now and then.
She is presented in the beginning of this chapter as a talkative girl whose ideas did not stick out from the others to begin with. In the later interviews her confidence rose and she showed an ability to talk about her own learning. Hedda, when she is not sure of the meaning of words expresses this just like Inger does. Hedda too has had problems with ‘evaporate’ but is, contrary to Inger, using it correctly and with confidence in the last interview.

Gunnar seems to be the perfect student; always interested and both willing and able to learn more and to express his ideas. He now and then makes a precocious impression. In the last interview Gunnar’s answers fall into category D but in the situation with the burning candle this is out of an idea of evaporation. Simon already from the beginning expressed ideas about the different situations and elaborated his ideas during the first years. When I in one of the later interviews said that I had the impression he was good in science he looked very puzzled and then said no he was not. Simon is one of few students who have mentioned energy now and then in the different interviews. In the last interview he talks about energy taken up by the worms (paper IV, page 8) and wax turning into heat. By this I want to make clear that even if these students can use the molecule concept, out of their understanding of the situation, in acceptable ways their understanding of the processes taking place is scattered. This agrees with the findings of BouJaoude (1991).

Gunnar, Hedda and Simon now and then made associations to everyday experiences, which seem to help them elaborate their ideas. They have also remembered learning situations from school and have been able to talk about their learning.

Of the three, Hedda is the one who has developed her ideas most. In the last interview she is one of few students who recognizes and explains processes with signs of chemical reactions in both the situation with the fading leaves and the situation of the burning candle. She is also the student who has most clearly and often commented on her own learning. Already when 8 years old, after having listened to the last interview from the year before, Hedda says: “now I know because then I was in grade ‘zero’ and then I did not know that the worms eat (the leaves)”. In the third interview when Hedda is 11 years old and has listened to the same
interview as above from the very first year her first comment is: “I do not think I really knew what we were talking about there”. In 1997 she had talked about a hut of leaves and now, at the age of 11, she expresses awareness that this is not exactly what I asked about or were interested in.

In paper IV, page 16 Hedda claims: “one has learnt more because one is older, one understands more and one can exclude more”. I would argue this is an advanced way of talking about one’s own learning at the age of 12. In the interview at the age of 15, Hedda says she thinks she has learnt about these things in school and stresses that one learns in school. Then she makes a reflection saying: “One probably knows about it when one is ten years old but now one can better explain and understand about things”.

Hedda’s comments in the above presentation indicate that she is aware of when she has new ideas and that she can compare and comment both on those and on her old ideas. From her comments above it is also evident that she is able to pronounce some ideas about what learning is all about. She mentions learning with the meaning of knowing more. Hedda seems to involve a process of the knowledge to gain understanding. She also mentions that to exclude ideas is part of learning. Another claim from her is that one learns in school. It seems that at least in the case of Hedda there is a connection between her view on learning, her ability to reflect on her own learning and her progress in science. Gunnar and Simon have not expressively talked about their learning but they have now and then in their comments shown they take an active part in their own learning (e.g. Gunnar, paper II, page 498).

When reflecting on the impression these students make concerning their own view of their school achievements, the picture is scattered. Gunnar seems satisfied and confident. He probably looks at himself as an overachiever. I have the impression that neither Hedda nor Simon think of themselves as overachievers. Hedda seems confident but not quite aware of how ‘good’ she is. Simon probably thinks of himself as a rather ordinary student, neither better nor worse than the average.
Summary

The strong personal flavour of the way students develop understandings of the phenomena is seen through the whole study. If and how a student changes her or his ideas are dependent on what the student focuses on and on the student’s personal experiences, language resources and ability to reason. What the student focuses on is often the anchorage idea mentioned at an early age and this idea is elaborated more or less successfully.

There are students\(^{27}\), and this is of course expected when following an ordinary group of students, who do not develop their ideas about the processes involved in the interview situations. These students are not able to use their everyday experiences in productive ways to elaborate their ideas. They do not seem to learn much of the science taught in school neither in the first years nor in the later years. They seem to look upon themselves as underachievers.

There are students\(^{28}\) who learn a lot of scientific words but it is uncertain whether they understand the meaning of the word. As the science material in the later years is full of new ‘words’ this ability then becomes observable. These students have not used everyday experiences much in earlier years and they have not shown an awareness of lacking knowledge. When they talk about learning they seem to think it takes place in school but also that, an important feature in learning is to know new words. They seem to look upon themselves as overachievers.

There are students\(^{29}\) who use everyday experiences in productive ways when elaborating their ideas. These students also during the first years seem to show a growing awareness about not having enough knowledge to understand the processes involved in the three interview situations. These students’ development of understanding and describing the processes follow more or less the same pattern up to the age of 13 but then they seem to fall into two groups.

The first group consists of students\(^{30}\) who continue referring to their own experiences and reflecting on their own lack of knowl-

\(^{27}\) A students are typical such students.
\(^{28}\) B students are typical such students.
\(^{29}\) Both C and D students are typical to this group to begin with.
\(^{30}\) C students are typical such students.
edge but they do not seem to be helped by the science taught in school to further elaborate their ideas about the situations. These students are not by themselves capable of combining their ideas formed at the age of 13 about the processes involved in the situations with the science taught in the last years of the compulsory school. When these students talk about learning it is the early school experiences but mostly family experiences that are mentioned. They seem to look at themselves as average students.

The second group consists of students 31, but they are few, who show capability to use the science taught in later years of school in productive ways to further elaborate their ideas into holding sound scientific explanations. When talking about their learning these students are reflective and they show signs of taking an active role in their own learning processes. The picture of how they look upon themselves as students is scattered.

31 The D student is a typical such student.
DISCUSSION

The theoretical framework of this thesis is based on Human Constructivism (Novak, 1993) and the assimilation theory of meaningful learning (Ausubel et al., 1978). Within this framework I will discuss some perspectives of students’ ideas and learning that, through the findings, have been shown especially interesting. Some of these findings confirm and some contradict earlier findings. Some of the findings shed new light on our ideas about students’ science learning. The first part of this chapter contains a discussion about the methodology of the study. The next section deals with questions concerning meaningful learning. In a following section special attention is paid to the insights from the longitudinal study. The discussion ends with suggestions for further research and implications for practice.

Discussing the study

The study of this thesis has lasted for ten years and I have followed students all the way from 7 up to 16 years of age. There is a lot of data gathered and analysed. It is possible, and so has been done, to analyse and present results before the study is finished but the whole pattern is not revealed until all data are gathered and analysed. Is it then worth it? What strengths and weaknesses have been seen? What about the trustworthiness of the study?
Attrition

One problem in all studies is attrition, but it could of course give special problems to a longitudinal study. In this study I started with a group of 27 students, a few students left during the first years because of moving to other schools and some new students started in the classes and were invited to join the research project and did so. There are 20 students who have participated in all interviews. Even the data from those students who have not participated in every interview have been taken into consideration in some of the analyses. All attrition has been due to moving. In my opinion these changes in the group interviewed did not affect the insights.

The three situations

The three situations chosen in the interviews need some commenting and reflection now when the study is completed. The situations involve phenomena that have challenged scientists over the past 200 years. This challenge has made scientists form ideas involving abstract concepts and models.

In the three situations different transformations of matter occur. In the situation with the covered glass of water evaporation and condensation take place. The small closed system was chosen in order to make the condensation observable and thereby challenging the students’ ideas, but now and then the closed situation has confused more than challenged. We could of course have chosen another burning situation than the burning candle which in many studies (e.g. BouJaoude, 1991; Johnson, 2000; Rahayu & Tytler, 1999) has been described as especially difficult. An advantage of using a burning candle is that it is familiar to young students and it is easy to present in an interview situation. The interviewer or interviewee can easily light the candle and blow it out during the interview. Any biological phenomena would be complicated and again young students’ familiarity with the fading leaves was in favour of that choice.

The three phenomena vary in the gap between the way we usually talk about them and the scientific explanation. In the situation
of the covered glass of water the gap is narrower than in the other situations. The ease of applying the notion of molecules in the explanations also varies between the situations and is also seen in the results.

As the interest was in finding out how students developed their ideas about transformations of matter in everyday situations and how they were able to use scientific ideas presented in school science when developing their ideas, we found it logical to use what could be defined as everyday situations. All such situations are complicated and the scientific ideas explaining them are more or less “hidden”.

The interview context

Interviews are social situations where the nature of the situation affects the responses. This study builds on data from interviews in which spoken language is essential. The interviewer and the student must place the same meaning on words or have to communicate until a shared understanding of a word is fulfilled. If I were to carry through a study like this again I would not just use spoken words, but pictures, drawings, and diagrams in checking the meanings of critical words.

These interviews were conducted during school time and even if I tried to assure the students that I was not looking for the correct answer but for their ideas about the phenomena involved in the situations the students probably liked to satisfy me by answering in a way expected in such a context. The students might in another context, for instance if the interview about the fading leaves had taken place outside in the woods, have answered differently. I could of course have tried these kinds of changes in some of the interviews, but the risk of changing too much is that the often subtle changes due to new learning could be even harder to trace. These aspects need further thought and I will come back to this when suggesting further research.
The longitudinal design

As mentioned earlier when presenting the study there have been comments about the effect of asking the same questions on later responses. The interview will of course have some effect on the interviewee and this would be the case also with just one interview. The responses made during an interview are co-constructed and dependent on the line of questioning. If the aim is to collect data at different occasions without at all influencing the interviewee the whole idea of longitudinal studies is impossible. Earlier measurements must affect later ones, by making students focus on aspects they might not otherwise have noticed, by initiating new thoughts, and by making later responses consistent with earlier ones. In this study where the students almost every second year listened to an earlier interview this last effect is increased.

When the students in the last interview 2006 answered almost the same as in 2003 and onwards I seriously began to fear that this effect was the only explanation for the students’ responses. As earlier told I decided to interview three students who had not been involved in the project. These students answered with the same kind of variation as the ones who had attended the whole project both in respect of the first part of the interview and in respect of the part about molecules. I dare to conclude that the design of the study has not affected or harmed the result that most students will not use the science taught in later school years when explaining the phenomena involved in the interview situations.

An ethical issue that has occurred to me when analysing the whole material is the fact that I have met the students many times and asked about the same situations. The students have responded and have mostly with enthusiasm informed me about their ideas but I have not helped them in elaborating their ideas more than by asking questions. I have not in the interviews corrected mistakes or presented them with new facts or knowledge. If I had done so the study of course had not been the same and I had been very far from the objective researcher sometimes asked for in order to conduct research of high quality. On the other hand I feel a bit guilty not having helped the students more in their abilities to scientifically explain the involved phenomena.
When analysing the data from a ten year study such as this there are great advantages but also great risks. By following the same students over a long period of time it is possible to become aware of the individual students’ meaning of different words and concepts. This gained knowledge increases the possibility of understanding the students’ explanations and of avoiding, to a large extent, interpreting wrong meanings into a student’s single word or expression but I am also aware of the risk that this knowledge could lead me to wrong conclusions. In this study my interpretations and findings have been continuously discussed with other researchers.

**Meaningful learning**

If meaningful learning, as the term is used in this thesis, has taken place students will, as a result of the learning, hold new or elaborated ideas. In relation to the interview responses meaningful learning can be traced if the students’ explanations change between interviews showing new or more elaborated ideas. If the science taught in school is seen productively used in the explanations I have, in the coming discussion, assumed that the science taught has been meaningfully learnt.

Ausubel et al. (1978) argue that the following three conditions are needed for meaningful learning to take place:

- The subject matter to be learnt must be potentially meaningful to the learner.
- The learner must know the meaning of concepts that relate to the new information to be learnt.
- The learner must choose to learn meaningfully.

If meaningful learning is traced in the interview responses all three conditions must have been fulfilled. If meaningful learning is not traced there is no possibility to know if none, one, or two of the three prerequisites are fulfilled. It is neither possible to know which of the conditions are fulfilled and which are not. In the following I will anyway consider the three prerequisites one by one and discuss
them in relation to the meaningful learning that has been seen in the students’ explanations of the three interview situations.

Before directly discussing the conditions I will go back to the science syllabi and the knowledge relevant to the phenomena involved in the three interview situations. I will here shortly summarize from what is said in the “Background”.

In the end of the fifth school-year the students should be familiar with the fate of fading leaves and the processes of evaporation and condensation. The level of explanation asked for is not clear.

In the end of the ninth school-year the students should have an insight in how matter can be studied in different levels of organisation. They should also be able to use the idea of the particulate nature of matter when explaining chemical reactions as respiration and combustion. They should probably recognize such processes in everyday situations as the use of knowledge is stressed in the syllabi. They should have deepened their understanding of the processes evaporation and condensation and should be able to use the particle idea when explaining situations holding these processes.

The knowledge needed to explain the three interview situations is presented in the summary on page 32. After having presented the teaching material it is concluded that the knowledge needed to explain the situations on a scientific level comparable with the goals in the syllabi is in the books.

With this as the point of departure I will continue by discussing the three conditions in relation to the findings of this study.

**Potentially meaningful subject matter**

The first condition formulated is: “The subject matter to be learnt must be potentially meaningful to the learner”. From my experience and from what I came to know from the students’ interview responses most of the science taught before school-year seven is in biology. Some experiments with for instance water in different phases, floating and sinking, electric circuits, and magnetism have been carried out. The explanations have probably been mostly descriptive and building on concrete observations.
In comparison with the goals to be attained at the end of the fifth school-year and the students’ changes in responses up to this age I would say most students have learnt meaningfully. By the end of the fifth school-year the students are 12 years old. There are many examples in both paper I (students up to 11 years old) and paper II (students up to 13 years old) of meaningful learning.

The students have attended different classes during the study and the teaching of course has differed. The subject matter needed to explain the interview situations in relation to the science syllabi seems to have been taught. This taught subject matter seems to be potentially meaningful to the students. The science taught is concrete and close to the way we talk about the phenomena in everyday language.

In the study a simple molecule concept was introduced in order to examine if the students would use this intellectual tool. What can be said about this subject matter? Has it been shown to be potentially meaningful to the students up to the age of 12? In the situations with the covered glass of water and the burning candle the molecule model seems to be a productive tool for dealing with the gaseous state to some of the students. The introduction and the time laid on using the model in different kinds of situations where transformations occur have been short. The total amount of time varies between 3 up to 5 hours up to the age of 12. Out of this I claim that the simple molecule model seems to be subject matter that could be potentially meaningful to many students aged 7 to 12.

In the syllabi there are also goals to be attained by the end of the ninth school-year. Comparing these goals with the interview responses from age 13 up to 16 few students in my study learnt meaningfully. The subject matter needed to elaborate the explanations of the three interview situations does not seem to have been potentially meaningful to the students and/or one or both of the other conditions have not been there. I will deal with the other two conditions later. Now I will look into the subject matter as it is shown through the teaching material.

The books presented earlier are from school-year seven to nine. This is when theories and models are introduced, especially in chemistry and physics. Now the science becomes more abstract. In
the books these theories and models are presented as ‘facts’; this is how it is. I have no reason to think that the teachers have presented the material differently. Important and fundamental concepts, such as substance, air, chemical reaction, the water molecule, and that organisms breathe and an explanation of this process, are presented on top of each other in the interval of about half a year.

Taking into consideration the amount of subject matter presented the last three years of the compulsory school and how the students in this study have slowly elaborated their ideas about the phenomena involved in the situations and how they have struggled with the meanings of different concepts, I suggest that for many students much of the subject matter has not become potentially meaningful.

Could more of the goals to be attained in the ninth school-year and more of the taught science become potentially meaningful to more students? Johnson (1998c) argues for the need of a particle model in order to understand water in the air and to understand evaporation below boiling point. Papageorgiou and Johnson (2005) show that a simple model, in line with the one introduced in this study, is helpful for students’ understanding of, for instance evaporation. Tytler et al. (2007) emphasise the importance of letting students use many different representations when trying to understand the world around them.

All these findings are in agreement with my suggestion that a simple molecule concept is potentially meaningful to young students. If this concept is used in school teaching, young students could probably understand and explain evaporation and condensation on a more scientific level than today. The students would probably also be better prepared for dealing with a more elaborated particle model and other abstract models introduced in science teaching later in the compulsory school.

**Meaning of concepts**

The second condition is formulated in the following way: “The learner must know the meaning of concepts that relate to the new information to be learnt”. The students show in the earlier inter-
views that they can use words and expressions like rot, turn into soil, burn, melt, mist, dew and air with meanings acceptable for continuing to broaden the ideas of these concepts and to connect them to new knowledge to be learnt.

The change of used words shows that the students learn to name some of the processes involved in the situations, for instance evaporation and decompose or moulder. The students also learn to differentiate between the meaning of words that in the beginning meant almost the same to them, for instance mist, dew, and damp. I will go on with this discussion using ‘evaporation’ as an example. Most of the students begin to use this word to explain what happens in the covered glass of water from about the age of 11. It is obvious from associations they make that this is an example of representational learning (Ausubel, 2000). The students name a process with the correct concept name and they seem aware of what the word represents. It is less clear if concept learning has taken place as that involves knowing what critical attributes the concept holds. Hedda and Inger have been struggling with the critical attributes of the concept evaporation. Ausubel et al. (1978) make, in my opinion, an important statement when saying:

Concept names do not necessarily possess the same meanings for individuals of different degrees of maturity. This is the case because young children have no other choice but to use precise, culturally standardized concept names for concepts whose meanings, for the child, are still vague, overinclusive, or underinclusive (Ausubel et al., 1978, p 88)

From my experience as a teacher the learning of new concepts takes time, especially if there are many concepts related to one another. This means that the understanding of the critical attributes to one concept is related to understanding critical attributes also to the related concepts. The subject matter presented to the students from the seventh to the ninth school-year includes many concepts related to one another.

The difficulty interpreting students’ understanding because of the vagueness in how they use words and in the meaning they have of them has been expressed by for instance Osborne and Cosgrove
(1983), Leach et al. (1996), Johnson (1998a) and Tytler and Peterson (2004). From following Hedda and Inger it could be concluded that Hedda at the end of the study has an understanding of the concept of evaporation. She seems to know the critical attributes of evaporation while Inger (paper IV) is still in the last interview struggling with these critical attributes.

The word ‘condensation’ is in a way an opposite example. This word is rarely used and it seems much more to be a word learnt without knowing what it represents. Most of the students who use it in the last interview use it wrongly. The correct word should have been ‘evaporation’. This might be an example of how new learning can mix things up. Canpolat’s (2006) finding of undergraduate students claiming that hot water would not evaporate but only transfer heat to the surroundings seems to be another example of the same thing. The students in Canpolat’s study attended a course in Heat and Matter where new subject matter about for instance temperature gradient was presented. This new knowledge seems to have confused the students’ ideas about evaporation as most other studies show that students think water left in an open container evaporates (e.g. Johnson 1998c).

That students choose to use the word ‘condensation’ might also pinpoint an expectation from the students that words that are used more frequently in daily life (evaporate) are not scientifically acceptable and/or correct. They seek for another word that sounds more scientific and choose condensation instead of evaporation as they remember having used both words in what they now remember as the same situation. The critical attributes for condensation are not recognized and perhaps the critical attributes for evaporation are vague. If this is the case, the confusion is understandable.

There is another concept ‘conservation of matter’ which I shall comment upon in relation to the second condition for meaningful learning. Paper I stresses the difficulties, seen in history within scientists and in studies of students’ ideas, of understanding transformations of matter. This has been seen especially concerning transformations in which some matter seems to disappear. One reason for these difficulties is assumed to be difficulty to understand the concept ‘conservation of matter’. In paper II, out of the students’ responses, I claim that few students in this study even at the age of
think that matter in these situations disappears. The students often in the situation with the burning candle firmly claim that nothing disappears even if they do not further elaborate this statement. Students’ lack of focusing on missing matter and the risk of wrongly interpreting this as not understanding the idea of conservation of matter is observed and commented on by both Bou-Jaoude (1991) and Tytler (2000). As the students seem to have the idea ‘nothing disappears’ I suggest this idea could be used as an anchorage idea in order to continuously elaborate the concept ‘conservation of matter’ until all its critical attributes make sense.

The amount of new concepts that are presented during the later years in school might be one of the reasons why many students’ meanings of concepts are vague as shown in many papers referred to in the literature review. When a new concept is introduced and supposed to be learnt the critical attributes of related concepts are missing and thereby one of the prerequisites for meaningful learning.

Choosing meaningful learning

The third condition is “The learner must choose to learn meaningfully”. What has been seen in relation to this from the findings presented? From one point of view this question is not possible to even discuss out of this study as this has not been directly examined. On the other hand if meaningful learning could be detected by examining if students have developed their ideas into more scientifically sound ones, something could be said in relation to the question. Before doing so I would just like to comment on the word ‘choose’. The word indicates a conscious choice but I am not sure that the students who show signs of meaningful learning have made such active choices. I will come back to this issue.

I have presented findings, from the interviews at the age of 16 years, showing signs of meaningful learning in the students whose answers fall into category D. These students have in the way they talk about their learning shown signs of being active learners. It
seems possible to conclude these students have, in some way, chosen to learn meaningfully.

In relation to the content presented in the teaching material and out of the goals in the science syllabi the other students do not show signs of meaningful learning that influence the interview responses during the later years in school. But what could be said about the choice they have made? The students, whose answers fall into category C, out of the last interview, seem to have chosen to learn meaningfully. The reason for not learning meaningfully should probably be related to the subject matter not being potentially meaningful to them. I have argued that too many new concepts are presented during the last years in compulsory school. This means neither the first nor the second condition is fulfilled to make meaningful learning possible for these students, with the result that choosing to learn meaningfully is useless.

The students whose answers fall into category B seem to have chosen to learn facts rather unreflectively and they could be seen more as rote learners than as meaningful learners. On the other hand this might just show that the other two conditions are not fulfilled. As these students seem confident in science when explaining the situations I draw the conclusion that the students by rote learning manage to deal with the subject matter in acceptable ways in relation to what is expected by the teachers.

The students whose answers fall into category A are the students who have shown least signs of meaningful learning throughout the study. They do not talk about their learning. This makes it difficult to know anything about their choices. The subject matter to be learnt might in the beginning have been potentially meaningful. One problem could be that their meaning of concepts related to the new information already early is vague or not there. This is said knowing that many of these students to begin with showed lower vocabulary skills than most of the other students in this study.

From having followed these individual students for ten years I want to emphasize that all the students to begin with showed signs of meaningful learning. They also gave impressions of being active and reflective when describing and explaining the situations during the very first years. Out of this one could say that all the students at the age of 7 had chosen to learn meaningfully.
The claims and suggestions made are due to the impressions I have received from having listened to the students over this length of time. These impressions can unfortunately not be confirmed by interview excerpts as these kinds of impressions are gained as results of the interviews as personal meetings in which more is said than is verbally expressed. One problem seems to be that a lot of the students as they grow older seem to lose confidence in their ability to be meaningful learners. When this happens, and within which areas, varies from individual to individual. In the way that the science subject matter is presented the last years in the compulsory school we probably lose more meaningful learners than necessary.

I will now come back to the word ‘choose’. I would start by saying that I do not have the impression that any student chooses not to learn meaningfully. Nor do Ausubel et al. (1978) claim this. In my opinion older students and adults can probably in certain situations actively choose between meaningful learning and rote learning. Students within the ages I have examined seem less inclined to make such active choices.

To end this part about meaningful learning I will connect to some studies that in different ways confirm or discuss some of the above issues. In longitudinal studies about students’ attitudes to science Lindahl (2003) and Reiss (2004) found evidence of a decrease in students’ interest in science from school-year five to nine. Out of how most students in my study decrease in their ability to further elaborate their ideas about the interview situations and out of the few signs of meaningful learning seen in the last interview it is likely to assume that these students’ interest in science also has declined.

When Reiss (2004) interviewed the students in his study a year later and asked them about what school science should consist of, they wanted the science in compulsory school to be useful in everyday life. It is interesting to notice this is said even by students who plan for further education where direct use of science is made. Driver et al. (1985) claim that the issue to be considered is not whether the students understand the theories and models presented but “whether they can use them or see them as useful and appropriate in interpreting actual events” (p. 168). There seems to be a
great challenge in changing the science taught in the compulsory school in the direction that students find it useful and worth learning meaningfully.

Novak (2005) claims that by underestimating the learning capability of young students and therefore not introducing for instance particle ideas, already in the early school-years science in the first years is restricted to descriptive studies of biological and physical phenomena. It is possible to change the science taught in school if taking into consideration the students’ potential in earlier years shown in the findings of both this study and others (e.g. Novak & Musonda, 1991; Papageorgiou & Johnson, 2005; Tytler, 2000; Tytler & Peterson, 2007). Introducing fundamental concepts earlier, giving them time to be meaningfully learnt, might increase both understanding of and interest in science.

**Insights from the longitudinal study**

What has been learnt about learning and teaching about these phenomena as a result of the longitudinal design? The longitudinal design makes it possible to see three trends in types of explanations: trends common to the group as a whole over time, trends common to sub-groups over time, and trends in the emergence and persistence of the individual student’s coherent pathway through the years.

The findings of trends common to the group as a whole over time would probably be the most easy to receive also from a cross-sectional study. The sub-groups (e.g. A, B, C, and D students) found in this study could of course, as such, have been detected in a study of 16 year olds but the possibility to connect these findings with common features of the students in the sub-groups or of features of individual students is only possible with the longitudinal design. Findings such as the change, persistence, and development of individual students’ learning pathways over the years are of course only possible to gain through the longitudinal design. To improve teaching taking advantage of these insights classroom research is needed.
The individual students’ struggle with their own understanding, which has been seen in for instance the cases of Hedda and Inger, is possible to detect and follow as well as the different outcomes of this struggle. Out of such findings it has been possible to detect patterns between on one hand the student’s capability of using facts and models taught in school and combining those with more concrete experiences from school and everyday situations, and on the other hand the student’s own feeling of learning and/or the student’s comprehension what learning is all about. The finding of these detected patterns is a result of the longitudinal design. The possibility to discuss these patterns is again due to the design of following individual students over a long period and thereby getting to know their specific features.

As the years pass, the students become more capable of using domain-specific knowledge and to combine more elements and ideas than in earlier interviews. This is a finding seen up to the age of 13. This capability naturally further develops also after this age. This is in a way a trivial finding. On a group level this is expected. But when following this on the individual level two interesting findings are made.

Firstly, with very few exceptions, all students to begin with gain and use more domain-specific knowledge and are capable of combining this new knowledge with other experiences both from school and out of school. Thereby their descriptions and explanations of the phenomena in the three interview situations become elaborated and more science oriented. These elaborated descriptions and explanations seem due to students’ meaningful learning.

Secondly, many of the students who seem both interested and able to elaborate their ideas into more science oriented explanations up to the age of about thirteen seem less able and/or interested to continue this progress. The science taught in school-year 7 to 9 seems, to most students, difficult to learn if meaningful learning is the aim. There could be many reasons for this change and out of this study it is only possible to speculate about the causes and to ask for more research.

In this study, the students for the first six years attended three different classes. The students’ responses through the years have been possible to analyse with this in mind. The differences in the
students’ responses in the last interview in the situation with the fading leaves could be detected and explained by different teaching experiences. Because of the longitudinal design the great impact of these early teaching experiences was seen (for more details, see page 93). Without the longitudinal design this finding could never have been made.

After having followed these individual students’ struggles in making meaning of words and concepts presented or just mentioned in everyday life or in teaching situations in school, an important conclusion is: meaningful learning takes time. Again it is a finding or conclusion that is possible to make thanks to the longitudinal design. It is obvious when following individual students’ serious attempts to understand the meaning of concepts and their critical attributes that school teaching too often does not take the time needed for meaningful learning.

Contributions to research

As a conclusion of the above discussion I claim that the results and insights of this thesis add new knowledge to the field of science education research especially because of the following four contributions.

Firstly, many studies have been conducted concerning students’ concept understanding and some are presented in the literature review. This study contributes by showing how individual students develop their ability to explain the processes decomposition, burning, evaporation, and condensation in three specific everyday situations. When following the students’ explanations over the 10 year period it is possible to detect what kind of experiences, both from school and out of school, influenced their explanations. Because of the early introduction of a simple particle concept it has been possible to follow how the students use a particle concept before, during, and after the more formal introduction is made.

Secondly, by letting students listen to earlier interviews and comment on them it has been possible to find out what the students themselves believe has influenced their learning. This knowledge combined with the knowledge gained from the students’ ex-
planations has highlighted both the young students’ competence to use experiences from school and everyday life and the older students’ difficulties in using the science taught in later school-years in productive ways in their explanations of the situations. But overall it emphasizes that meaningful learning takes time.

Thirdly, one conclusion of this study is that the repeated interviews do not affect later interview statements in a way that influences the results and insights. It seems repeated interviews influence later statements much less than has been expected, suggested, and/or feared for. This shows that we do not know enough about the strengths and weaknesses of different kinds of interviews even if the method of using interviews has been the object of many animated discussions.

Fourthly, as has been argued in the discussion many of the insights are due to the longitudinal design and would have been impossible to gain with any other design. If these insights are thought of as important, as I claim they are, the conclusion is that more longitudinal studies are needed and worthwhile although the risks, costs, and efforts needed to undertake them.

**Future research**

When here making suggestions for future research I will start with precise ones leading directly from this study and pass over to more general issues that have come up in discussions concerning this thesis.

I would like to follow up all or some of the students attending this study. If this is done in the end of spring 2009 it coincides with most of the students’ last semester in upper secondary school. The aim would not be to ask again about the situations but to receive more insights about the students’ different ways of handling learning situations and their own opinions about themselves as learners. It would also be interesting to know how they look upon their participation in my study. Has it in any way influenced them as learners or their interest in science or in any other way? The students will be 19 years of age and even more capable of reflecting and discussing their experiences than earlier.
Different kinds of classroom research are in my opinion needed in order to inform us further about students’ meaningful learning in relation to science curricula. Studies designed and conducted in cooperation with regular teachers and in which different fundamental concepts are introduced early would be valuable. These studies should preferably take metacognitive issues into consideration and have longitudinal designs. Hopefully this thesis will stimulate such studies.

Another possible thread to follow could be different participants’ ideas about the purpose of schooling. Different students in my study seem to have different ideas about what learning is all about and these ideas seem to influence their learning. What about teachers, what kind of ideas about the purpose of their endeavours in the classroom do they have and do these ideas change over time? What about students? An interesting research project would be a longitudinal study revealing how students’ and/or teachers’ appreciations change over time\textsuperscript{32}.

Lastly I will come back to the interview situation. In the section above about contributions I claim we do not know enough about the advantages and obstacles for interviews. We know they are social situations. The interviewee’s perception of the nature of the situation affects the responses but we do not have much research about the effect of different contexts. How do the responses change if the context differs? One example: would students’ responses about the burning candle come out differently if the students had been interviewed during a dinner party or in a laboratory with also the book in chemistry present? Further research is needed to give us a theory of context.

\textbf{Implication for practice}

If the goal of the compulsory school science is that people should be able to use the science taught in school in an everyday context and should be able to scientifically explain phenomena in everyday

\textsuperscript{32} Writing this I realise there are also teacher students, teacher educators, headmasters, school officials, and school politicians whose ideas about the purpose of different participants’ endeavours in the classroom it would be very interesting to learn about and to be able to follow, especially through a time of school changes. This though might fall aside the area of research in science education.
situations the curricula/syllabi, the teaching material, and/or the teaching have to be reconsidered.

The study reveals, as well as commonalities, great diversity among students. This diversity seemed to increase when the students grew older. Classroom practice deals well with commonalities, but less well with diversity. Tytler et al. (2007) show how students’ understanding is enhanced by being allowed and encouraged to use many different representations when explaining evaporation phenomena. Teachers might need to present the same information in a diversity of formats in order to make subject matter potentially meaningful to all students.

Another implication from this thesis is that fundamental concepts such as the particle model could be introduced earlier than today thereby taking advantage of the young students’ learning abilities and curiosity. But this is only fruitful if these concepts are continuously worked on in order to make frequent revisions of the concept possible. Meaningful learning, in this case to reach a suitable level of comprehension of an abstract concept takes time. To make such learning pathways possible more teachers with confidence and knowledge in science are needed, especially during the first years in school.

The study also brings out the importance for teachers to emphasise commonalities in phenomena. For instance, in the burning candle and the decomposition of leaves the processes are the same. Chemical reactions take place in which the role of oxygen, the formation of the product gases, and the release of energy are common. Learning that general principles can explain different phenomena is an important part of science knowledge.

Too many concepts are taught during the later years of the compulsory school. The challenge for curriculum designers is to identify a limited number of key principles such as conversation of matter and energy. They should also identify key ideas such as the nature of science, the relevance of the methods of science to its validity, and the use of science models. Topics that are relevant to students’ needs and interest should also be identified. To curriculum designers this is not an easy challenge to meet. There are a lot of
interests and traditions to challenge. But this is not enough, the authors of textbooks and the teachers themselves have to make such curricula/syllabi concrete in the classrooms. The presuppositions to make this possible are teachers who are well educated in science, who are offered continuing professional development, and who have possibilities to, in cooperation with researchers in science education, conduct research and development projects.

33 To some extent this has been successfully done in Sweden as the syllabi in science are goal driven and not concept overloaded.
Levere (2001) gives a vivid picture of how a scientist in the eighteenth century could become attracted and intrigued by new discoveries in the field of chemistry:

Was it not wonderfully strange that an inflammable gas and a gas supporting combustion and life could combine to produce pure water, showing no trace of its gaseous origin? So it seemed to many chemists around the time when the composition of water was discovered. (Levere, 2001, p X)

This study has confirmed my opinion that all children are curious about and fascinated by different phenomena in nature and daily life. They exert themselves in making meaning of the world around them. Unfortunately many students seem to lose confidence and pleasure in this meaning-making as school passes. A dream would be that students due to the science taught in compulsory school could keep their scent of fascination and become challenged to explore both nature and the construction of science during their life-long learning.


candle get smaller when it is burning?). In E. K. Henriksen & M. Ødegaard (Eds.). Naturfagenes didaktikk – en disiplin i forandring? (pp.329-344). Kristiansand: Höyskoleforlaget AS.


A Long-Term Study of Students’ Explanations of Transformations of Matter

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Abstract: We report on a long-term study of young children’s understanding of matter and its transformations. Interviews concerning children’s conceptions of three different natural phenomena were carried out regularly. These conceptions could be seen in the idioms, personal framings of experiences, that became apparent as a result of the longitudinal design of the study. As part of the project, we also made an early (at the age of 6) introduction of the concept, molecule. Depending on the phenomenon presented to them for explanation, some of the children used the molecule concept as a tool for understanding and explaining, while others did not. By focusing on a few examples, which we analyse in detail, we argue that long-term studies give rich detail and important information about children’s learning that other kinds of studies do not.

Sommaire executif : Aujourd’hui les particules et la conservation de la matière sont des vérités scientifiques fondamentales. Mais pour les non-spécialistes, il est souvent difficile de comprendre les discussions scientifiques sur la transformation de la matière lorsqu’il est question de sujets controversés tels que la gestion des déchets, le trou dans la couche d’ozone ou le réchauffement global. En effet, beaucoup de gens estiment encore tout à fait normal de se défaire de certains objets en les brûlant, sans songer un instant à l’énorme quantité de gaz qui est la conséquence de cette action. En milieu scolaire, les enseignants chargés de former nos futurs citoyens se rendent compte que les enfants éprouvent des difficultés du même type lorsqu’il s’agit de comprendre les processus impliquant la transformation de la matière, en particulier dans les cas où la matière semble disparaître, comme dans la combustion et la décomposition, ou encore lorsque la matière semble apparaître spontanément, comme dans la condensation. Ce sont là des phénomènes au sujet desquels nous avons interviewé des étudiants dans le cadre d’une étude à long terme menée en collaboration avec Gustav Hellédni et Ann-Charlotte Lindner à l’université Kristianstad, en Suède. Depuis 1997, nous suivons les progrès de 60 étudiants nés en 1990 tout au long de leur formation scolaire obligatoire. L’objectif général de notre étude est de chercher à en savoir plus sur la façon dont les étudiants construisent les signifiés sur les phénomènes impliquant la transformation de la matière.

Le but de cet article est de montrer le type de résultats qu’il est possible d’obtenir pour chaque étudiant dans une étude à long terme. Pour ce faire, nous avons analysé en détail un certain nombre de cas d’étudiants, en donnant des exemples explicites de la forme personnelle que prend souvent la construction des signifiés. De plus, nous avons introduit le concept de molécule dès le début du projet, et nous montrerons comment ce concept peut servir d’outil pour parler de choses qui sont invisibles. Notre recherche est centrée sur la construction individuelle des signifiés. À cette fin, il n’est pas suffisant d’étudier des groupes d’enfants d’âges différents pour tenter de cerner des conceptions communes, conceptions qui sont souvent erronées et qui persistent étonnamment même en présence d’un enseignement de qualité. Pour pouvoir creuser sous la surface de ces conceptions, nous avons voulu suivre certains étudiants dans le temps afin de voir comment évolue leur capacité d’expliquer et de comprendre les phénomènes scientifiques.

L’approche longitudinale permet de suivre l’évolution des explications et des concepts chez les étudiants au fil des ans, et de déceler certains éléments susceptibles d’influencer ces concepts, par exemple différents types d’expériences précoces.

Les entretiens ont été analysés de différentes façons. Chaque phénomène a été analysé en soi, sous l’angle des catégories de concepts exprimés par les étudiants. Cependant, nous avons également cherché à dégager des caractéristiques dans l’évolution des concepts dans le temps. Les extraits d’entretiens mettent aussi en évidence le fait qu’une entrevue peut servir à éclairer des interprétations provenant d’entretiens antérieurs. En effet, grâce à l’utilisation d’une approche métacognitive, les étudiants ont exprimé des points de vue fort utiles pour interpréter les entretiens précédentes. Nous avons également vu des cas où les étudiants se servaient spontanément d’analogies et de métaphores pour expliquer certains phénomènes. Cette utilisation du langage pour articuler les idées affine notre compréhension de la conscience dans le temps, mais aussi de l’évolution, des signifiés chez les étudiants.

Comme le souligne Shapiro (1994), l’apprentissage des sciences chez les étudiants revêt des aspects très personnels, aspects qui restent invisibles dans les recherches conventionnelles à cohortes. Une étude de type longitudinal est donc nécessaire si l’on veut analyser ces aspects. Les différences entre individus sont des différences dans lesquelles certains signifiés dominent à différents moments.

Un élément particulièrement frappant de nos données est la persistance de ce que nous appelons le cadre personnel. Les étudiants recourent souvent à leur expérience personnelle lorsqu’ils tentent d’expliquer différents phénomènes. La méthode longitudinale fait émerger d’une part les tendances dans les types d’explications fournies par le groupe au fil des ans, et d’autre part l’émergence et la persistance des approches personnelles lorsqu’il s’agit « d’encadrer » les idées. À l’âge de 7 ans, ils ne se servent que d’éléments concrets dans leurs explications. À mesure qu’ils grandissent, leurs explications s’enrichissent et ils se servent de plus en plus d’associations d’idées, de métaphores et d’analogies.

L’un des objectifs de cette étude est d’analyser l’impact que peut avoir l’introduction précoce du concept de molécule sur la compréhension des phénomènes liés à la matière chez les élèves. Nos résultats montrent qu’en général, ils ne se servent de ce concept que s’ils en perçoivent d’une façon ou d’une autre l’utilité. Nombre d’entre eux s’en servent par exemple avec profit pour expliquer avec assurance les processus d’évaporation et de condensation. Nous constatons toutefois qu’ils ne l’utilisent guère pour parler de substances telles que l’eau, la cire ou les matières organiques comme les feuilles mortes. Il va de soi que les jeunes enfants n’ont pas la capacité de comprendre pleinement la complexité de processus tels que la formation de molécules à partir de plusieurs atomes différents. Les étudiants doivent d’abord se familiariser avec ces concepts de façon informelle. Cela leur consentira plus tard de construire des signifiés plus conformes aux concepts scientifiques réels.

Une première conclusion de notre étude a trait à l’importance des expériences qui sollicitent les étudiants sur le plan émotif. Il peut s’agir d’expériences vécues en milieu scolaire, par exemples des expériences de laboratoire, des discussions ou d’autres tâches, ou encore à l’extérieur de l’école. Il n’est pas facile de prévoir quelles sont les activités susceptibles de provoquer ces expériences, car il semble qu’elles varient considérablement d’un étudiant à l’autre. Une autre conclusion qui ressort de nos données est qu’il est hautement improbable que les étudiants puissent découvrir et formuler par eux-mêmes des idées reliées aux changements chimiques.

Les résultats présentés dans cet article n’auraient guère pu être obtenus dans une étude transversale. L’apprentissage est un processus complexe, qui comprend de nombreuses facettes personnelles et sociales (Shapiro, 1994). Pour qu’un enseignant soit en mesure de comprendre les efforts que font les étudiants pour élaborer des signifiés scientifiques, il est essentiel de mieux connaître les possibilités de variations individuelles de même que les raisonnements complexes que doivent affronter les étudiants au cours de leur apprentissage scientifique.
Background

The struggle to understand matter has been long and challenging. Not until the end of the eighteenth century—when an understanding of air as a mixture of different gases, with different chemical characteristics, emerged—did controversy give way to comprehensive explanations (Butterfield, 1974; Toulmin & Goodfield, 1962). This new understanding of matter involved the introduction of quantitative measurements and a conception of matter as consisting of atoms.

Today, the particle view of matter and the conservation of matter are scientific \textit{elementa}. But, for the layman, it is often difficult to understand the scientific arguments involving the transformation of matter that arise in the context of discussions of controversial issues like waste management, the ozone hole, or global warming. Many people believe that it is possible to get rid of things by burning them, for example. They are unaware of the huge volume of gases that burning produces.

Teachers are aware that children encounter difficulties understanding the transformation of matter, difficulties similar in kind to those encountered by scientists in earlier times. This is especially true when matter seems to disappear, as in burning or decomposition, or appear out of nothing, as in condensation. These difficulties are well documented in the science education research literature, as reviewed by Driver, Guesne, and Tiberghien (1985) and Krnel, Watson, and Glazar (1998). Even student teachers have difficulties (Eskilsson & Holgersson, 1999).

Research on learner ideas often describes the different categories of conceptions or misconceptions that children exhibit and draws conclusions, from the general trends found, about approaches to developing their understanding of matter. To understand how the child develops an understanding of science is, however, a more complex matter than this. We are concerned with asking, How is this understanding built up? and What are the kinds of things that facilitate or obstruct concept development? One way to learn more about these matters is to study individuals in more detail and over longer periods of time. To accomplish this, long-term or longitudinal studies have, for some time, been called for in the literature (Arzi, 1988; White, 2000). At Kristianstad University we have tried to meet this need with a variety of projects using a longitudinal design. Most of these are concerned with students’ conceptions of matter and matter transformation (Eskilsson, 2001; Helldén, 1999; Holgersson, 2001). Recently, work has focused on students’ attitudes towards science (Lindahl, 2001).

Aims

In this article, we report on a long-term study we conducted with Gustav Helldén and Ann-Charlotte Lindner at Kristianstad University in Sweden. Since 1997, we have been following 60 students, born in 1990, through their compulsory schooling. The overall aim of our study is to learn more about how students actually make meaning and come to understand different phenomena in science. We also seek to understand why scientific models involving particles of different kinds are so hard to understand and adopt. We investigate students’ conceptions of matter and its transformations by interviewing them regularly. The aim of this paper is to give examples of the kind of results we have obtained from long-term studies with several individual students. We present data from our cases in some detail, explicitly giving examples of the ways students have shown a personal framing of their understanding. We introduced the \textit{molecule concept} at the start of the project, and we illustrate how some students have used this concept as a tool for explaining phenomena. In order to study the use of the molecule concept in different contexts, we conducted interviews allowing students to explain the transformation of matter in three situations:

- the fate of decaying leaves left lying on the ground
- the disappearance of the wax of a burning candle
- the appearance of mist on a piece of glass placed over a cup of water
Theoretical and methodological framework

In this study, we focus on aspects of individual meaning making. Our intention was not to study different children at different ages to try to find out common conceptions or ‘misconceptions.’ Our purpose was, rather, to dig deeper into the process of concept development, by following individual students over time to see how their ability to explain and understand scientific phenomena changed as they grew and developed.

The theoretical framework for this study is a perspective on learning that Joseph Novak has termed human constructivism (Novak, 1993). Based on Ausubel’s assimilation theory (Ausubel, Novak, & Hanesian, 1978), human constructivism asserts that one of the characteristics of human beings is the capacity to note the perceived regularities of events and to fit them into already existing knowledge structures. This formation does not take place in isolation; on the contrary, explaining and making sense of what we perceive is highly dependent on social interactions and on the use of language with others. Although learning and understanding can be uniquely situated, children also show consistencies and patterns of thought over different contexts. This tendency to make successive efforts to make meaning has encouraged us to use interviews with students on a regular basis to learn more about their conceptions of a particular phenomenon.

We believe that the best way to gain information about how children learn and think about different phenomena is through communicating with them. This can be done by studying the ways they respond during tasks, either in writing or in conversations with peers, teachers, or researchers. Like many other researchers, we have found that friendly engagement, through a structured conversation with an individual child about some phenomenon or event, gives useful information about his or her ideas about that phenomenon (Duit, Treagust, & Mansfield, 1996). We have documented the persistence and survival of ideas from year to year. The interviews we have performed can be classified as a form of revised clinical interview. This type of approach to research offers fairly good flexibility, with the possibility of following up different themes raised during the interview (Ginsburg & Opper, 1988).

There have been very few studies published that follow the development of individual students over a period of years, but some of these investigated students’ understanding of matter and its transformations (Eskilsson, 2001; Helldén, 1999; Johnson, 1998; Lichtfeldt, 1996; Peterson & Tytler, 2001). The main inspiration of our research was a longitudinal study performed at Cornell during the seventies and eighties (Novak & Musonda, 1991), which also used, as an investigative tool, the early introduction of molecules to explain the transformation of matter. The three special phenomena we study with children have also been investigated previously. Helldén (1999), Leach, Scott, and Wood-Robinson (1996), and others researched children’s understanding of the decomposition of organic matter. BouJaoude (1991), Johnson (2002), Kremel et al. (1998), and Meheut, Saltiel, and Tiberghien (1985) reported on children’s difficulties in understanding the process of burning. Most of these investigations studied the ideas of students in secondary school, but many of the findings are consistent with the views of younger children. Osborne and Cosgrove (1983), Bar and Galili (1994), and Tytler (2000) described investigations of evaporation phenomena. We examine several similar examples in our project.

Design of the study

To study the development of conceptions of matter for individual students throughout compulsory school (i.e., from age 6 to 16), we employed a longitudinal design. Over the years, this has meant gathering a lot of data. The longitudinal approach has made it possible for us to follow how students’ explanations and conceptions develop over the years, and we have attempted to detect some of the features that influence idea development.
The students in the study come from two different schools in a mid-sized Swedish town. At the start the study, 58 students were evenly distributed over the two schools. They came from seven different classes, with 8 to 10 children in each class. Due to the policies of the local school authorities, all classes are age-group-integrated; that is, they consist of about equal numbers of children aged 6, 7, and 8 or children aged 9, 10, and 11, respectively.

In School A, most children are from working class or immigrant families, but there are also children from middle class families. In School B, the children are mostly middle class, with almost no immigrant population. Due to the tendency of immigrants to move more often, the turnover of students in School A has been much greater than in School B, where there is almost no turnover. This means that the number of children we have been able to follow differs for the two schools. From a total of 58 children in 1997, the number of participants had decreased, in 2001, to 43—from 33 to 19 in School A and from 25 to 24 in School B. To support the regular teaching in the classes, members of the research team carried out several teaching sessions every second year; that is, in 1997, 1999, and 2001. During these sessions, we worked only with the students who were a part of the project. All of the teaching sessions were around 30 minutes long. They took place during the spring term and were documented on videotape.

In order to be able to discuss the transformation of matter in more detail, we followed the practice of Novak and Musonda (1991). Right from the start of the project, we introduced the molecule concept. We did this by presenting molecules as the smallest parts we, in principle (without exerting special force), can divide a substance into. To support this introduction, we let the children experience how we can divide different materials into smaller parts. We let the children file on wood and iron and look at the filings with a magnifier. The children ground two stones against each other and studied the sand that was produced. They were allowed to lift water droplets of different sizes from a glass of water, using small glass sticks. To discuss air, we first demonstrated the existence of air, by taking a small plastic bag, opening it up, and tying it tightly. The resulting cushion was then discussed as being formed by trapped air. The children then blew soap bubbles, and afterwards we let them shake a can of bubble soap and study the tiny bubbles that were produced. Lastly, the children ground a piece of chalk in a mortar and studied the tiny bits produced. After they had looked at these examples, we asked them if they thought we could continue like this and divide things into smaller and smaller parts. We told them that there are particles we can divide matter into and that we call these molecules. We can talk about air molecules, water molecules, etc. These molecules are, however, so small that we cannot see them. In addition, they are in perpetual motion, although they are stuck together in solids and liquids. But they can also move about more freely, as parts of the air or of another gas. To illustrate this, in 1997, we let them experience how the smell of fruit syrup can fill the air when heated. In 1999, we let them dramatize what it is like to be a water molecule. We did this by gathering them in one of the corners of the room we were in, letting them feel what it is like to be unable to move about. We then let them move around each other, still in close contact, as in liquid water. And lastly, we let them evaporate one by one, moving freely in the room.

Individual interviews were conducted and recorded on tape. The structure of the interviews used was as follows:

**Situation 1: Leaves**

We started by presenting the children with some leaves that had been lying on the ground during the winter. The leaves were in different stages of ongoing decomposition. Then we asked, "What do you think will happen to the leaves if they are left lying on the ground?" Later on we asked, "What will become of the leaves?"
Situation 2: Candles

We presented the children with two candles, one long and one short. Then we lit the longer one and asked, "This candle (pointing to the shorter) used to be as long as this one (pointing to the longer). What do you think has happened to all the wax that was there before?"

Situation 3: Water

In the third situation we presented the children with a glass jar containing water, covered with a glass-plate. Mist formed on the glass. We started by asking, "What do you think it is that we see on the glass?" Then we continued by asking, "Where do you think it came from?" and "How do you think it came up there?"

These three situations, along with the questions, have been used every second year; that is, in 1997, 1999, and 2000. We conducted one interview before the teaching sessions and one in the weeks after. Experience from an earlier project showed us that children can often cast new light on their own statements by being allowed to comment on them at a later time (Helldén, 1996). Therefore, in 1998 and in 2000, we used a more metacognitive approach, letting the children listen to the interview from the year before and asking them to comment on it. We presented them with the same equipment and let them listen to a section of the interview at a time. Then, we asked them what they thought about what they had just heard, whether they thought in the same way today or in another way, and if they thought in another way, we asked them to explain what they thought today. In this way they themselves contributed to our interpretation and analysis of the data.

In 2001, we decided to extend the interviews in the following way. In situation 1, we presented the students with leaves, dry grass, and a peg, which we had brought in from the woods. We then asked them, "What happens to all of these things?" We also presented them with a sample of soil and asked, "How is soil formed?" In situation 2, we substituted long candles for tea lights, one new and one nearly completely burned. In this scenario we asked, "What do you think happens in the flame?" In situation 3, we continued the interview by taking off the cover and laying it on the table. Then we asked, "What do you think will happen if the jar is left for a fortnight without a cover?" and "What do you think will happen to the moisture droplets on the cover if it is left like this for a fortnight?"

All the interviews have been transcribed verbatim and, as the years have passed, we have gathered a large amount of data. Every phenomenon has been analysed by categorizing the conceptions the students express. The data are rich, and over the years, we have noted individual differences. Although the interview data can be categorized, we have sometimes felt that we are forcing a pattern on the data. There is a personal framing that appears in the expressions the students use, in what they choose to focus upon, and in their use of analogies and metaphors. This accords well with the findings reported by Shapiro (1994), who used a personal construct framework. Many times it has seemed as if there were certain key experiences that acted as references for a student's meaning making. In analysing the data, we endeavoured to preserve what we perceived as important personal themes. To address the challenge of noting differences over time, we developed interview summaries to help us to get a better overview of different students and give us an opportunity to detect patterns in the development of ideas.

Results

In this section, we illustrate the kinds of conceptions we found in the analysis, by giving examples from the transcripts of three students. First, we report on the different conceptions the students expressed in the different contexts and on how these conceptions varied from student to student and over time. We give the results for each situation, illustrating them with an overview of the different
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conceptions, and then sum up some common trends in the data. Finally, we report on some general patterns we found while comparing the different situations.

Conceptions in different contexts

In the report of results for each phenomenon, we give an overview of the conceptions we found among the students. In Tables 1 to 3 we present the conceptions we have found useful in our analysis. The conceptions are tentatively ordered from more descriptive and more concrete to more advanced and more reflective of scientifically correct ideas.

The fading leaves

Brown leaves left on the ground can meet different fates. In the garden, we often collect them and throw them away or compost them. Others can blow away during autumn or winter storms. When the students were young they tended to focus on how leaves looked, on whether they were crumpled and dry or on whether they were broken in some way. They tended to speak about features of leaves, and explanations about their fate were often very concrete. As the students got older, additional experiences brought new observations. These experiences included walking in the woods, playing with leaves, interactions with worms and woodlice, and perhaps, handling compost. Then, explanations about leaf decay tended to include more references to animal activity and many of the students used words such as rot and decay and realized that the leaves would eventually turn to soil. The range of student conceptions about what happens to leaves is given in Table 1.

Table 1: Student conceptions in explaining what happens to leaves left on the ground

<table>
<thead>
<tr>
<th>Number</th>
<th>Conception</th>
<th>Citations Characteristic of the Conception</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Just Disappears</td>
<td>Nothing is left</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mm, they have blown away during the autumn</td>
</tr>
<tr>
<td>2</td>
<td>Change Due to</td>
<td>They have perhaps been kicked away. [T]they have become a hut of leaves that somebody has built over there.</td>
</tr>
<tr>
<td></td>
<td>Human Activity</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Become Soil</td>
<td>They could have turned into soil. The leaves become very, very small and then they turn into soil.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>When you throw them on the compost then they turn into soil.</td>
</tr>
<tr>
<td>4</td>
<td>Breaking Up</td>
<td>They become small pieces.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>If someone treads on them ... they become small pieces.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>They blow away and they get crushed.</td>
</tr>
<tr>
<td>5</td>
<td>Rot</td>
<td>Then they rot and get old</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I think they would mould away ...</td>
</tr>
<tr>
<td>6</td>
<td>Animals Eat Them</td>
<td>Then the worms eat them and then they come out and turn into soil.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>They mould and then the worms eat them and have a poo and they turn into soil.</td>
</tr>
</tbody>
</table>

For the most part, students expressed more than one conception during an interview. A few of the students mentioned, even during the first year, that the leaves would turn into soil. For some of them, worms were an essential part of this process. Others started with more concrete descriptions but later stated that soil was the end product. In the 99-2 interview, the majority of students fell into this group. However, some of the students never explicitly referred to animal activity or bacteria as
a part of the process of turning leaves into soil. Instead, they tended to use expressions like \textit{rot away} or \textit{rot into soil}.

Two conceptions were introduced in the first interview in 97-1 (7 years old).

\textbf{Ida:} They will get brown.\textsuperscript{1}

\ldots

\textbf{Ida:} Perhaps they \ldots perhaps some worm will come who will eat them. Yes, it eats a little of them.

Here Ida focused on the colour of the leaves—that is, that they are brown—but she also saw the possibility of some of them being eaten by worms. In 97-2, she added that ‘that [was] because they don’t get any nourishment’ and that ‘they might blow away.’ In 1998 (8 years old), she changed to talk about how they rotted away. In subsequent interviews, she said that this meant that they got brown and crumpled. But in 99-2 (9 years old), she associated the word \textit{rot} with ‘grubs \ldots some animal w[ould] perhaps eat them up,’ but then changed her mind and said that they could rot away. She added that if there were bad weather sometime they could also blow away, and that if the wind were very strong it could make holes in them. When this happened, they became tiny little bits that came down into the earth, where they then would rot away.

So it seems that Ida believed that they could rot away only if they were split into small bits. Animals could eat them, but this was not the only reason for their disappearance. A year later, in 2000 (10 years old and after listening to 99-2), her view changed:

\textbf{Ida:} But then, perhaps, there will come other small animals that will live on them and so they will have it as their food supply or something.

\ldots

\textbf{Ida:} No, actually they will perhaps not rot so much, but \ldots it is probably mostly animals that \ldots yes.

She was not confident or consistent in the explanations she gave and the explanations were not linked to the formation of soil. This became apparent in 01-1 (11 years old):

\textbf{Interviewer:} What is soil?

\textbf{Ida:} Oh, dear, that I don’t know \ldots perhaps it is eh \ldots I don’t know.

\textbf{Interviewer:} No\ldots Is it something that \ldots It is just there or \ldots?

\textbf{Ida:} Mm \ldots yes it is there or it is perhaps grass that has rotted away. Ah, I don’t know.

In summary, Ida’s conceptions about what happens to leaves left lying on the ground revealed that there were several possibilities open to her, and that there might not be only one principle explaining the phenomenon. She recognized that small animals could eat them, but this did not explain what happened to all leaves. They were so many. Some of them just rotted away, but not until they had been broken up in some way.

In 97-1 (7 years old), Lars said that the leaves ‘w[ould] get brown’ and that they ‘w[ould] not have so much colour left on them any more.’ They would, perhaps, get ‘a little harder than before’ and ‘become crumpled’ when left for several years. In 97-2 he spoke more about animals:

\textbf{Lars:} Some animal like a worm can come, and a woodlouse, and eat them.

\textbf{Interviewer:} Is there something else that can happen to them?

\textbf{Lars:} They can \ldots if you walk on them, they can \ldots be shredded apart.

In the 1998 (8 years old and after listening to 97-2) interview he explained why. He and a playmate had given a rather big but faded leaf to a worm. It was a rather thick (‘pencil-like’) worm and
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the leaf was gone in only one day. They had also kept woodlice in a jar and given them two smaller leaves. These had also disappeared. Then the interview continued:

**Lars:** Well, they fall down from the tree and then they fade.

**Interviewer:** And if they are left on the ground even longer?

**Lars:** Yes, then they will turn into soil.

...

**Lars:** They will lie there for a long time and then they will rot.

...

**Lars:** That is the way it is with our chestnuts. We have found chestnuts, which have taken root there, but some are completely rotten.

In the 1998 interview he referred to two different experiences that shed light on his ideas about what happens to leaves left on the ground for a very long time.

In the 99-1 (9 years old) interview, he focused on some leaves that were partly transparent and suggested that the reason was that they had gotten into water. But in the 99-2 interview, he returned to the worms and woodlice, which, he said, would ‘make them (the leaves) break apart a lot.’ He indicated that if they were in a compost pile, they would turn into soil.

In the 2000 (10 years old) interview, he gave many alternatives. Then in the 01-1 (11 years old) and in the 01-2 interview, he was presented with leaves, grass, and a peg that had been lying in the woods for a long time.

**Lars:** ... the leaves will disappear, or blow away or something like that ... perhaps down into the soil, no. Eh, what is it, it can be eaten ... not the peg, but the hay and the leaves. But the peg ... I don’t know.

**Interviewer:** Okay. I have brought some soil here. Where does soil come from?

**Lars:** Mm, hard to say ... it was there before the dinosaurs so ...

Not only did he talk about different things happening to different leaves, but Lars also referred to different objects meeting different fates: Leaves and grass are similar, but the peg is different. Of course, the peg is harder and denser than the leaves and grass. Lars did not express any ideas about how soil is formed, although two years before he had looked at soil through a magnifier and had been told by us that what he was looking at was mainly worm excrement and sand grains.

In 97-1 (7 years old), Jenny said that the leaves faded or died, which she said meant almost the same thing. In 97-2, she developed this idea further, saying that when they died, they broke into small pieces and went into the soil. The interview continued:

**Jenny:** Yes, when they have broken, the small pieces go down into the soil, and then the summer comes, and then new leaves will come.

It was not clear whether she meant that new leaves came from the small pieces in the soil or whether she was commenting on her experience of seeing trees in the summer that had new green leaves. In 1998 (8 years old), she also mentioned the possibility that worms might eat the leaves. In this interview she confidently stated that, whatever happened, the leaves would, in the end, become soil. All interviewees from Jenny’s class said in the 1998 interview that the end product was soil and most of them mentioned worms’ eating the leaves. The teacher in Jenny’s class discussed leaves with her class and talked about what happened when they decayed. In 99-1 (9 years old), Jenny did not mention worms but clearly stated that leaves turned into soil. She also suggested that when the small leaf pieces became very small, all the air in them disappeared and then there was
nothing left. In the following interviews, she moved back and forth between these different possibilities, sometimes mentioning several ideas in one interview. The following segment, from 01-2 (11 years old), is a good example of Jenny’s approach to discussing leaves:

**Jenny:** They have dried. Mm. The leaves have dried, for instance, and then they become a little bit harder … Mm … and a little … yes, some of them could be a bit … soft and so, but then, some people might come and tread on them. Falling down from the tree they rot and won’t get any oxygen into them, then perhaps someone comes and walks on them and they get broken and then they turn to soil. Okay. And then perhaps some grub or something comes and eats them and so … Mm … then it also turns to soil, when they have a poo.

Jenny used different words that she seemed to see as synonymous, words such as *fade, die, get old, rot,* and *get mouldy.* The leaves changing colour and turning wet or dry were, to Jenny, very concrete proofs of these processes. The leaves could then become small pieces, or different small animals, like worms or grubs, could eat them. In either case, the end product was soil. Jenny was rather unusual in the student sample in mentioning the possibility of air or oxygen’s being involved in different ways in the process of decay.

*The burning candle*

Understanding what happens when a candle burns is very difficult; most students in secondary school do not even fully understand the explanations, involving chemical reactions, that they are given (Johnson, 2002). Children and adults have the common experience of observing that the wax simply disappears as the candle burns. To grasp their ideas, we asked the children to explain where all the wax had gone once a candle had burned. In Table 2, we give the most common conceptions in explanations given by the children about where the wax had gone.

**Table 2: Student conceptions in explaining the burning candle**

<table>
<thead>
<tr>
<th>Number</th>
<th>Conception</th>
<th>Citations Characteristic of the Conception</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A Description of Events Instead of an Explanation Is Given</td>
<td>You’ve burnt more on that candle. It has been burning longer …</td>
</tr>
<tr>
<td>2</td>
<td>Wax Runs Down</td>
<td>It runs down, and then it gets a bit thicker down here. It melts down and get here. Then you take it away.</td>
</tr>
<tr>
<td>3</td>
<td>Wax Melts</td>
<td>It melts … and it is burned in the end. It melts … and dries up again.</td>
</tr>
<tr>
<td>4</td>
<td>Wax Gets out into the Air</td>
<td>… then it becomes smoke and flies away … … it gets up into the air too …</td>
</tr>
<tr>
<td>5</td>
<td>Signs of Chemical Reaction</td>
<td>The wick absorbs the wax, then the wax goes up and then it burns …</td>
</tr>
</tbody>
</table>

All students believed that the melted wax at the top of the candle was a key to explaining what had happened. But then they focused on quite different things. Some of them thought that the wax that ran down the sides of the candle then was taken away or disappeared, in some way explaining ‘missing’ wax. Others focused on what happened at the top of the candle, suggesting that either the wax ‘evaporated’ out into the air, or it shrank during the process of melting and drying up. The idea of conservation of matter is a difficult concept and its validity was not established until well into
the nineteenth century (Toulmin & Goodfield, 1962). Stavy (1995) reported that many students in secondary school seem unaware of the conservation of matter, especially when phase transformations take place, as when solids melt. Perhaps the prototypical event for thinking about melting is when ice or snow melts. Melting water often flows out over a larger area than that covered by the original snow or ice, giving the impression that there is not so much water formed or that it actually is just about one tenth of the volume of the snow it comes from. This can give us a clue as to why the conservation of matter is not immediately evident in matter transformations.

Over the years of the study, some students persisted in giving explanations involving wax running down the sides of the candle (see Lars below). Others never mentioned this as a possibility and tended to give explanations expressing conceptions 3 (wax melts) or 4 (wax gets into the air). To some students, there was a possibility that the wax both ran down and went into the air. A general trend in our data is that many of the students moved from conception 2 (wax runs down the candle) to conception 4, as they grew older. But very few gave explanations in which wax had an active role in interaction with the fire. Although a majority of students in the later interviews stated that oxygen was needed for a fire to keep on burning, they referred more to the idea of keeping it alive than to the concept of oxygen as a fuel for the process itself.

In interviews 97-1, 97-2 (7 years old), and 1998 (8 years old), Ida answered, ‘I don’t know,’ to the question, ‘Why does the candle get smaller?’ A year later, in 99-1 (9 years old), something happened during the interview. After telling us that it became wax, she was struck by another idea:

**Ida:** But there is not enough room in there [at the top], is there? No there isn’t.

**Interviewer:** No ... but the wax ...

**Ida:** It becomes molecules, doesn’t it.

...

**Ida:** Eh, the wax becomes molecules, perhaps.

...

**Ida:** ... but it cannot be thicker either. No.

She suddenly explained the phenomenon in terms of evaporating water. This interpretation was strengthened by the interview a month later, in 99-2.

**Ida:** I don’t know if it is like that, but I cannot think of anything better.

**Interviewer:** So what happens with the molecules then?

**Ida:** Mm ... they will probably get up into the air. I think.

A year later, in 2000 (10 years old; after listening to 99-2), her idea was not as vivid any more, and she turned to a more macroscopic explanation. But in 01-1 and 01-2 (11 years old), she returned to the evaporation analogy.

Ida appeared to have rather demanding criteria for what she presented as an explanation. She did not understand why a candle got smaller while burning. During the first years, she simply stated that she did not know. Then, during the 99-1 (9 years old) interview, she made a connection using the analogy with evaporating water, and although she could not recollect her thinking in detail in the 2000 (10 years old) interview, she kept her focus on the melted wax at the top of the candle. This was not a common reference. Many students were not really concerned about the conservation of candle matter. To Ida this was a concern. This was expressed in the 99-1 (9 years old) interview, where she stated that it ‘could not be thicker either.’ To her, the flow of wax along the sides of the candle was not sufficient to explain the disappearance of the burning candle.

In 97-1 (7 years old), Lars said,
**Lars:** The fire makes the wax smaller … then it burns all the time against the candle and then the wax which melts like that candle there. There will be a lot happening, like a small sea there in the beginning.

…

**Lars:** Yes … you could say that it looks like water there, so it will soon begin to run in the waterfall, you can say.

Here Lars had a quite different focus than Ida had had. His concern was with the flame and the candlewick. He referred to the flame as the agent that made the wax melt and flow like water. Lars also used metaphors in explaining the phenomenon.

In the next interview segment, Lars stuck to the theme of the importance of the wick. In the 99-1 (9 years old) interview, he clearly stated that the wax melted and ran down, and that you then had to take it off and throw it away. In 99-2 (9 years old), he returned to referring to the wick and now told about how candles were made and about the importance of the long thread that runs through the whole candle. In Sweden, it is not uncommon for families before Christmas to make their own candles at home, so some children had had first-hand experiences with candle-making.

In the 01-1 and 01-2 (11 years old) interviews, he was confronted with another type of candle, called a tea light (wax in a small aluminium can). In this sequence, his idea of how the wax disappeared was challenged. In 01-2, he said:

**Lars:** It melts … then I suppose you can say that it is burned up at the end, so that it gets smaller and smaller.

**Interviewer:** Mm, it is burned up, what does that mean?

**Lars:** Ah, but I suppose there are some funny molecules, which … are inside the wax that is burned up. Melt and then are burned up.

Lars’ use of the molecule concept here was quite different from Ida’s. His was not based on an analogy with evaporation, and he focused more on macroscopic characteristics, referring to molecules’ being able to melt and burn.

In the first interviews, Jenny spoke about the candle melting into wax and running down on the outside. In 97-2 (7 years old), she also proposed that the wax could go into the candle. In 98 (8 years old), she explained this in the following way:

**Jenny:** Yes, or it goes in … into the candle again, so when it (the wax) has gone rather old then it gets hard in small, small molecules or whatever you call them (laughs).

In the interviews in 1997, Jenny did not mention molecules. Now, one year after our interventions, she suddenly used the concept, *molecules*, in her explanation that the melted wax could ‘disappear’ into the candle. In the following interviews, she continued talking about the wax running or melting into the candle, but never again mentioned molecules. In 2000 (10 years old), she also suggested that the wax could melt away because of the heat. In 01-2 (11 years old), Jenny started by telling us that this was the phenomenon she did not understand and then said,

**Jenny:** So it gets warmed by the oxygen and so, so I think it … goes up in the air with yes, fire yes, when it gets so hot.

Although Jenny used more than one explanation, she often came back to the idea that the melted wax could get into the harder wax in the candle and, in that way, ‘disappear.’ The idea that the melted wax went into the air was, for some reason, less attractive to Jenny and only appeared as a possibility on a few occasions and in short comments.
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The covered glass of water

Except for in the first interviews, in 97-1 and 97-2, almost all the children were aware that what they saw on the cover was water in some form. Alternative terms used were air bubbles and ice. The questions posed to the children were how and why the mist was formed. The conceptions expressed by the students are summarized in Table 3.

Table 3: Student conceptions in explaining the moisture on the covered glass of water

<table>
<thead>
<tr>
<th>Number</th>
<th>Conception</th>
<th>Citations Characteristic of the Conception</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>External or Anthropomorphic Features</td>
<td>I think you've used some magic. I think it has been sucked up. ... it goes up to the cover and sticks to it, because it wants to get out ...</td>
</tr>
<tr>
<td>2</td>
<td>Air</td>
<td>... and no air has come in there. ... then there is no air, so such molecules can appear.</td>
</tr>
<tr>
<td>3</td>
<td>Heat</td>
<td>It will be warm, the water, and then there will be rising mist. ... then it will be a bit warm, so there will come some steam.</td>
</tr>
<tr>
<td>4</td>
<td>Evaporation</td>
<td>... then the water evaporates, I think. ... then the water evaporates and goes out into the air ...</td>
</tr>
<tr>
<td>5</td>
<td>Particle</td>
<td>There are tiny water droplets that fly up and stick to the glass. ... water molecules ... they can get up in the air ... stick to the glass ... then there will be some mist ...</td>
</tr>
</tbody>
</table>

Most often the students expressed more than one conception during an interview. For example, they might focus both on air and on heat, or a focus on heat could be combined with ideas about evaporation and particles. Some students stuck to the same conception in most of the interviews but, in other interviews, combined their ideas, using more than one conception. Most often this was the case when heat or air was the main focus in the explanation. Other students showed less consistency in their explanations.

Ida began in 97-1 (7 years old), certain that it was water we could see on the cover. At first, she said that she did not know how it got there. Then she made a suggestion:

Ida: Maybe it has been, eh colder.

Interviewer: Yes, how? What happens when it gets colder?

Ida: Then it might come up here.

...  

Ida: Do you know why I guessed that? 'Cause when we bath in lukewarm water, and then let it sit for a while, we took it and poured it on ourselves, and then it is all icy-cold. That's why.

Here Ida focused on heat, although in an indirect way. She also gave her personal evidence for this. She associated the moisture with a situation where something similar had happened—while taking a bath she had noticed moisture on the mirror. But in her experience this happened towards the end of the bath when the water was getting cold. A month later in 97-2 (7 years old), she expressed another conception.

Ida: That water comes up into the air. Water from down there.
This was an example of evaporation. During the lessons, when the students were 6 years old, we introduced the possibility that molecules from heated fruit-syrup would go out into the air and reach our noses, explaining why we could smell it from a distance. Although the students participated in the lessons, few of them used the term, molecules, when explaining the moisture on the glass cover. A year later, in 1998 (8 years old; after listening to her own interview in 97-2), Ida was one of the first students to talk about the possibility of molecules:

_Ida_: Perhaps it's molecules.

_Interviewer_: Molecules? What is that?

_Ida_: It's small water droplets.

_Interviewer_: What is it that we see up there then?

_Ida_: Water droplets.

_Interviewer_: Water droplets? We don't see any molecules?

_Ida_: No.

_Interviewer_: No. Why not?

_Ida_: It can be ... very many.

Ida used a molecule concept and the fact that molecules came from the water to explain why some of the water had travelled all the way to the cover and stuck to it. Another year later, in 99-2 (9 years old), she expressed the same view, but it became a bit more elaborated.

_Ida_: Eh, the water down there, it ... when it is left alone, then it becomes molecules. And since the glass cover is there, it stops it from coming out into the air. So then the molecules will stick to the cover. So in the end we will see them, when there are a lot of them.

Why did Ida think the way she did? At first, we speculated about the impact of our teaching sessions. But the following year, in 2000 (10 years old; after listening to herself in 99-2), she responded with her own idea:

_Ida_: I think it is the same. 'Cause our teacher in second class, she had a glass jar with a plastic like this on, yes, and also she had one without. And so she had water in them.

Here Ida was quite explicit about what had formed her view of this phenomenon. In 01-1 and 01-2 (11 years old), she gave the same kind of explanation, showing that the view that molecules were the chief agents was a well-understood and integrated conception of hers. She seems to have been receptive, adopting ideas at school that she found meaningful. It also appeared to be the case that the concept of molecule was something she had learned in school and that it had not been introduced by her parents, neighbours or playmates.

Now Lars. He also thought that there was water on the cover and associated it with a phenomenon that produced the same kind of moisture. Lars talked about getting into a car when it was cold or rainy outside and seeing moisture being formed on the inside of the windows. But his explanation about why and how the moisture moved to the cover was much more complicated. In 97-1 (7 years old) he said:

_Lars_: The plate was cold and the water was warm, a bit warm, and then the warm went away up to the cold.

But in 97-2 (7 years old), he said that the moisture was bubbles of air. He gave his explanation in the 1998 (8 years old; after listening to 97-2) interview:

_Interviewer_: What do you think ... why ... where do you think you got that idea from?
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Lars: I don’t know … Yes, I think I know … so that they would lift and go up, perhaps.

In the same interview, he said that water molecules coming from the water stuck to the cover, and he explained why he thought this way.

Lars: ’Cause when we took snow inside it melted … and after every day the water shrank. The last day it had totally disappeared. There was only dirt left … after the snow. Just like chalk molecules.

The teacher told the children that there were water molecules in the air all over the classroom. In subsequent interview sequences, Lars gave the same explanation, and in 99-1, 99-2, and 01-1, he referred to the same experience. Observing snow turning into water and evaporating had made a great impression on Lars. He returned to it year after year, and it formed the basis for his explanation that molecules came from the water and went up into the air.

In 97-1 (7 years old), Jenny said that there was water, or that the water had ‘gotten old’ on the inside of the cover. In 97-2 (7 years old), she said that there was water or air. In the rest of the interviews, she used different words, such as steam, mist, and vapour, but it was clear that she meant that there was water on the cover. In 97-1, she provided the following descriptions:

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 can’t breathe then. Then it has become like that up there. It has gone old and so. It has flown away.

Jenny used the idea of water movement in her first interview. She made an association to an earlier experience, observing a burning candle and a glass that was put over it. Jenny’s explanatory theme became one of suffocation. Just like the burning candle, the water trapped inside the glass would choke, and in trying to escape, it would rise. She referred to this theme throughout the years, even though it was not explicitly mentioned in every interview.

In the interviews in 1999 (9 years old), Jenny made reference to steam, and the explanations involved evaporation, even if she did not use that word. In 99-1 she commented,

Jenny: It’s water, and steam comes from water. Yes, because it comes up here and it is steam then, water steam.

In 2000 (10 years old), Jenny was talking about small, small droplets of water that we could not see but that could be in the air. In 2001 (11 years old), she also mentioned heat, but focused mainly on air or oxygen, stating that the water ‘want[ed] to get out.’ In 01-1, she expressed these ideas together:

Jenny: Yes, I think … yes it is water, well, when it gets so warm or when it is covered with air then it goes up, well, there it is the same, I think it is oxygen … oxygen can’t get out so it (water) goes up to the cover and gets stuck because it wants to get out.

In 01-1 and 01-2, she mentioned heat but did not suggest that heat was causing the water movement. The heat caused the water and/or the air to want to get out, but it was the desire or need to get out that caused the movement. When we opened up the system in 01-2, Jenny commented,

Jenny: It goes up in the air.

Interviewer: Water can go up in the air, then?

Jenny: Mm … small, small, small water molecules, I think.

In 2000 (10 years old), Jenny used the phrase ‘small, small droplets’ to explain the phenomenon. In 2001, she used the concept, water molecules for the same purpose.

In the first interview, Jenny explained water movement with the idea that the water chokes. In all of Jenny’s explanations, air played an important role. Many of the students made reference to
air, but it was only Jenny who mentioned the theme of breathing and suffocating in most of her interviews.

Trends and themes raised by the interviews

In the preceding sections, we met three students and saw the way each explained the different phenomena. In this section, we attempt to delineate general trends that appeared when we compared students through time and across situations. We frame these trends by showing how each person used evidence in her/his explanations to support her/his view, as well as to show how each used the molecule concept we introduced in 1997.

Ida was, on the whole, not willing to give explanations if she did not feel confident that she was correct. This can be seen in her responses both to the candle task and to the leaves task. She appeared to be a receptive girl, and referred to things she experienced when she was taught in school, as well as to some experiences outside of school. The molecule concept was something she has met primarily in school, both during lessons and during the teaching sessions for this project. She used it early on to explain the evaporation phenomenon, where it helped her to explain something that was not directly observable. She also used it about a year later, to explain what happened to the burning candle by analogy what she understood of evaporation. But she did not find any use for it in explaining the decomposition of leaves. The same use of the molecule concept was reported by Stavy (1995) for lower secondary children, who referred to it, after introduction in class, mainly to explain events involving gases, rather than liquids or solids. Stavy also noticed that the use of molecules in interview tasks could lag more than a year or so behind the actual teaching taking place. This may have been the case with Ida too.

Lars was a very verbal person who had vivid experiences, which he referred to in his explanations. These experiences were mainly from outside of school, with the exception of the melting snow. The melting snow activity made a lasting impression on him and he brought it up in all the interviews in the years to follow. Lars used the concept, molecule, to explain the formation of moisture particles, but he did not find any use for it in explaining the disappearing wax. On the contrary, he seemed absorbed by the visible, macroscopic features of the flame on the wick and the melted wax. Perhaps, his conception of molecules was not integrated well enough to allow for a transfer to the situation with the candle. In explaining the decay of the leaves, he once more made reference to personal experiences from out of school. Although he made reference to experiences with animals' eating leaves, he did not link this to the formation of soil.

Jenny was unique, as in all three interview situations, she mentioned the conditions for living and the role of air or oxygen. She often spoke about matter as if it were a human being; for example, the leaves needed oxygen, the wax got old, and the water choked. She also very clearly thought that water and air had needs and desires. She was the only student, consequently, who attributed human qualities to matter. Jenny was an expressive girl who referred to experiences both in and out of school. She was clearly aware of the difference between when she understood or had a scientifically correct knowledge of things and when she was guessing or simply proposing ideas. We saw this in the 01-2 interview about the candles, where she demonstrated the view that there was a difference between what she knew about the fading leaves and the covered glass of water and what she knew about the burning candle.

The interview excerpts show examples of how one interview can help to cast light on interpretations from previous interviews. When, in 1998 and 2000, we used a metacognitive strategy for interpreting interviews (sharing the interviews with the children), we found that the students made comments that were quite useful in interpreting previous interview segments. We also noted examples of students' spontaneous use of analogy (Ida) and metaphor (Lars) to explain phenomena. These ways of using language to articulate ideas strengthened our understanding of both the continuity and the change in students' conceptions over time. It could be argued that students remem-
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bered from year to year what they had told us during the interviews. However, none of the children made any references to their prior conversations with us.

Discussion

As highlighted by Shapiro (1994), students' approaches to learning science are mediated through a variety of personal traits. In conventional cohort studies of students' conceptions, these traits are not apparent. To understand why students have difficulties understanding and adopting the particle model for explaining matter and its transformations, our research group had long felt the need to explore personal variations in conceptions, using a more penetrating data gathering and analysis procedure. A longitudinal design then became necessary to distinguish those parts of learner conceptions that were more stable from those that were more transient. In our study, we found categories of conceptions that are useful in analysing the development of individual students. Differences between individuals can be seen as differences in the types of conceptions that are dominant during different periods of schooling. For some students, one conception seems to dominate, while for others, several conceptions are considered equally possible alternatives for explaining a phenomenon.

What we found even more striking in our data was consistency in what we call a personal framing. Students often relied directly on their experiences when trying to explain different phenomena. The longitudinal approach used allowed us to see two trends in types of explanations—trends common to the group as a whole over time and trends in the emergence and persistence of personal approaches to 'framing' ideas over time. At 6 years old, the students used only very concrete causes or actions in their explanations. As they get older, their stories became richer and more detailed, and the use of associations, metaphors, and analogies increased. Across the years, explanations were most often framed in a personal setting, relating directly to some experience. The features different pupils focused upon in a specific phenomenon varied and were also a part of this personal framing. This variation seemed to be determined by formative experiences, including the stories/explanations they heard from fellow students, playmates, and the adults in their lives. Overall, we observed continuity, both in focus and in the expressions used for explaining a phenomenon.

For some students, the particle model—that is, the molecule concept—became a convenient tool for understanding evaporation; for others, it did not. For the latter, thinking appeared to be dominated by more macroscopic 'essences,' the sort of features that dominated before the scientific revolution, from the time of Aristotle to the seventeenth century. This thinking is a common sense view, which springs out of the interpretation of what we directly perceive. The children we studied relied heavily on immediate perceptions when interpreting natural phenomena and, over time, learned to appreciate the use of more complex models, such as the particle model, in explaining these phenomena—models that science teachers often take for granted. We interpret student reliance on earlier experiences and their use of analogies and metaphors as part of their efforts to understand different natural phenomena. This analysis views human knowledge as an aspect of the embodied mind (Lakoff & Johnson, 1999). From this point of view, metaphors are essential features of the natural way we come to understand any phenomenon that has some degree of complexity.

One of the aims of the study has been to investigate what impact an early introduction of the concept, molecule, can have on children's understanding of material phenomena. A general finding is that students do not use this concept unless they have use for it. It does appear to help many of them more confidently explain evaporation and condensation. We found very little use of it when students spoke about substances such as water or melting wax, or about organic matter, such as leaves. Stavy (1995) observed the same thing in secondary students.
We found that our first teaching sessions, in 1997, had an indirect effect. Very few students used the molecule concept in their explanations, but the number of superficial, descriptive explanations or anthropomorphic attributions did decrease, in favour of more science-oriented explanations. Generally, students seldom referred to our teaching sequences. Although the students’ use of the molecule concept in later interviews was not as frequent as we expected, our general feeling was that, with an elementary school curriculum that is more dedicated to discussing the roles of molecules in matter transformations, the outcome can be different.

Implications for teaching, learning, and curriculum design

Science teachers have always been very puzzled by the difficulties students in secondary school have understanding atoms and molecules. Even in teacher preparation courses, we find that students are frequently confused about these concepts (Eskilsson & Holgersson, 1999). However, Novak and Musonda (1991) reported that the early introduction of a particle model—that is, a concept molecule—can have an impact on a students’ performance many years later. This encouraged us to test the impact of an early introduction of molecules as protagonists in explanations of matter transformation.

Of course, we know that young children do not have the ability to grasp fully the complexities of molecules composed of different atoms. On the other hand, children are quite capable of learning the unfamiliar names of strange creatures (dinosaurs) that we tell them existed a long time ago, even if their view of what things were like millions of years ago is neither realistic nor scientific. In this study, we aimed at introducing agents of matter transformation through the introduction of science. We adopted our view of scientific explanation from Ogborn, Kress, Martins, and McGilliguddy (1996). Thus, we spoke of molecules as air molecules, water molecules, stone molecules, wood molecules, or even iron molecules. Strictly speaking, this is not the common scientific way of using the molecule concept, but we wanted to introduce the concept of smaller and smaller parts of matter that are in constant motion, although in a restricted sense in solids and liquids. With these ideas, we can begin to discuss matter transformation with young children. Without these ideas, such discussions are much more difficult. As scientists, we are trained to value rigorous definitions and arguments, but we believe that it is important to introduce central scientific concepts to younger students in an informal way at first. This view is consistent with a conception of learning that starts with basic-level concepts and from there moves on to more general and more detailed analytical concepts (Lakoff, 1987).

A tentative conclusion from our study is recognizing the importance of experiences that, in some way, engage students emotionally. These can be both in-school experiences—experiments, tasks, or discussions—and out-of-school experiences. Another tentative conclusion from our data is that students are highly unlikely, on their own, to discover and formulate ideas connected to chemical change. In the later interviews, for instance, many of the students knew that a flame needs oxygen to burn, but they could not explain why this was so. What happens when a candle burns or a leaf is decomposed appears to be a concept so well hidden that we need a teacher to assist us in learning it.

The kind of results described in this paper could not have been obtained without a longitudinal design. Learning is complex and involves many personal, as well as social, influences (Shapiro, 1994). If teachers are to understand their students’ efforts at making sense of science, it is essential to know about the complex ways in which students develop an understanding of science and about some of the ways individuals vary. Although some studies focus on finding general laws to explain learning, we believe that the use of categories of conceptions oversimplifies the picture. Our conviction is that more in-depth data about how individuals actually cope with learning helps us to better understand learning, particularly as the complexity of concepts increases. In our work, we found
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a longitudinal design, using the in-depth study of individuals, was very effective in capturing complexity.

Notes

1 All names are pseudonyms. All translations of participant comments are the authors’.

References


FOLLOWING YOUNG STUDENTS’ UNDERSTANDING OF THREE PHENOMENA IN WHICH TRANSFORMATIONS OF MATTER OCCUR

ABSTRACT. In order to develop successful teaching approaches to transformations of matter, we need to know more about how young students develop an understanding of these processes. In this longitudinal study, we followed 25 students from 7 to 13 years of age in their reasoning about transformations of matter. The questions addressed included how the students’ understanding of transformations of matter changed and how we can make sense of individual learning pathways. In interviews performed once or twice every year the students described and explained three situations: fading leaves left on the ground, a burning candle, and a glass of water covered with a glass plate on which some mist had formed. When analysing the interviews, we found a common pathway of how the students’ ideas changed over the years in each one of the situations. When analysing individual student’s interviews with Ausubel’s assimilation theory we could discern subordinate, superordinate and combinatorial learning. How these findings can contribute to an improvement of teaching about transformations of matter is discussed.

KEY WORDS: longitudinal study, primary education, science learning, transformations of matter

INTRODUCTION

In this study we wanted to learn more about how students actually create meaning and come to understand different phenomena in which transformations of matter occur. We followed individual students over time to see how their ability to explain and understand three different phenomena changed as they grew, had new experiences and learned more about the world. Questions concerning humankind’s survival on earth often have a connection to where different materials come from and go in processes in nature and society. Many of these processes include phenomena we cannot apprehend with our senses, such as the burning process transforming solid matter into gas and the evaporation process turning water into vapour. Students’ difficulties in understanding processes in which matter seems to disappear, as in decomposition or burning, or to appear out of nothing, as in condensation, have been well
documented in the literature of science-education research (e.g. Driver, Guense & Tiberghien, 1985; Andersson, 1990; Krnel, Watson & Glazar, 1998). Research on students’ understanding of ecological processes shows that the students’ early experiences can significantly influence their further scientific understanding of processes in nature (Helldén, 1995; 1999; 2001). BouJaoude (1991), Rahayu & Tytler (1999) and Johnson (2002), among others, have reported about the nature of students’ understanding of the process of burning. Investigations about evaporation phenomena such as those by Osborne & Cosgrove (1983), Bar (1989), Bar & Galili (1994) and Tytler (2000) show both similarities and differences in students’ understanding of different evaporation situations.

We still need to know more about how young students develop an understanding of processes, including transformations of matter. We need to know more about how they develop this understanding in different contexts. This further knowledge can help us develop appropriate approaches to teaching these concepts. To understand how a student actually develops her or his understanding in science is a complex matter. It is essential to know more about how individual students develop their understanding of these processes to really understand what supports learning and thereby to be able to develop effective science teaching. To accomplish this, long-term or longitudinal studies have been called for in the literature (Arzi, 1988; White, 2001). This study tried to meet this need by studying individual students in detail and over a longer period of time.

The questions addressed in this paper are as follows:

- How does students’ understanding of three different phenomena in which transformations of matter take place change from the age of 7 to 13?
- How can we make sense of individual students’ learning pathways?

THEORETICAL AND METHODOLOGICAL FRAMEWORK

The theoretical framework of this study builds upon the theory of 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. Novak tries to “conflate issues
that deal with the nature of knowledge construction into the issues that
deal with the psychology of meaning making” (p. 190), and he also stresses the important role of language in learning processes.

The assimilation theory (Ausubel, 2000) explains acquisition, retention and forgetting of knowledge as well as how knowledge is organised in the cognitive structure of the learner. The theory deals with school learning in the form of meaningful reception learning but we think the theory can also help us understand the development of students’ learning that occurs from lots of different experiences within as well as outside school and over a longer period of time. In the cognitive structure, there are anchorage ideas or subsumers (Ausubel, 2000). These are ideas, thoughts or concepts to which one can link new learning material. The cognitive structure consists of superordinate and subordinate segments structured in a hierarchical system. The main organisational principle is progressive differentiation, and the second subsuming principle is obliterative subsumption.

The core of the assimilation theory (Ausubel, 2000) is the idea that new meaning is gained by the interaction of new potentially meaningful ideas and earlier learned concepts and propositions. The new idea is connected by subsumption to an established idea. Both ideas are then modified and interact through retention and can become more complicated and greater than the sum of the two ideas. This process of assimilating new meanings results in progressive differentiation of concepts and propositions by consequently elaborated understanding, and it also yields a readiness to anchor further new meanings to the newly built ideational concepts and propositions. When concepts and propositions are elaborated by successive new learning processes, new and different understandings can occur and conflicting understandings can be solved by a process of integrative reconciliation. When the assimilation process goes on, the understanding of the different components in concepts and propositions can not be dissociated from the anchoring ideas and obliterative subsumption has occurred.

Three different learning processes or forms of meaningful learning can be seen (Ausubel, 2000): subordinate learning, superordinate learning, and combinatorial learning.

1. Subordinate learning or subsumption

   In concept and propositional learning, the new information most typically is anchored to more general ideas in the learner’s cognitive structure. The new information is linked to an anchorage idea either by
broadening the idea with a new example or by extending or modifying the critical attributes of the idea. In this learning process, the student’s original idea is elaborated.

2. Superordinate learning

In this case, some already established ideas are recognised as specific examples of a new, more general, and thereby superordinate idea. The new superordinate idea encompasses the already established ideas as subordinate ideas.

3. Combinatorial learning

In combinatorial learning, a new idea is related to one or more already existing ideas. The new idea is seen to have some critical attributes in common with the already established idea or ideas. The new idea is neither more inclusive nor more specific than the existing idea or ideas.

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 her or his ideas. Having concrete things present that the student can look at but also sometimes feel and manipulate in different ways is natural and quite generative when interviewing about phenomena in natural sciences. The design also provides flexibility, allowing the possibility for following up different themes raised during the interview (Ginsburg, 1997).

In this study we were interested in how the students developed an understanding of transformations of matter of different phenomena during a longer period of time. We did not have the possibility nor did we wish to document either the teaching or other experiences that the students had during the years of the study. In the interviews we used three different situations reflecting the phenomena. We presented different materials to help explain the situations to the students and we asked questions. The students then tried to understand the situations and, out of that, answer the questions. We wanted the students, led by our questions, to show us what they knew about each situation. By our follow-up questions, at least now and then, we tried to make the students see the situation through the lens of natural science and not just from an everyday viewpoint. We were interested in their everyday explanations as well as in their natural science explanations. We were interested in the change of their explanations through the years. By our follow-up
questions, we sometimes got to know what kind of experiences changed and influenced their explanations.

**DESIGN AND ANALYSIS**

In our seven-year study, we followed 25 students from 7 to 13 years of age. Table I shows an overview of the different parts of the study.

The students were all born in 1990 and started school in a middle-sized Swedish town in August 1996. The students came from two different schools: two classes from school A and one from school B.

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. In school A, most students were from working-class or immigrant families, but there were also students from middle-class families. In school B, the students were mostly middle class, with almost no immigrant population. Due to the tendency of immigrants to move more often, there has been a turnover of students in school A but none in school B. During the first years, five students left school A and two new students started in 1999. In school B, one new student started in 1999 and none has left.

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

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<tbody>
<tr>
<td>Interview 7y(1)</td>
<td>Interview 8y</td>
<td>Interview 9y(1)</td>
<td>Interview 10y</td>
<td>Interview 11y(1)</td>
<td>Interview 12y</td>
<td>Interview 13y</td>
<td></td>
</tr>
<tr>
<td>Teaching sessions</td>
<td>Teaching sessions</td>
<td>Interview 9y(2)</td>
<td>Interview 11y(2)</td>
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*aThe first number is the age of the student; the number within brackets indicates whether it was the first or second interview at that age.

bThis interview started with the student listening to the last interview from the year before.
four age-homogenous classes in the following numbers: 2, 9, 6, 8. This means there were 25 students, 13 girls and 12 boys, who participated in most of the interviews and whose interviews have been analysed. The schools are ordinary Swedish schools, and the teaching has been rather traditional. We would argue by this that the 25 students are a good sample of ordinary Swedish school students and not extreme in any sense.

In the interviews, we used three different situations illustrating different phenomena, which all include transformations of matter:

- 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

In an earlier project, Helldén (1999) showed that students’ ideas about conditions of 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 this experience in mind it seemed logical, interesting and potentially rewarding to choose the three situations above to further investigate students’ understanding of transformations of matter.

The three situations represent different contexts and very different kinds of transformations of matter. If the students were to meet these situations in their school education, it would be in biology, chemistry, and physics, respectively. In the situations with the fading leaves and the burning candle, chemical reactions occur which change some or 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 but only a change of state occurs.

The interviews were performed individually and recorded on tape. The main structure of the interviews was as follows: The student was 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, were presented. The interviewer asked, pointing at the candles: “What do you think has happened to that piece of the candle?” Lastly a glass with some water in it, covered with a glass plate on which some mist has formed, was
shown and the interviewer asked, “What do you think it is that we can see inside on the cover?” and then, “How do you think it could become like this?” Depending on the student’s answers, the follow-up questions differed. In 2000 and 2002, the students were also asked when and how they believed they had learnt about these phenomena.

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. We decided, at an early point, that in a longitudinal study of this kind (seven years and starting at such an early stage) the students would have so many experiences in daily life and school that could influence their knowledge of the examined phenomena apart from the regular teaching within the area (which during these early years is rather sparse) that it would be pointless to follow the teaching in detail.

As an earlier study of Novak & Musonda (1991) has shown that young students have the ability to use a concept of the molecule introduced early on, and that this introduction seems to benefit students’ understanding of transformations of matter, we decided to introduce the idea of the particulate nature of matter to the students in a first teaching session in 1997. This intervention was followed up in new sessions in 1999 and 2001 where we discussed situations, never the same as in the interviews, in which transformations of matter occurred. In the discussions we used the molecule 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. The findings of the students’ use of the molecule concept will not be the purpose of this paper but will be presented in a coming paper.

The interviews were transcribed verbatim and analysed according to the students’ descriptions of the different phenomena. When the data up to 2001 had been collected, four researchers analysed the material. Each phenomenon was analysed to construct categories of conceptions that the students expressed. Firstly we developed interview summaries to help us to get a better overview of the large amount of data. Secondly we constructed categories of conceptions, each researcher concentrating on one of the phenomena. Then we exchanged our findings, discussed, went back to the original data and refined the categories. We then went through the material to allow consistent coding and to insure all aspects
were covered. Through a sequence of discussions, recoding and category refinement, we decided on the conceptions shown in Table II, III and IV. As seen in Holgersson & Löfgren (2004), where the student conceptions and explanations are presented in more detail, a student usually expressed more than one conception within one interview.

More data have been collected since that paper and the analysis has progressed. As the data are rich, it is difficult to get an overview over the years for each individual and also to get an overview on the group level. What kind of similarities and differences can be seen? Conceptions vs. time diagrams for each individual and each phenomenon were made to detect the development of understanding the transformations of matter in the different situations. We analysed the diagrams on an individual and on a group level. We found that as the group of students grew older they changed their ideas about the situations, following more or less a common path. In analysing the individual students’ change of understanding about the transformations of matter in the three situations, we looked for occasions where meaningful learning in the forms of subordinate, superordinate, and combinatorial learning were seen.

### TABLE II

Student conceptions for explaining what happens to leaves left on the ground

<table>
<thead>
<tr>
<th>No.</th>
<th>Conception</th>
<th>Citations characteristic of the conception</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Just disappears</td>
<td>It is nothing left. Mm, they have blown away during the autumn.</td>
</tr>
<tr>
<td>2</td>
<td>Change due to human activity</td>
<td>They have perhaps been kicked away. ...they have become a hut of leaves that somebody has built over there.</td>
</tr>
<tr>
<td>3</td>
<td>Become soil</td>
<td>They could have turned into soil. That it becomes very, very small and then it turns into soil. When you throw them on the compost then they turn into soil.</td>
</tr>
<tr>
<td>4</td>
<td>Break up</td>
<td>They become small pieces. If someone trots on them ... they become small pieces. They blow away and they get crushed.</td>
</tr>
<tr>
<td>5</td>
<td>Rot</td>
<td>Then they rot and get old. I think it would mould away ...</td>
</tr>
<tr>
<td>6</td>
<td>Animals eat them</td>
<td>Then the worms would eat them and then they come out and it turns into soil. They mould and then the worms eat them and do a poo-poo and they have turned into soil.</td>
</tr>
</tbody>
</table>
The students on a group level showed a change in ideas as they grew older that could be described as a common track, one track for each of the three phenomena. A track is the group direction of all the students’ pathways. We present and discuss our findings by showing these tracks, illustrated by excerpts from some students, phenomenon by phenomenon. In the presentations we indicate when meaningful learning was seen. 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.

There are two aspects of 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 we 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

<table>
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<tr>
<th>No.</th>
<th>Conception</th>
<th>Citations characteristic of the conception</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A description instead of an explanation given</td>
<td>You’ve burnt more on that candle.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>It has been burning longer...</td>
</tr>
<tr>
<td>2</td>
<td>Wax runs down</td>
<td>It runs down, and then it gets a bit thicker down here.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>It melts down and get here. Then you take it away.</td>
</tr>
<tr>
<td>3</td>
<td>Wax melts</td>
<td>It melts... and it is burned in the end.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>It melts...and dries up again.</td>
</tr>
<tr>
<td>4</td>
<td>Wax gets out into the air</td>
<td>...then it becomes smoke and flies away...</td>
</tr>
<tr>
<td></td>
<td></td>
<td>...it gets up into the air too...</td>
</tr>
<tr>
<td>5</td>
<td>Signs of chemical reaction</td>
<td>The wick absorbs the wax, then wax goes up and then it burns...</td>
</tr>
</tbody>
</table>

**TABLE III**

Student conceptions for explaining the burning candle

**CHANGING IDEAS—ONE TRACK FOR EACH PHENOMENON**

The students on a group level showed a change in ideas as they grew older that could be described as a common track, one track for each of the three phenomena. A track is the group direction of all the students’ pathways. We present and discuss our findings by showing these tracks, illustrated by excerpts from some students, phenomenon by phenomenon. In the presentations we indicate when meaningful learning was seen. 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.

There are two aspects of 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 we 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.

**The Fading Leaves**

In the early (7–8y) interviews about the fading leaves, the students answered in different ways. They used expressions such as blow away, rot, break (sometimes because of people walking on them but sometimes because they dry and then go to pieces), die, fade, get wet, eaten by animals, and turn into soil. Some students also mentioned that then there will be new flowers. The descriptions of what happens to the leaves often included human activity such as treading on them or gathering them and throwing them on a compost pile. They quite often used the word ‘rot’ to describe the physical effect of the leaves changing colour.

In the next (9–11y) interviews, the students still talked about different possibilities but more and more of them included the idea that animals, such as worms, larvae, or wood-lice, eat them and then turn them into soil. They used words like ‘rot’, ‘get mouldy’, ‘molder’, and ‘decay’ but more and more as part of the process of turning leaves into soil.

---

**TABLE IV**

Student conceptions for explaining the mist on the covered glass of water

<table>
<thead>
<tr>
<th>No.</th>
<th>Conception</th>
<th>Citations characteristic of the conception</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>External or anthropomorphic focus</td>
<td>I think you’ve used some magic.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I think it has been sucked up.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>... it goes up to the cover and sticks to it, because it wants to get out ...</td>
</tr>
<tr>
<td>2</td>
<td>Air focus</td>
<td>... and no air has come in there.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>... then there is no air, so such molecules can appear.</td>
</tr>
<tr>
<td>3</td>
<td>Heat focus</td>
<td>It will be warm, the water, and then there will be rising mist.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>... then it will be a bit warm, so there will come some steam.</td>
</tr>
<tr>
<td>4</td>
<td>Evaporation focus</td>
<td>... then the water evaporates, I think.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>... then the water evaporates and goes out into the air ...</td>
</tr>
<tr>
<td>5</td>
<td>Particle focus</td>
<td>There are tiny water droplets that fly up and stick to the glass.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>... water molecules ... they can get up in the air ... stick to the glass ... then there will be some mist ...</td>
</tr>
</tbody>
</table>
In the later (12–13y) interviews, the students said that animals eat the leaves or that the leaves rot, and almost every student (but not Nils below) said, without the interviewer asking, that this will turn the leaves into soil. The students very often expressed more than one possibility, such as that some of the leaves will rot and turn into soil, some will be eaten by animals and thereby turn into soil, and some may just blow away. A few students in the later interviews showed signs of needing to understand what happens during the process of leaves turning into soil. They seemed to wonder what, in more detail, happens in the animal when the leaf turns to soil or what really happens in the rotting or moulding process. This was a question that never occurred in the early years.

If we summarise the individual students’ ideas at a group level, we find the group track illustrated in Figure 1.

Figure 1. The group track of the fading leaves

Not all students followed this track precisely. However the excerpts below show one student, Nils, as an example of a student who followed this track in a representative way.

[7y:1]
Nils: They die and they rot, then I do not know anything else.
Interviewer: What do you think happens to them when they die or rot?
Nils: They become all brown and then I do not know anything more.

[11y:1]
Nils: Well, worms had taken some and it would rot. All of it had perhaps gone rotten.
Interviewer: When you say that it rots what do you think happens to it then?
Nils: I do not really know.
Interviewer: You said something about worms too?
Nils: Yes, the worms will eat and turn it into soil.

[13y]
Nils: They will disappear.
Interviewer: When you say disappear what does that mean?
Nils: Well, it would rot or the worms take care of it.
Interviewer: And when you use the word rot what do you think happens when it rots?
Nils: ... I do not really know ...
Interviewer: Does it become anything when it rots or?
Nils: Well, it turns into soil or something like that.
Interviewer: And then you said that the worms take care of it. Does it become anything then?
Nils: Yes, soil.
In the interview at age 7, Nils used the word rot to describe the change of colour in the leaves (box 1, Figure 1). In the interview at age 11, he used the word rot and said he does not know what happens when the leaves rot. In that interview, he also mentioned the worms and that these could turn the leaves into soil (box 2, Figure 1). In the interview at age 13, both rotting and worms eating the leaves were described as a way to turn leaves into soil (box 3, Figure 1).

The first idea that Nils expressed was ‘rot’ and he stuck to this idea in all the interviews. From letting rot mean a change in colour, Nils changed the idea of rot to include the process of turning the leaves into soil. This is an example of subordinate learning. Nils, from the age of 9 onwards, said that worms or animals will eat some of the leaves and, when asked to further explain, said that this will turn leaves into soil. In the last interview, both his first idea ‘rot’ and his second idea ‘worms eating’ led to the same result ‘leaves turn into soil’. He has related his original anchorage idea ‘rot’ to the newly learned idea ‘worms eating’; both ideas turn the leaves into soil, but neither of them is more inclusive nor more specific than the other. Here we see an example of combinatorial learning.

As in Helldén’s (1995) study, we found that most students see soil as the end product of the decomposition of the leaves. The students were quite satisfied with descriptions and explanations like the ones above, and they were not challenged by the situation and/or our questions to go further. In this situation we had an end product and this was enough to satisfy most students’ understanding of the phenomenon. But it is interesting to note a dissatisfaction in the later interviews. In this context, we saw a lot of examples of subordinate learning in concept and propositional learning, and there were also many examples of combinatorial learning in our individual student pathways. The students often, already at the age of 7 or 8, had an anchorage idea which could be elaborated through new information or related to newly learned ideas.

**The Burning Candle**

When the students talked about the burning candles in the early interviews, they said that the wax in a burning candle runs or melts and that this means the candle gets shorter. Some of the students said they did not know what had happened.

As the years passed, most students began their explanations of what happens by saying that the candle runs or melts, but more and more they
also said that the wax goes into the air as smoke, gas, or steam. Some students used molecules in some way as part of explaining the process. In the later interviews, a few students expressed the idea that the burning wax may transform into other kinds of matter. Most of the students said the melted wax goes into the air, but most of them said they did not really know how and why. In this situation there was a more obvious change in most students’ understanding of the phenomenon than in the situation with the leaves. The track found in this situation is shown in Figure 2.

Inger is a student who illustrates most aspects of the track mentioned above as we can see in the interview excerpts here.

[7y:2]
Inger: It has been running and then got stuck in the candle.
Interviewer: And where is that part of the candle now?
Inger: It has been running and it has been running that much that the candle has got thicker.

[11y:1]
Inger: When it burns I think that it does not turn to steam but that it evaporates in some way and then it disappears, because I know it disappears up in the air for instance. But I do not really know what it is called because evaporate that is water, is it not? I have planted such seeds of avocado and so with toothpicks and then the water evaporates.
Interviewer: And it is something like this that happens here, you think, that it disappears in the same way or in a way like that.
Inger: Yes, it gets warm and heat does rise.
Interviewer: So it has gone out in the air in some way, you think?
Inger: Yes.

[13y]
Inger: In some way it burns and melts and smoke comes up. I do not really know but it must change, not all the wax, but in some way it must transform so that some of it goes up just like smoke or something when it melts.

For the first three years, from the age of 7 to 9, Inger talked a lot about the wax running down, but in some of these interviews, she also talked about the wax melting and she tried to explain where the wax goes (box 1, Figure 2). If the wax melted, it could go into the candle. She seemed to have an idea of conservation of matter (and probably even if it was not articulated this was her anchorage idea) already from the first interviews. From the age of 11, she claimed that the wax goes into the air (box 2, Figure 2). Inger used the word ‘disappear’, but it is quite clear she did not mean that the wax disappeared into nothing, but the word was used to say that the wax could not be seen.
Inger tried to connect knowledge and experiences from other areas as well as from the burning candle to understand how the process of wax going into the air is possible. Inger used her previous experiences in her explanations of the burning candle. She referred to things that happened and things she has been told both at home and in school. In the interview at age 11, she used both her idea of ‘wax going into the air’ and the new idea of ‘evaporation’ (combinatorial learning). We can also see how she tested and thereby elaborated her understanding of the idea of ‘evaporation’ (subordinate learning). She was obviously using things she knew, and she tried to connect these to her thoughts and explanations. In Inger’s interview as a 13 year old, she introduced a new idea that “wax can in some way change or transform when it burns and melts”. This new idea explained why the wax can go into the air and do so without us seeing it (box 3, Figure 2). We believe this could be a productive new idea which could be elaborated into the idea of chemical reaction.

The students had a lot of experiences of candles burning, but when we asked what happens to the piece of candle that has ‘burned down’ this was a new and challenging question. The concrete observable experience is that the wax disappears. The students did not seem to believe that the wax really disappeared into nothing but were more inclined to think that the wax would go into the air. They then had to explain how the melted wax can go out into the air without us seeing it. To explain this invisibility they either used the introduced molecule concept or, as also seen in Rahayu & Tytler (1999), connected the disappearing wax with an evaporation idea. In this situation, there was no visible end product of the chemical reaction, and this challenged the students’ understanding of the phenomenon.

Also in the interviews in this context we found a lot of examples of subordinate and combinatorial learning in concept and propositional learning. To begin with, the students focused on different things but most of them came to the conclusion that wax in some way rises into the air.

Figure 2. The group track of the burning candle
This idea was often used as an anchorage idea and could be elaborated to increase the understanding of the phenomenon.

*The Covered Glass of Water*

Almost all the students said that it was water on the cover already in the first interview. When asked how this could happen, some of them said that they did not know. Some of them would not give any answer at all. Others suggested that we had manipulated the situation in some way, for example by shaking the glass. There were a few who said that the water rose because of the lack of air or because the air could lift the water. A few students declared that they knew that if the water was hot it would rise.

In the next interviews, more and more students used air or heat or both in their explanations of the phenomenon. As the years passed, it was more and more common for students to use the word ‘evaporation’ to explain the situation. In explaining this situation, the students fairly often used the word molecules. Mostly the students used more than one of the ideas mentioned above during an interview. They combined, for instance, the idea of air with the idea of heat, or combined the idea of heat with the ideas of evaporation and molecules.

When they got older, the students seemed to need an explanation of why we could see the water again as water droplets inside the cover. Even if they were not familiar with the word ‘condensation’, the idea of condensation was there. In the later interviews, many students also used their understanding of evaporation and/or the molecule concept to explain the water movement’s invisibility. The group track is illustrated in the four boxes in Figure 3.

If we look at interviews from the different students, we cannot strictly find the track within one individual. Sune is an example where most of the track could be seen, as the excerpts below show.

[7y:1]

*Sune: This is what I think it becomes warm water and then it becomes mist. That is there is no air. It is no air in there.*

![Figure 3. The group track of the covered glass of water](image-url)
Sune: But the water evaporates and now when you have put a cover on top then the water, what is it called, the water things put themselves on the cover. It is like mist. And the water molecules [mixes the word], I think they are called, put themselves up there.

Interviewer: Yes.

Sune: It is water that evaporates. It becomes vapour and the thing up on the cover are water molecules ...

Sune in his first interview at the age of 7 mentioned both the absence of air and the importance of heat when trying to explain how water could change places (box 2, Figure 3). In the interviews when he was 9 Sune mentioned water molecules as part of the explanation of the phenomenon. As seen above, Sune used both the concepts of evaporation and molecules (box 3–4, Figure 3) in the interview at age 10. In the interview at age 13, he seemed to be quite aware of the connection between evaporation and vapour. The molecule concept also seemed to help him understand the process of condensation (box 4, Figure 3). The idea of ‘heat’ was important in all the interviews. To Sune this seemed to be an anchorage idea which was linked to the idea ‘molecules’ without either of them being more inclusive or specific than the other, but both of them explaining the moving water. This means a new example of combinatorial learning. Sune learned the word ‘evaporate’ and combined and elaborated this concept with the ideas ‘heat’ and ‘molecules’. At the age of 13, the new ‘evaporation concept’ was linked to the established ideas ‘heat’ and ‘molecules’ and became a superordinate idea, indicating that superordinate learning has occurred.

The students in this context used ideas like ‘heat’ and ‘lack of air’ as anchorage ideas. We found a lot of examples of subordinate and combinatorial learning in the interviews and some examples of superordinate learning in concept and propositional learning. The different states of water—ice, liquid, and vapour—were known to the students from an early age. The word ‘evaporation’ became familiar to the students, and they had ideas about what causes evaporation. In contrast, none of the students used the word ‘condensation’ although they talked about the effects of it. In this situation, as well as in the other situations, there was an invisible part and there was, as in the situation with the leaves, a visible end product (mist). In contrast to the leaves, the visible end product is the whole result of the transformation of matter. It is the invisible part of the transformation that needed to be explained and
a lot of students used the introduced molecule concept to explain this part of the phenomenon.

MAKING SENSE OF INDIVIDUAL PATHWAYS

The analysis of the individual students’ responses to the interview questions showed that there was a strong personal flavour to the way students developed understandings of transformations of matter for the three different phenomena. The unique individual changes in understanding depended on the student’s personal experiences, language resources, and ability to reason. Without the longitudinal design, it would not have been possible to make sense of the individual pathways, and they would perhaps not even have been apparent. As we saw from the excerpts, there were students who elaborated an early idea as Nils did with the idea of rot, there were students like Inger who made connections to other situations in trying to make sense of what happens, and there were students who learned new concepts and elaborated the meaning of them as Sune and Inger did with the concept of evaporation.

Some students referred to daily experiences and were able to use these experiences in order to elaborate their ideas. Inger (8y), for instance, in the situation with the fading leaves, associated the leaves with other material she had also seen fade: “They perhaps turn into soil just like apples and such things.” Ruben (10y) made associations with human beings growing old: “Yes, they fall off the trees. Then they grow old like people but they grow old faster.” Maria (12y), in the situation with the burning candles, made an association with human beings: “But then I thought that perhaps... We, people need energy to function and oxygen. Perhaps the candle also needs energy and oxygen.” Gunnar (9y) made a connection to mist on the windows in a car: “It is like when you drive a car. Sometimes it gets stuck ... you drive and such things appear.” Hedda (13y) referred to an outdoor experience: “If it is outside in a puddle it evaporates.” All these experiences and associations helped students in developing their understanding of the phenomena as far as the students used them when elaborating their already established ideas.

But there were also students who did not seem to integrate what they had experienced with their ideas. In the excerpts below we follow Nancy talking about the fading leaves. Nancy had had concrete experiences of leaves with holes, and she had seen worms on leaves.
Interviewer: What happens to the leaves when the worms come?
Nancy: Holes.

[11y:1]
Nancy: Some worm had perhaps eaten the leaves.
Interviewer: What happens then?
Nancy: There is a hole in the leaf and perhaps there is no leaf if it eats the whole leaf.
And then yes ...
Interviewer: What does become of it then when the worm has eaten it?
Nancy: Well, then it becomes full of holes.

[13y]
Nancy: They will be eaten.
Interviewer: Who would eat them?
Nancy: Small animals ... worms ... insects.
Interviewer: If they eat them what happens then?
Nancy: I do not know.
Interviewer: Could anything else happen to the leaves?
Nancy: They could perhaps turn into soil.
Interviewer: How could they turn into soil, do you think?
Nancy: Well, perhaps they are drawn down into the soil.

In all the interviews, Nancy focused on the change of appearance of the leaves or the change in their position. The experiences she had had did not become tools to broaden or elaborate her ideas, and she did not seem to be aware of or curious about the process of turning leaves into soil. Nancy then becomes a student for whom no meaningful learning has occurred, and we can explain this as her incapability of connecting her experiences to already established ideas.

When the students in the interviews in 2000 and 2002 were asked which situations they themselves remembered as learning situations, we got an insight into their own experiences of learning situations. Without the longitudinal design which gave us the possibility of letting students listen to earlier interviews and reflect on learning situations, we would not have gained this knowledge. Our results show that the students referred to early school experiences in the situations of the fading leaves and the covered glass of water as in an excerpt of Julia (12y): “We were out in the woods quite often earlier in school. Then we followed what became of the leaves and how it worked and so on”, and the one from Maria (12y): “When I was in the ‘3–5 class’ I did some research about water.”

The students also quite often referred to experiences with their families, as Inger (12y): “It is a lot from daddy.” They also claimed, as Gunnar (12y) did, that they had “heard and asked and seen”. The students also claimed that they had learned about the different situations
from reading and from television. In the situation with the burning candles, they did not mention school or family but claimed that it was mostly our questions that made them realise the problem of the situation. In an everyday context, this is not a situation which leads to questions about the disappearance of material. Many of the students, as Jenny [12y], also claimed that this situation was difficult to understand and that they did not really know what happens with a burning candle:

_They are difficult. Well, I have no idea but ... it is like some of it runs down the candle here but then it also disappears but ... I think the heat, yes that I could think, the heat that is oxygen. I do not really know but I think it disappears up in the air and become small, small molecules, I almost think._

The early concrete experiences were remembered, and the learning gained in these situations could be elaborated and reflected on later. These kinds of concrete learning situations seemed to be less frequent as school went on. The connections between what was learnt in school and the descriptions and explanations of the interview situations were less common from the later years. This does not have to indicate that no such learning situations were present but could be explained by the difficulty of reflecting on situations which are close in time. As we plan to follow the students for another three years, we will be able to examine this in more detail at a later stage because of the longitudinal design.

We have seen Jenny claiming that she did not understand the situation of the burning candles and that she found it difficult to understand. If we look back at the excerpts from the interviews with Inger about the burning candles, we notice that Inger’s awareness of understanding or not understanding the processes increased as she grew older. Not all students come to such awareness, but we can see it in more students as seen by the examples below:

Astrid [13y] about the fading leaves:

_It probably rots in some way and then slowly turns into soil, I do not really know how but ... in some way it is like this._

Jenny [13y] about the covered glass of water:

_The water rises because it needs air. But I actually do not know how it rises because one cannot directly see when the water rises. I do not know, I do not understand why the water needs air. No, I think it feels as if it is because it (the cover) suffocates the glass ... and then obviously the water wants to rise, ... they will be drawn to it (the cover)._
These kinds of awareness and the signs of the need to understand what really happens in the processes did not occur in the earlier years but seemed to be a feature of development. Because of the longitudinal design, we know the students’ way of talking, and these differences are thereby noticeable.

**LEARNING AND DEVELOPMENT: GENERAL ISSUES**

In our teaching sessions, we introduced a simple molecule concept in order to make it possible for the students to use the idea of the particulate nature of matter when developing their understanding of the transformations of matter. We have seen that these students did not use the molecule concept in the situation with the fading leaves but in the candle and water situations. The molecule concept seems to be a productive tool for dealing with the gaseous state in both the candle and water situations. The students used the molecule idea as an intellectual tool, only insofar as it was useful for solving or clarifying some conceptual problem, for instance how wax goes into the air, or how water becomes invisible water vapour. The idea offers a fruitful model for breaking down or transforming something into invisible things. In the situation with the fading leaves, the invisible parts of the process were not noticed by the students, as in this situation there is an end product, and this satisfied most of the students at least up until the later interviews. This might explain why the students did not use the molecule idea in this situation. As already mentioned, the students’ use of the molecule concept will be presented in a later paper.

One conclusion from BouJaoude’s investigation of 1991 was that students, aged 13–14, based their understanding of different burning situations on the concrete and observable changes that took place. Rahayu & Tytler (1999) notice a high proportion of “simple descriptions” from 12 year olds concerning a burning candle, which they interpret as being due to the fact that students are very familiar with a burning candle, and therefore take the question to refer to the object. We found that in all situations, especially to begin with, the students based their understanding and explanations on the concrete and observable changes that took place in the different situations. Our findings confirm in a way that the more familiar the students were with the situation, the more simple descriptions they gave. But we also found that by coming back and asking the same questions year after year,
trying to challenge the students with follow-up questions, they were more and more willing to change their descriptions to explanations using experiences and knowledge they gained through the years. The students in our study at the age of 13 explained, in some way, the invisible parts of the phenomena in the candle and water situations but not in the situation with the leaves.

The conservation of matter has been discussed in and been the focus of many studies (e.g. Osborne & Cosgrove, 1983; Andersson, 1990; Bar & Galili, 1994) since Piaget & Inhelder (1974) claimed that this was an idea that young children could not grasp. In our study, different students in all three situations now and then during the years said that matter disappears. When then asked to further develop their answer, it was mostly quite clear that they did not think that matter really disappeared, but they used the word ‘disappear’ for matter they could not observe with their senses. BouJaoude (1991) claims that the students in his study did not focus on the conservation of matter, it was not an issue to them. Tytler (2000) claims: “From an adult perspective, these children do not conserve. From the child’s perspective the question is not particularly pertinent.” (p. 461). Our results confirm these findings, and we claim that very few students even at the age of 7 really think that matter in these situations disappears into nothing.

When looking at the interviews from one student from one of the situations (in principle, it does not matter what student or what situation) and comparing them over the years, we can notice three things, as in the examples from the presented students. Firstly, the student increased her or his domain-specific knowledge and was able to use this knowledge to build up a narrative that became increasingly rich in content. Secondly, a student very often has a personal idea that is used as an anchorage idea. This personal idea returned in more or less every interview even if new knowledge and experiences were used in parallel or integrated with the idea. Tytler & Peterson (2005) and Helldén (2005), also in longitudinal studies, have identified similar features of change and continuity in students’ knowledge processes. Thirdly, in the later interviews, the students seemed less satisfied with just a description of the situation but seemed to demand more of an explanation in order to be satisfied with their own interview statements. This demand also seemed to raise new questions which could be used either by the student or by a classmate or teacher to increase understanding of the phenomenon.

We would also argue that by following the same students over a long period of time, we became aware of the individual students’ meaning of different words and concepts, which increased the possibility of really
understanding the students’ explanations and of avoiding, to a large extent, interpreting wrong meanings into a student’s single word or expression. There was a coherent pathway through the years, for each student, through which we could trace phrases and ideas and the way they were transformed. Thus, we were able to match these findings with the Ausubelian framework in ways that have not been possible, for instance, in cross-sectional research designs.

CONCLUSIONS AND IMPLICATIONS

In this study, the students’ discussions were more sophisticated and confident in the later interviews than in the earlier ones. The students used more domain-specific knowledge and combined more elements and ideas than in the earlier interviews. This also seemed to raise more questions for them, and they realised that there were new problems still to be solved. They themselves seemed to demand richer explanations for everyday situations. The study shows that young students have personal ideas which influence their learning and also that these ideas can be used as anchorage ideas. Some students did this by themselves, others seemed to need more support to be able to use them in a productive way. Using the growing demand for richer explanations of everyday situations and the students’ personal ideas could provide a productive teaching opportunity for improving students’ understanding of transformations of matter. We suggest this could be done by using everyday phenomena and creating an atmosphere that gives students opportunities to talk about, investigate, and discuss their ideas in different challenging situations.

To develop understanding of the meaning of new concepts goes well beyond using them correctly in one situation. Developing an understanding of complex and abstract scientific concepts takes time, and the concepts have to be elaborated and used in many different situations and need to be tied in different ways to personal meanings and representations. The implications for teaching are that we have to introduce scientific ideas early to make it possible for students to connect them to already established ideas and to elaborate their understanding of the ideas gradually.

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REFERENCES


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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. In 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 seems to 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’ aged 13–14 years)—the ‘whole’ theory is introduced and the teachers claim it is an important area on which a lot of time is spent through school Years 7–9 (Oscarsson & Jidesjö, 2005).

Andersson (1990), in a review of published studies of students’ conceptions of matter and its transformations, summarises 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, b). 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 whether 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 as follows:

- 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; and
- 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 10-year longitudinal study starting with students aged 7 years and following them throughout the compulsory school. In the study we have accomplished the interviews and interventions presented in Table 1.

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 emphasise 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 programme 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 years are age-group integrated; that is, they consist of about equal numbers of students aged 6, 7, and 8 years, or students aged 9, 10, and 11 years. 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 into small groups and mixed with other students from classes of their old schools but also from new schools. The students ended up in four age-homogeneous classes. In 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 in 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 are 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 years, 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

<table>
<thead>
<tr>
<th>Year</th>
<th>Year Interviews and Interventions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>Interview 7y:1(^a), Interventions, Interview 7y:2</td>
</tr>
<tr>
<td>1998</td>
<td>Interview 8y, started with listening to the 7y:2 interview</td>
</tr>
<tr>
<td>1999</td>
<td>Interview 9y:1, Interventions, Interview 9y:2</td>
</tr>
<tr>
<td>2000</td>
<td>Interview 10y, started with listening to the 9y:2 interview</td>
</tr>
<tr>
<td>2001</td>
<td>Interview 11y:1, Interventions, Interview 11y:2</td>
</tr>
<tr>
<td>2002</td>
<td>Interview 12y, started with listening to the 11y:2 interview</td>
</tr>
<tr>
<td>2003</td>
<td>Interview 13y, Interventions</td>
</tr>
<tr>
<td>2004</td>
<td>Interview 14y, this was a small group interview</td>
</tr>
<tr>
<td>2005</td>
<td>Interview 15y, started with listening to the 11y:1 interview</td>
</tr>
<tr>
<td>2006</td>
<td>Interview 16y, this ended with prompting a molecule concept</td>
</tr>
</tbody>
</table>

Note: \(^a\)For example, interview [7y:1] means it is the first interview conducted when the student is 7 years old.
interventions in spring 1997 when the students were 7 years old. These first interventions lasted for about 20 min 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. They studied the tiny bits and we asked whether 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 40 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, dramatised molecules in ice, water, and water vapour; and in 2001 we presented the idea that, for a burning match, 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 to demonstrate and discuss similar situations to those 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 transforms, 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 first 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 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 is 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 on 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 that change, in the first situation some of, 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, Helldén (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 you think today?'

In the 2006 interview 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
How Students Use a Molecule Concept

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 categorised 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 recognise 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 recognise the evaporation and condensation processes in the situation with the covered glass of water. We would expect some of the students to recognise 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 for molecules. We 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 categorising the individual students’ answers, we have had discussions within the research group and with an external researcher. It is difficult to categorise 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 has helped in the categorisations 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 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 judgement 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 years old. 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 these two parts.

### Students’ Use of the Molecule Concept at Age 16 Years

#### Four Categories of Answers

When analysing the interviews at the age of 16 years 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 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, 16 years old, 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 that are short, as the next example shows:

[Hedda, 16 years old, 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 categorising 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, 16 years old, 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. Since 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. Contrary to students in the D category, the students do not use the idea of molecules in perpetual motion, gaining and losing 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 categorised into the C category who say (without any explanation) that molecules can turn to other molecules.

There are then 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, 16 years old, 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 moulder?
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 illustrate category A:

[Hilda, 16 years old, 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: No distinction between molecule and substance.** 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: Scientific facts used in a non-productive way in relation to the described situation.** 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: A molecule concept used in a productive way as a small part of the substance.** A good one-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.

**Outcome of the Categorisation**

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. Table 2 presents the outcome of the categorisation of the students’ answers in the different situations.

From Table 2 we see that there are about the same amount of students 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 category 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.

<table>
<thead>
<tr>
<th>Category</th>
<th>Covered glass of water (number of answers)</th>
<th>Burning candles (number of answers)</th>
<th>Fading leaves (number of answers)</th>
<th>Total for category</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>21</td>
</tr>
<tr>
<td>B</td>
<td>3</td>
<td>6</td>
<td>5</td>
<td>14</td>
</tr>
<tr>
<td>C</td>
<td>10</td>
<td>5</td>
<td>7</td>
<td>22</td>
</tr>
<tr>
<td>D</td>
<td>4</td>
<td>5</td>
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<td>12</td>
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<tr>
<td>Total</td>
<td>23</td>
<td>23</td>
<td>23</td>
<td>69</td>
</tr>
</tbody>
</table>

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

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 into the air and that it is not part of the burning process.
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Of the five students in category D in the situation with the burning candles, only one 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, 16 years old) or because of leaves being ‘green and then there are more living molecules’ (Jenny, 16 years old).

From the final column in Table 2, where the answers from the three situations have been summarised, 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 years, 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 there is 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 categorised in the B category and this student’s answers in the other two situations could be categorised in any of the four categories.

Insights from the Longitudinal Study

In this section we shall start by comparing the results in the age 16 years 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–D students. We will present one B student, one C student, and one D student as examples of what is achieved within the circumstances present in this study. Finally, we will show examples of how the students have used a molecule concept before formal teaching occurred, and make some comments in connection with 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 one-half of the students in category C and category 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 category B have used the molecule concept in about one-third of the earlier interviews. Students from category C have used the concept in one-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 category D. Gunnar from category D does not use the concept spontaneously in the interview at 16 years of age 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 category 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, thereby making the candle last longer. In the analysis forming the categories A–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 years, 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 mentioned previously, most \((n = 14)\) students’ answers do not fall into the same category in the three situations but there are three students in category A, two students in category B, three students in category C, and one student in category 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 shall now follow Paul in the water situation, showing his awareness of learning new words as a part of his learning process. At 7 years of age Paul understands the situation through some kind of manipulation with the glass. At the age of 9 years, 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 11 years:

```plaintext
[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 15 years, Paul goes on in the following way:

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 vaporised. (Paul, 15 years old)

Now he uses new words such as condensate (probably mixed with evaporate) and vaporise. 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 16 years of age, we can again notice how he enjoys using new words and showing his knowledge:

[16 years old]

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 whether he believes that oxygen atoms can pop off or whether this is an answer given ‘in the minute’ without much thought.

We have seen in the earlier excerpt (about fading leaves, at 16 years old) 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:

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. (Jenny, 7y:1)

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:

[16 years old]

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 in 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 age 16 years interview. When asked about this in the age 15 years 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 realised 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 earlier quote (age 16 years). From the following excerpts we can see how Gunnar 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 that started in autumn 2003. In the following excerpts we shall see two other examples of students in the D category using a simple molecule concept in order to explain the evaporation process:

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. (Sune, 10 years old about the covered glass of water)

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. (Katja, 11 years old about the covered glass of water after having taken the lid off)

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 years. 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, before formal teaching of the concept:

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. (Hedda, 11y:2 about the covered glass of water)

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:

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. (Inger, 11y:2 about the covered glass of water)

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’:

I do not really know but I think it (the candle) disappears up in the air and becomes small, small molecules, I almost think. (Jenny, 13 years old 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. (Katja, 13 years old about the candle situation)

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 from this study. We can only establish this difference and speculate about what could help 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 whether 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; and 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 age 16 years interview. Only in one-fifth of the answers do 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 manage 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 is still worth considering and reflecting upon:

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)

Almost one-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 are 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 age 16 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 the present 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.

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

References
L. Löfgren and G. Helldén


In this paper we present results from a 10 year longitudinal study with the aim to investigate how students use experiences when they develop their ideas about decomposition, burning, evaporation, and condensation. The theoretical framework of this study builds upon social constructivist perspectives. In our study (1997-2006) we have followed 23 students all born in 1990. We have conducted interviews allowing the 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. Most students make progress in describing and explaining the situations in the first years of the study. Then there is a vast spread in the students’ capability to use their experiences and science taught in school in productive ways to improve their understanding of transformations of matter. We discuss the implications for science education research, compulsory school science curricula, and school science education out of these findings.

Introduction

The results reported in this paper are part of a broader project (e.g. Helldén, 2005; Holgersson & Löfgren, 2004; Löfgren & Helldén, 2008a; 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.

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, Guesne & Tiberghien, 1985; Krench, Watson & Glazar, 1998). Students’ ideas about transformations of matter in decomposition are highly related to their limited conception of the gaseous state (Helldén, 1995) and also include phenomena such as burning, evaporation and condensation (Helldén, 1999). Therefore in this study we wanted to learn more about how students actually make meaning and come to understand
transformations of matter in decomposition, burning, evaporation, and condensation.

In the study presented in this paper we wanted to more deeply look into the students’ use of their experiences, both from school and everyday life, when developing their understanding of transformations of matter in some different situations. The aim of the study is to investigate:

- how students use previous experiences when they develop and express their ideas about decomposition, burning, evaporation and condensation
- how students talk about their own learning when given the opportunity to listen to earlier interviews.

**Methodology**

The theoretical framework of this study builds upon Human Constructivism formulated by Joseph Novak (1993). This perspective underlines the unique interplay that occurs between thinking, feeling, and acting in human learning 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. Building upon this means that students gradually, in social cooperation with classmates, friends, teachers, and other grown-ups, elaborate the meaning of concepts. This perspective also makes it possible to use interviews in order to find out about students’ ideas.

In our study (1997-2006) we followed 23 students all born in 1990. In spring 1997, 1999 and 2001 we had teaching sessions. Inspired by Novak and Musonda (1991) we already in 1997 introduced the idea of the particulate nature of matter by introducing a simple molecule concept to the students. From autumn 2003 the students had more conventional lessons in biology, chemistry and physics. We conducted interviews at least ones every year allowing the students to explain the transformation of matter in three situations. The students were interviewed 14 times. More details about the teaching sessions, interviews and student sample can be read in Löfgren and Helldén (2008b). The three situations asked about in the interviews were:

- 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.

Helldén (2003) has shown that students often can shed light on their own statements by being allowed to comment on them at a later time. We therefore in the interviews 1998, 2000, and 2002 let the students listen to the last interview from the year before and they were then asked to comment on their ear-
lier statements. In 2001 the students listened to and commented on the second interview from 1999. In 2005 the students listened to and commented on an interview from 2001. In the later interviews the students were also asked if they knew what had changed their ideas about the phenomena.

The main structure of the interviews was: The student was 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, were presented. The interviewer asked, 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, was shown and the interviewer asked, “What do you think it is that we can see on the cover and how do you think it could become like this?”

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 leave 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 14 times through the years. All these interviews have been tape-recorded and then translated verbatim.

Table 1: Overview showing the interviews and teaching sessions that each student has attended

<table>
<thead>
<tr>
<th>Year</th>
<th>Interviews and teaching sessions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>Interview 7y:1; Teaching sessions; Interview 7y:2</td>
</tr>
<tr>
<td>1998</td>
<td>Interview 8y, started with listening to the 7y:2 interview</td>
</tr>
<tr>
<td>1999</td>
<td>Interview 9y:1; Teaching sessions; Interview 9y:2</td>
</tr>
<tr>
<td>2000</td>
<td>Interview 10y, started with listening to the 9y:2 interview</td>
</tr>
<tr>
<td>2001</td>
<td>Interview 11y:1; Teaching sessions; Interview 11y:2</td>
</tr>
<tr>
<td></td>
<td>Interview 11y:3, started with listening to the 7y:2 interview</td>
</tr>
<tr>
<td>2002</td>
<td>Interview 12y, started with listening to the 11y:2 interview</td>
</tr>
<tr>
<td>2003</td>
<td>Interview 13y; Teaching sessions performed by the teachers</td>
</tr>
<tr>
<td>2004</td>
<td>Interview 14y; this was a small group interview</td>
</tr>
<tr>
<td>2005</td>
<td>Interview 15y, started with listening to the 11y:1 interview</td>
</tr>
<tr>
<td>2006</td>
<td>Interview 16y, this ended with prompting a molecule concept</td>
</tr>
</tbody>
</table>

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

Analysis and earlier results
As this is a longitudinal study different results have been presented earlier. The different conceptions the students express, until 2001, in the different situa-
tions were presented in Holgersson and Löfgren (2004). When analysing the interviews of the individual students, until 2003, with Ausubel's assimilation theory we could discern subordinate, superordinate and combinatorial learning. We also found a common pathway of how the students’ ideas changed over the years in each situation (Löfgren & Hellén, 2008a). Results from especially analysing the use of the early presented molecule concept have been presented in Löfgren & Hellén (2006) and in Löfgren and Hellén (2008b).

In the interview at 16 years of age the students were especially asked about molecules and that demanded a movement from everyday talk into scientific descriptions. When analysing the students’ answers we found four different ways of answering, namely:

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 (Löfgren & Hellén, 2008b)

In the analysis for this paper we have concentrated on the experiences that students express in the different interviews. We have then followed these expressed experiences trying to find out how they have been used by the students in their development of understanding and their descriptions of the interview situations and the phenomena involved in the situations. One interesting result is that in the situation of the fading leaves we have found a group story. It is more or less the same experiences expressed by the different students and their understanding of the situation in the last interview at the age of 16 does not differ very much. In the other two situations there is more diversity both in the experiences mentioned through the years and the expressed ideas in the last interview. Because of this we now present the results concerning the fading leaves in one section as a group story. In another section the results from the burning candle and the covered glass of water will be presented with examples from individual students. We have also tried to interpret the students’ statements by especially concentrate on the students’ comments in the interviews where they were allowed to comment on their own earlier interviews. These results and reflections on them are presented in a separate section.

The fading leaves, a group story
All the students, already in the first interview at the age of 7 (or 6 depending on their birthday), have experiences of leaves lying on the ground and they have ideas about what will happen to them. They will go to pieces, grow old,
fade, rot, and die are common answers in the very first interview. A few students also mention turning brown or turning into soil.

The first years the students are divided into three different classes (K, 9 students; L, 7 students; M, 6 students). It is obvious from the interviews that the students in class K and L between the second interview at age 7 and the interview at age 8 have had lessons and experiences from which they have learnt that animals eat the leaves, do a poo-poo and then it turns into soil. In class K the animals talked about are worms but in class L there is a greater variety, for example worms, wood lice, larvae, and beetles. In class M the interventions in the research project between interview 9y:1 and 9y:2 and school experiences have had impact on the students’ learning as they in the second interview now also answer that worms, larvae and wood lice eat the leave, do a poo-poo and then it turns into soil.

This taught and obviously, by most students, learnt material could be seen as a scientific description of the phenomenon suitable to this age-group. Most students seem to be able to connect this scientific description with their own experiences and the way we talk about fading leaves in everyday situations. We can conclude that even though the Swedish school syllabi are goal driven and a lot of freedom is given to the teachers these matters are usually in some way attended to during the very first school years.

In the syllaby there are goals to aim for through the nine years of the compulsory school but there are also goals that the students should have attained by the end of the fifth and by the end of the ninth school year. The goals are given under three different headings: ‘concerning nature and Man’, ‘concerning scientific activity’ and ‘concerning use of knowledge’. By the end of the fifth year in school there is one goal saying

**Biology 5th year**

Pupils should

- be able to give examples of the life cycle of some plants and animals and their different growth processes

(Skolverket, 2007)

In the interviews in the end of the second and third school year the students have learnt and are able to describe the fading leaves as we have seen above and this seem to be a productive start to further understanding. When we follow the students through the years we find that the students describe the situation and explain the fate of the fading leaves more or less in the same way and in the last interview at 16 years of age they still claim animals will eat the leaves and then do a poo-poo and then it will turn into soil. They use rot, break down and moulder more frequently as they grow older. These are expressions they obviously learn probably both in and out of school. When

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1 The 23rd student did not start in the school until later.
asked to in more detail explain what happens for instance when the leaves moulder they answer like Ruben in the excerpt below:

[16y]

Ruben: Well one could also say rot.
Interviewer: Could you tell more about what happens when they moulder or rot?
Ruben: They break down by different materials (substances) in nature.

From this example we can notice that moulder, rot and break down are used more or less in the same way. If asked if there are things that can influence these processes the students answer weather, heat, light and different small animals (some mention insects and one student mentions bacteria).

We could conclude that the students have learnt from school experiences in the very first years of schooling and from experiences with their families. Later they learn new expressions that they connect to their ideas and use in their explanations but they do not in the end of the compulsory school have any deep insights in how fading leaves turn into soil. The interviewer tried to challenge and prompt some of the students in the last interview with questions that probably would remind the students of other end products if they at any time had made (or had been shown upon) connections between fading leaves and combustion.

[16y]

Gunnar: It had broken down as time goes.
Interviewer: What do you think happens when it is broken down?
Gunnar: Well, one could say it turns into soil then.
Interviewer: Could anything else happen to it?
Gunnar: It could be food to some animals.
Interviewer: And what happens then?
Gunnar: Well, I would say that in the end it turns into soil.
Interviewer: Does all of it then turn into soil or are there any other end products?
Gunnar: I would say in the end it turns into soil.

In this last interview the interviewer tries to challenge Gunnar about all this material turning into soil and wants to know if he has any ideas about other end products from the fading process.

We will now go back to the Biology syllabus and look at some of the goals that students should have attained by the end of the ninth year in school.
Biology 9th year
Pupils should
- have an insight into photosynthesis and combustion, as well as the importance of water for life on earth,
- be able to give examples of recycling and accumulation in an ecosystem (Skolverket, 2007)

In the biology text book some is said about where carbon dioxide comes from and one can read:

All substances that are formed by the photosynthesis contain carbon. Carbon comes from the carbon dioxide in the atmosphere. The amount of carbon dioxide in the air is very small – just about 0.03%.

As carbon dioxide all the time is used in the photosynthesis one could ask why the carbon dioxide in the air does not cease. Carbon dioxide is all the time formed by all combustion of materials that contains carbon. It happens for instance in our own body. Dextrose (grape-sugar) is burned in our cells. Then carbon dioxide is formed, which we breathe out through our lungs. Carbon dioxide is also formed in combustion in engines, boilers, factories, volcanoes etc. (Linnman et al., 1995, p. 149).

In a chapter called Ecology there is a paragraph called ‘Producers, consumers and decomposers’. Concerning the decomposers one can read:

A group of consumers are called decomposers. They are mushrooms, bacteria and a lot of small animals as for example worms, beetles or mite. They live by the energy in dead material as for instance faded leaves, cones, skeletons, branches, excrements and urine. They “break down” the dead material into such substances that the plants can take up again. The decomposers are therefore very important in the eco system circulation. (Linnman et al., 1995, p. 104).

The students have in the later school years been taught and many of them have probably learnt formal scientific facts as the ones presented above that could be used when explaining the situation but the students do not use this knowledge and do not even seem to be aware of the possibility of using it in this situation. One could of course always discuss and come to different opinions about what should be known and able to express in order to have achieved the goals mentioned above. We would argue that most students in this study have not attained the goals above in relation to the question asked in our interview and we would also argue it is important, in the end of the
compulsory school, to be able to see the process in fading material and to know that in all these processes a lot of the material turns into gases, such as carbon dioxide and water vapour, that are not seen but influences the air around us and the atmosphere.

Most students in the situation with the fading leaves are satisfied with an explanation where the leaves fade and are eaten by animals, thereby turning into soil. The students do not seem to reflect on all the material that comes from all leaves that fall off the trees every year. They seem to be satisfied with the end product soil and do not reflect on any other products as the result of the processes involved. Jenny, though, has an idea which in some way includes processes and especially the photosynthesis.

[16y, the fading leaves]

Jenny: They will moulder and turn into soil

... Interviewer: If you imagine a molecule in the leaf what will happen when the leaf moulder, when it turns into soil?

... Interviewer: But those that are left in here, because you said you thought that the material turned into soil then?

Jenny: Well there are molecules everywhere so I suppose in the soil as well.

Interviewer: But is it the same kind of molecules, do you think, in the leaf and in the soil?

Jenny: They are different kinds I think. Well, I do not really know how but it probably has to do with air and water and the sun and then the photosynthesis which changes everything. Well, I do not really know but everything has got its processes one could say.

Nils (16y) explicitly claims he does not know how the worm can turn the leaf into soil and goes on “we have not read about that yet”. Hedda (16y) says “the leaves are broken down into smaller things and then new things are created”. Simon (16y) claims there must be a small difference between what happens if the worms eat the leaves or if they moulder, saying: “The worms, well they take up energy from the leaves and so, which means it is not there anymore.”

The last examples show that there are students who realise there must be processes that change the material and that these students are also aware of their lack of knowledge of these processes.

In the situation with the fading leaves all students have early experiences from school or from an intervention in the project that have impact on their ideas about this situation. Even in the interview at the age of 16 we can trace the very first learning situation in the way that more students from class K
mention worms and just worms when they say the leaves are eaten. Especially students from class L mention a variety of animals that can eat the leaves and turn them into soil. The students from class M have more different experiences. It seems important to be aware of the impact of early experiences in reflecting on suitable, challenging and productive learning situations.

The burning candle and the covered glass of water, individual stories

Experiences that follow through the years

There are early experiences or associations that seem to have a strong impact on the further learning. As an example we will now meet Sune in the situation with the burning candles. In the very first interview Sune says that the candle melts and then in the interviews up to the age of 9 he says it runs down. In the second interview at the age of 9 Sune answers in the following way:

[9y:2]

Sune: The candle melts and most of it rises in the air.

Interviewer: How can it rise up in the air?

Sune: But the candle is water, what is it called wax something, and then the water is water vapour, perhaps half of it or more is water, that rises up in the air as water vapour.

This statement could be understood in different ways. Sune might see the melted wax as water or he might think there is water in the candle. In the next interview at the age of 10 Sune more or less answers in the same way. In the first interview at the age of 11 he expresses an experience of making candles and introduces by himself water molecules in his description.

[11y:1]

Sune: When you make candles then you have water and wax. Because I use to do candles with my mum and those. And then the water, the water molecules when they become hot and the wax melts then the water molecules they go away and the candle becomes smaller and smaller and the wax can rise up to air sometimes.

Here we probably have the explanation to Sune’s idea about water vapour from the interview above. He has an experience of making candles and from this experience he concludes that a candle is made up from water and wax. The water can naturally rise into the air as water vapour when heated.

Sune will continue remembering his early experience of making candles using the knowledge he thought he gained from this experience when trying to understand and explain what happens with the burning candle as we can see from the following excerpts:
Sune: Some runs down here but it is not much as the candle, well perhaps 70 to 80 percent is water meaning that most of it becomes water molecules that disappear in the air.

Interviewer: What becomes of the burning wax then?
Sune: It is heated just like boiling water, well the candle is 90 percent water and when it is heated many times, the water disappears more and more. In the end there is no wax left.

Sune: Well, the candle is mostly water so then it turns into water vapour.

Sune: There is a lot of water in the wax and then the water molecules they move off and rise out into the air and then in the end all of it disappears into molecules while the wax, some of the wax runs down and is used again when the candle burns down.

In this case Sune tries to make sense of his experience and it helps him explain to himself what happens. On the other hand this experience does not help him to understand the burning process. Sune is satisfied with the evaporating water. It is interesting to notice how precise Sune is talking about how many percent of the candle that is water. This amount also rises through the years up to the point where he claims the wax is made of mostly water.

Expressing relevant experiences

Many of the students, especially in the interviews up to the age of 11 refer to experiences from both out and in school when describing and explaining the situation with the burning candle and the covered glass of water. In Löfgren and Helldén (2008a) we have given examples from students who referred to daily experiences and were able to use these experiences when elaborating their ideas about the phenomena but also given examples of students who did not seem able to do this. In Löfgren and Helldén (2008a) we only had analysed the students' interviews up to the age of 13. In the interviews at the age of 13 the students were in the end of their sixth year in school and the teaching in science had mostly been in biology. The students had performed experiments within the physics and chemistry areas but the explanations of the observed phenomena had probably not been scientific with the purpose of presenting models or abstract science concepts. We have already mentioned one goal in the Biology syllabus that should be achieved after the fifth school-year.
We will now present some goals from the chemistry and physics syllabys concerning the same year.

**Chemistry 5th year**
Pupils should
- have a knowledge of the concepts of solids, liquids, gases and boiling, evaporation, condensation and solidification,
- be familiar with different kinds of mixtures and solutions,
- be familiar with some factors that cause substances to be broken down, and be able to give examples of how this could be prevented,

**Physics 5th year**
Pupils should
- have an insight into basic meteorological phenomena and contexts, (Skolverket, 2007)

Most of these goals are probably attained or thought of as attained within an ordinary and everyday discourse. In order to attain these goals it is not necessary to join a specific science discourse. We still at this time talk about the phenomena with the same words as the ones used in everyday language. There is no real need to use or to understand specific science models. This means it is fairly easy to combine everyday experiences with the science knowledge taught in school and it is possible to integrate these experiences and new gained knowledge into already established ideas. If we look into the goals for school year 9 the following could be relevant in respect of our phenomena.

**Chemistry 9th year**
Pupils should
- have a knowledge of some of the elements, chemical compounds and chemico-technical products,
- have a knowledge of the most important cycles in nature, and be able to describe some dispersion processes of matter by air, water and the ground,
- have knowledge of the properties of water and be able to describe its role as a solvent, and as a means of transport over the earth and by plants,
- have a knowledge of the properties of air and its importance for chemical processes, such as corrosion and combustion,

**Physics 9th year**
Pupils should
- have a knowledge of pressure, heat and temperature in relation to different forms of matter,
- have an insight into how matter is built up out of elementary particles and atoms,
The goals above could of course be attained on different levels of understanding. In these goals there are more concepts mentioned that are specific science concepts than in the goals that pupils should have attained by the end of the fifth school-year. This means there is an expectation that the students by the end of the compulsory school should have been invited into and have some understanding of the science discourse. This expectation or intention is obvious if one reads the whole syllaby which include the ones presented but also both the goals to be attained under the two headings 'concerning scientific activity' and 'concerning use of knowledge' and the goals aimed for.

In our analysis of the later interviews we could conclude that most students do not quite manage to use their experiences in a productive way in order to connect the scientific ideas taught in the last years in the compulsory school with the situations asked about in the interviews. The descriptions and explanations do not show much deepening of the understanding of the processes taken place in the situations. Inger is one of the students that most frequently uses experiences from everyday situations and makes associations from other situations in explaining the situations over the years. We had expectations that this ability (or habit) would show to be beneficial in deepening the understanding of the processes involved in the situations. Firstly because these experiences and associations would broaden the ideas but also secondly as we thought a student who usually did this would more or less automatically make connections between science taught in school and her experiences. We thought she would connect these to the processes involved in the interview situations. We will now show excerpts from the interviews with Inger in the situation with the covered glass of water.

Interviewer: What do you think it is (the condensed water on the inside of the lid placed on top of the glass of water)?
Inger: It has become misted.
Interviewer: Where do you think it has come from?
Inger: From the water in the glass.
Interviewer: And how do you think this has happened?
Inger: If the water is warm then the water rises upwards.

Inger already at the age of 7 thinks that water has gone from the glass up to the lid. She knows the word mist and it has a meaning to her. We can also notice that she uses knowledge that she must have been told and perhaps in some way has experienced, namely “warm water rises upwards”. This knowledge is a kind of fact, something she has been told and therefore knows but probably at this time nothing she reflects upon or asks herself why it is like this.
Inger: It is like dew. Just as when you take food and on the lid it is full with that. It is water droplets.

Interviewer: If I take the lid off?
Inger: Then the water will go away.
Interviewer: And that is because it has evaporated?
Inger: Yes.

Interviewer: When you say it is gone, what do you mean by that?
Inger: It cannot go on being water if it disappears it will become vapour or something, but that cannot be when it is not hot. But perhaps it could become air.

Interviewer: What is vapour then?
Inger: It is like in a sauna. We have a sauna at home. Then perhaps you throw water on the stones and then it becomes vapour because the heat rises.

From this excerpt we can see that Inger is precise in using the words. One problem is that she cannot make sense of her ideas and reflections. Also in the responses in the situation of the burning candle Inger reflects upon and tries to understand what evaporation actually means and when it is appropriate to use the concept. But we will now go on with excerpts from the water situation.

Inger: But perhaps not all of it would evaporate ... but if had been in the sun then it would easier, because it is just like water puddles. They disappear when it is summer or the sun shines.

The above excerpt is from the beginning of the interview when Inger comments on her own description from last year of the open system (the lid is taken away: what will happen then?). When we then go back to the closed system she says that perhaps it does not evaporate but it rises and she says that perhaps it is not the same water perhaps it has to do with the closed situation and then continues: “when one has a shower, then sometimes there is water vapour”. In the interview at 15 years of age after having listened to the first interview from the age of 11 Inger says:

I still do not know what happens to it, it is water up there. Perhaps it could come from the air because it could become like that without water.
Interviewer: If we just put an empty glass of water with a lid on?
Inger: No I mean for instance on a window in a room between the warm and the cold, then condensation is formed.
Interviewer: Why does it become like that?
Inger: Actually, I do not know.
Interviewer: You have not talked about this is in school then?
Inger: We have not talked about any of this (referring to all three situations) in school.
Interviewer: Could you think of any other situations where condensation is formed then?
Inger: They said, when I bought my mobile, that if I have in the inner pocket then condensation could be formed and it would destroy the mobile because it is warm from the inside and cold from the outside.

In this interview Inger uses the word ‘condensation’. She uses it in an appropriate way. Again she is capable of reflecting on and connecting to experiences from her daily life in relation to the question asked about in the interview. In the last interview at the age of 16 Inger answers in the following way:

[16y]
Inger: It is water.
Interviewer: And that water has come from there (the water in the glass) or?
Inger: Yes, it had not become like that without it.
Interviewer: But how do you think the water can move like that?
Inger: Well, I do not think it jumps there but it probably rises in some way, well it evaporates but I do not really know because if it evaporates I think it should go away completely but it is perhaps like this that if there had not been any glass lid then the water that lies there would just have disappeared up in the air but now perhaps the glass lid catches it or something.
Interviewer: And when you say disappear then you think it has evaporated? The word disappear is a bit tricky because it could mean disappear into nothing or that we cannot see it.
Inger: No, it disappears out into the air and I think it is still water but they are small sort of, I do not know if one could say molecules or, yes small parts which means one does not notice them. It is almost as when you have a sauna and throw water on the stones and it becomes water vapour instead and you can almost feel it in the air but you cannot see it.

We can notice that Inger does not in the 16 year interview have a clear concept of evaporation and she does not at all show any awareness of the condensation process. This is interesting as she in the interview at the age of 15 is
quite specific in her connections to condensation processes she knows about. As we have seen above Inger has through the years made many associations to everyday situations but she does not seem able to connect these observations with the science taught in school in order to in more detail understand the situation. In Löfgren and Hellén (2008a) Inger was an example of a student who used everyday experiences and used them in elaborating her ideas. This was true up to the age of about 13 but then she failed to continue doing this. This seems to coincide with the time when the science taught in school becomes more dominated by presenting new abstract concepts and scientific models.

Reflecting the results in relation to the students’ comments on their own learning
In the situation with the fading leaves the students have a lot of experiences from situations with their families which they claim have impact on their knowing as Inger (9y:2) who says: “We use to put leaves and grass in our compost and the next year we put it into another one and then it is soil.” Ruben (12y) says answering the question of what has influenced his thoughts about these matters “before when we visited our cottage then there was a sandpit and sometimes there was soil beside it and it was as if something had eaten and then had done a poo-poo.” Julia in the interview at 10 years of age says she has learnt about these things from her older sister and the family when they have been in their summer-house that has a big garden.

The students also remember the learning situations from the first years in school and mention them in the later interviews when they are asked to comment on their statements and what have had impact on their learning. For instance, Simon (12y) says “She (the teacher) talked a lot about soil and all such things and about mouldering and so. I suppose I have learnt this then.” Frida talks in the interviews at the age of 8, 10 and 12 about what they did during the first three years (age 6 to 8) in school. Edvard remembers things they did in his first school (he moved from another school and joined the project in 1999) and claims these experiences has had an impact on his understanding of what happens to fading leaves.

In the situation with the burning candle the students talk about experiences from home when they have had burning candles. But these experiences are very concrete, they have seen the melted wax run and they have picked it away after the candle has been put out. We have seen the impact on Sune’s ideas about the burning candle after his experience of making candles. But on the whole there are more reflections in the interviews saying this situation is difficult and still not understood than reflections giving us insights in what has influenced their ideas. Jenny (11y:3) says: “I think this with the candle is really difficult.” and in the interview at the age of 16 she says almost at once that she still does not understand this situation.
In the situation with the covered glass of water the students connect to many experiences from both in and out of school. When especially asked to describe what has influenced their learning in this situation they mention they have ‘carried out research’ on water in school year 4 to 6. They also mention individual work or group work made in school. Some of them mention a TV program called Brain Office as the main influence.

If we look at the individual student’s answers on what has influenced her or his learning and compare that with the student’s ideas in the last interview and especially her or his ability to use the molecule concept in a productive way in the last interview (for more details Löfgren & Helldén, 2008b) we have found some interesting trends.

Paul, Emil and Nils who know a lot of facts within the science area but can not use this knowledge in a productive way in the interview at the age of 16 do mostly mention things from school and very seldom things from family experiences when asked about what has influenced their learning. Nils also very confident says when there are things he cannot answer: we have not learnt that in school yet.” To Paul it is very important to inform us that he has now learnt new words when listening to and commenting on an earlier interview. Paul seems to mean learning new words is an important part in a learning process.

Inger to begin with used a lot of experiences in a productive way but is not capable of doing that in the later interviews. Inger in the interview at the age of 15, says: “We have not talked about any of these things in school” and then, when especially asked about the molecule, she goes on: “I have not cared much about molecules, I do not know much about it.”

Gunnar and Hedda who in the last interview show that they can deal with the facts and processes learnt in school in a productive way in explaining the situations asked about in the interview say they have asked, thought by themselves and learnt in school and that this have had an impact on their learning and understanding of the phenomena involved in the situations asked about. Hedda in the interview at the age of 12 claims "One has learnt more because one is older, one understands more and one can exclude more."

From these examples we can conclude there seem to be connections between, on one hand the capability of using facts and models taught in school and combining those with more concrete experiences from school and everyday situations and, on the other hand the students’ own feeling of learning and/or the students’ apprehension of what learning is all about.

Another reflection from having followed these students’ development of understanding of transformations of matter in these three situations over this ten year period is that the students already very early use ‘facts’ they have heard or by themselves have concluded out of experiences. These ‘facts’ do not

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2 These students’ responses in the last interview mostly fall into category B
1 Inger’s responses in the last interview fall into category C.
4 These students’ responses in the last interview fall into category D.
seem to be reflected on or questioned. A lot of the early learning is ‘facts’ learnt in this way. A question arises out of this: Does the learning in science go on being not reflected on as we very often present the science knowledge as ‘facts’? One is not used to reflect or question such ‘facts’. Of the students presented above Paul, Emil and Nils learn these ‘facts’ but have so far no use for them, Inger does not learn the ‘facts’ because she cannot imagine how to use them in a productive way. Gunnar and Hedda are better off as they seem to be able to connect these ‘facts’ to their own ideas and thereby elaborating their ideas. They seem to reflect upon them and to intellectually work with the new ‘facts’ or conceptions taught in school year 7 to 9. In many other subjects, where discussions are more frequent, it is more obvious that ‘facts’ can be questioned and sometimes also be expressed in different ways. Does this have an impact both on what students learn in science, their motivation to learn science and their attitudes to science?

Conclusions and Implications
There is a great difference in the individual students’ learning pathways. Some students explicitly use their experiences and reflections when developing their ideas about the different phenomena and some do not. Most students change their ideas and make progress in describing and explaining the situations in the first years of the study. We can out of the interviews learn that all students at almost the same age learn that leaves lying on the ground are eaten by animals and then turn into soil and they also learn at the same, but another, age that oxygen is needed for burning to take place. On the other hand there are facts and processes obviously taught that only a few students seem to find useful in developing understanding of the phenomena. On the whole there is a vast spread in the students’ capability to use their experiences and taught facts in productive ways to improve their understanding of transformations of matter.

One interesting finding is that the early experiences, gained in school, about the fading leaves have such an impact on the students’ ideas almost ten years later. Those students who met a variety of animals involved in the process still mention different animals in the last interview, while those students who were only told about worms eating the leaves do only mention worms in the last interview. We would by this claim two things. Firstly the importance of early experiences through the first years in school and we would claim these experiences should also include phenomena from the chemistry and physics domains. Secondly the importance of teachers with deep science knowledge in the first years of school in order to present experiences and talk about them in such a way that the students gain knowledge possible to later elaborate and build upon.

Another finding is that it seems difficult for most students to connect the science taught in the later years of the compulsory school to the knowledge they have gained in earlier years and to their own experiences from daily life.
Out of this study we can only guess or have a feeling that one possibility to obtain more students to know more science and to obtain more students with positive attitudes to science is to make clear when models are used and how different concepts have been established and accepted as science knowledge.

Following these individual students’ learning pathways and often noticing the lack of impact from the school teaching on their pathways we would emphasize the importance of finding methods to spread and discuss the results from the last decades of science education research among school teachers, teacher students, and curriculum designers.

**Bibliography**


Doctoral Dissertations in Education
published by the Malmö School of Education

From the publication series Studia Psychologica et Paedagogica - Series Altera
Editors: Åke Bjerstedt & Horst Löfgren

42. Eneskär, Barbro: Children’s Language at Four and Six. 1978.
122. Ursberg, Maria: Det möjliga mötet: En studie av fritidspedagogers förhållningssätt i samspel med barngrupper inom skolbarnomsorgen. 1996.
45. Löfgren, Lena. Everything has its processes, one could say. A longitudinal study following students’ ideas about transformations of matter from age 7 to 16. 2009.
Doctoral Dissertations published elsewhere

