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ABSTRACT

During the last decades, an increasing awareness has developed that humankind will have to make important decisions about the environment which will demand substantive knowledge of critical ecological phenomena such as the production and decomposition of biomass (World Commission on Environment and Development, 1987). As a biology teacher the researcher found that students at different levels have great difficulties expressing, in their own words, how biomass builds up and breaks down; also where matter comes from and where it goes. This can be true even of students who have studied photosynthesis and respiration. The researcher has also found very limited knowledge about issues concerning transformations of matter, such as decomposition and combustion, when people discuss general environmental issues. Could this lack of knowledge be due to the fact that teaching has not been based on students thinking about ecological phenomena? In order to create teaching situations in which students' ideas about natural phenomena can be challenged, educators must understand how students' thinking about different phenomena develops over time. Therefore the researcher started a longitudinal study of students' understanding of some ecological processes by following a class of students from the age of 9 to 15 (Hellden, 1992; Hellden, 1993; Hellden, 1995). These ecological processes comprised dealing with conditions for life, decomposition, and the role of the flower in the plant's reproduction. The purpose of this research project is: to describe the students' ideas about some biological processes at different ages and how they change over time; to study how the students' ideas are influenced by experiences of everyday life; to describe features in students' ideas about their own learning, and on the basis of these findings, suggest possible ways of challenging their ideas in order to help to develop them. (Contains 22 references.) (Author/ASK)

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# A Longitudinal Study of Students' Conceptualization of Ecological Processes

by

Gustav Hellden

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# A LONGITUDINAL STUDY OF STUDENTS' CONCEPTUALIZATION OF ECOLOGICAL PROCESSES

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**Paper presented at the Annual Meeting of the National Association for Research in Science Teaching San Diego, April 19-22, 1998**

## INTRODUCTION

During the last decades an increasing awareness has developed that humankind will have to make important decisions about the environment which will demand substantive knowledge of critical ecological phenomena such as the production and decomposition of biomass (World Commission on Environment and Development,1987). As a biology teacher at different levels, I have found that students at different levels have great difficulties expressing, in their own words, how biomass builds up and breaks down; also where matter comes from and where it goes. This can be true even of students who have studied photosynthesis and respiration. I have also found very limited knowledge about issues concerning transformations of matter such as decomposition and combustion when people discuss general environmental issues. Could this lack of knowledge be due to the fact that teaching has not been based on students thinking about ecological phenomena?

In order to create teaching situations in during which students' ideas about natural phenomena can be challenged, educators must understand how students' thinking about different phenomena develop over time. Therefore I started a longitudinal study of students' understanding of some ecological processes by following a class of students from the age of 9 to 15 (Helldén, 1992; Helldén, 1993; Helldén, 1995). These ecological processes comprised dealing with conditions for life, decomposition, and the role of the flower in the plant's reproduction. The purpose of this research project is:

to describe the students' ideas about some biological processes at different ages and how they change over time,
to study how the students' ideas are influenced by experiences of everyday life,
to describe features in students' ideas about there own learning,
on the basis of these findings suggest possible ways of challenging their ideas in order to help to develop their ideas.

The following three important biological processes can be problematic for students to understand and have to do with the concept of matter and its transformations.

1. Organisms maintain equilibrium with the environment, i.e. homeostasis, through exchange of energy and matter. This exchange means, among other things, exchange of gases with the environment.
2. Several ecological processes include the water cycle as an important part. This cycle also involves phase changes between the gaseous, liquid and solid states.
3. When biomass is decomposed, the products are carbon dioxide and water.



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These three examples of gas exchange processes cannot be seen by the ordinary observer. Several studies have shown that students are not initially aware that air and other gases possess material character. They take for granted that everything they cannot observe does not exist (Driver et al., 1994) and may construct their own explanation in order to understand and describe the phenomenon.

Several studies have shown that it is difficult for many students to imagine that a plant assimilates a gas as a raw material in building up the plant. Instead, they think that plants obtain their food from the soil through the roots (Wood-Robinson, 1991; Leach, 1995).
Russell & Watt (1989) found that many 5-11 year old children thought that the plant's germination and growth was a result of the unfolding of different parts. Children often thought that growth itself generated new matter, for example, during the development of an egg, or a plant from a seed.

We can learn a great deal from research on students' conceptions of matter and the transformations of matter which are studied in physics and chemistry, when we want to describe students' ideas of matter exchange between the organism and its environment and other processes that are important in environmental education. Andersson (1991) has given a description of five general categories of conceptions based on a large amount of material collected from the many published research reports about students' conceptions of matter and its transformations.

These five categories are as follows:

1. Disappearance.
2. Displacement: a substance can appear in a given place simply because it has been displaced from somewhere else.
3. Modification: a substance retains its identity while some of its properties are changed.
4. Transmutation: transformations that are "forbidden" in chemistry.
5. Chemical reaction.

## THEORY OF LEARNING

The predominant currents in psychology, educational psychology and education during the first half of this century concerning learning built upon a behaviouristic theory that explained learning as a stimulus - respons process. Research about human learning as a change in cognitive structure was generally neglected. Jean Piaget started to analyse the development of children's cognitive structure by interviewing children during the 1920's (Piaget, 1926; Piaget, 1982). In 1964 Piaget personally presented his ideas in the USA during conferences at Cornell University and at the University of California (Piaget, 1964).

Piaget described a child's conceptual development as a passing through the following four stages: A sensory-motor stage (birth to two years), a preoperational stage (two to seven years of age, a concrete operational stage (seven to eleven years) and a formal operational stage (eleven plus years). He argued that the child develops logical-mathematical cognitive structures that are context independent.

Research during the last decades has shown that children's possibilities to learn are not restricted to such stages. Young children can think hypothetically and learn much more at an early age than the stage theory would suggest ( Donaldson, 1978; Carey, 1985 and Novak & Musonda, 1991).

Ausubel's theory of meaningful learning is an alternative description of the conceptual development to Piaget's stage theory (Novak, 1977; Mintzes & Wandersee, 1998). The theory is focusing on concept learning. Concepts are defined as perceived regularities of objects or events or of records of objects and events designated with the same label. Meaningful learning occurs when the learner chooses to relate the new concept to a relevant existing concept and proposition in her/his cognitive structure. Cognitive structure is a given individual's organization of knowledge. This means that there must be the following three prerequisites for meaningful learning.

1. The subject matter to be learnt must be meaningful.
2. The learner must have a conception that relates to the new information to be learnt.
3. The learner must choose to learn meaningfully. (Ausubel, Novak & Hanesian, 1978)

There is one quotation that express the most important idea in Ausubel's theory:

*If I had to reduce all of educational psychology to just 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 et al, 1978, epigraph)

Ausubel's idea seems to be simple but how do we ascertain what the learner knows? In order to explain and describe key ideas in his learning theory, he has invented several concepts. Here are some of the most important.

<u>Meaningful learning</u> occurs when the learner relates substantively new knowledge to concepts that exist in the learner's cognitive structure. The new knowledge interacts with the existing concepts and is assimilated to these concepts. When there are no recognized relevant concepts in the person's cognitive structure, rote learning may occur. The concepts are aquired idiosyncratically because of the learners different experiences. Therefore there is a continuum from rote to meaningful learning.

The process during which new concepts are assimilated to existing cognitive structure is called subsumption and the anchoring concepts are subsumers. Any learning task can be made meaningful if the teacher ascertains what ideas the learner has concerning the subject matter to be taught and teaches her/him accordingly.

Knowledge is hierarchically organized in the learner's cognitive structure. That means that more inclusive and general concepts are superior to less inclusive and more specific concepts and propositions. Subsumers can be more elaborate and specific through integration with related concepts and new linkages can be established. The whole matrix of concepts will in that way be modified. This process is called progressive differentiation and starts in childhood and continues throughout life. When new concepts are introduced they can have a superordinate relationship to concepts that already exist in the cognitive structure. This is called superordinate learning and means that subordinate concepts aquire new meanings.

When new ideas are integrated, the already existing concepts can recombine themselves and new meanings can be added to the existing concepts. This is what Ausubel calls integrative reconcilation. This also occurs when a child begins to recognize that the language codes the meaning of concepts.

Also in meaningful learning forgetting occurs but, unlike information learned by rote, meaningful learning and subsequent forgetting does not result in proactive interference of learning of similar information. On the other hand, fragments of concepts that remain after subordinate concepts or details that are lost can facilitate new meaningful learning. To distinguish this "meaningful forgetting" from forgetting, Ausubel introduced the concept obliterative subsumption.

Ausubel proposed that new knowledge can be more easily linked to existing relevant concepts in the cognitive structure if advanced organizers have been introduced. *In short, the principal function of the organizer is to bridge the gap between what the learner already knows and what he needs to know before he can meaningful learn the task at hand.* (Ausubel et al 1978, p 171). That means that advanced organizers facilitate meaningful learning only when the material to be learned is meaningful to the learner.

## METHODOLOGY

### A longitudinal study
Although many studies about children's conceptions in science have been carried out around the world, very few have been longitudinal studies. It is obvious that short-term studies can not capture the full story. In order to elucidate long-term conceptual development, we must stretch the duration of research project and study the same subject over time (Arzi, 1988; Budd & Gunstone, 1993; Driver et al., 1994). I hope to elucidate intra-individual changes in children's conceptions in ecology across time and how this can be influenced by different experiences. A longitudinal study of the development of students' conceptions in physics has pointed out the great possibilities there are to study such a development by using clinical interviews (Novak & Musonda, 1991).

### The clinical interview
As a result of a pilot study, and several projects undertaken by student teachers investigating students' conceptions, I have found that clinical interviews give the best information on children's ideas about processes in nature. The flexibility of the interview makes it possible to repeat questions if the child has misunderstood something. It is easy to follow up the questions carefully and the intimate and open atmosphere makes it easier for shy and sensitive children to talk. The interviewer can pose questions that open up and challenge the interviewee. The first question is formulated in advance; the first answer is then interpreted and a new question is posed. The interviewer is therefore an integrated part of the research procedure.

### The interview procedure
The interviews in the present study were carried out at a small primary school surrounded by mostly private houses and later at a larger secondary school in Kristianstad, a town in southern Sweden. The children were interviewed over the years on different occasions from grade 2 (9 years) to 8 (15 years) of the Swedish comprehensive school. In grade 2 there were 25 students (12 male, 13 female), in grade 3 there were 26 students (11 male, 15 female), in grade 4 and 5 there were 29 students (14 male, 15 female) and in grade 6 to 8 there were 30 students (15 male, 15 female). 23 students belonged to the same class during grade 2-9 and 25 during grade 3-9.

My experience of studies in similar classes had shown that it is important to meet the class on many occasions before the interviews start and to let the children be familiar with the purpose of the study. I therefore visited the class regularly during a period of six months before the study and showed the children that I was really interested in their thoughts about phenomena in nature. During the interviews I made it clear to them that I was interested in their thoughts per se, not whether the answer was right or wrong. To show the children that I was primarily interested in their thinking, I usually started the first question of the interview with the words: "What do you think .......?"

### Interviews about conditions for life
I have found that children tend to explain certain phenomena by saying that things fly away or that something is added from outside. Therefore we cultivated plants in sealed transparent plastic boxes (12x12x18 cm) with glass lids to challenge their ideas about conditions for growth, and to define the limits for the process we were going to discuss.

During the first interview in grade 3 (10 years) about conditions for life I showed both a box with its lid and a sweet violet and asked: 'What do you think the plant needs to be able to grow in the box with the glass lid pasted on?' Another question was: 'What do you think will happen to the plant in the box if we plant it there and glue the lid on?' At the end of the first day the children planted boxes and glued the lid on. After 3 and 24 weeks the children were interviewed about the outcome.

In grades 4, 6 and 8 I repeated the procedure and asked the following question: 'What do you think the plants need to grow in the box?' At grade 6 and 8 I did not show an empty box but a sealed box with violets and daisies growing in it. In grade 5 I interviewed the students about conditions for life in a sealed box compared with a closed aquarium, both of which contained plants and a few invertebrates.

**Interviews about decomposition in nature**

During the first interviews about decomposition in grade 2 (9 years), I asked: 'What do you think will happen to the leaves on the ground in the autumn? Perhaps there will be nothing left next spring.' I also used the following question: 'Where does soil come from?' The next day the children investigated the litter from a deciduous forest containing fungal mycelia, woodlice, millipedes, springtails and beetles. After having investigated the litter, the children were interviewed one by one with the question: 'Where does soil come from?'

In grade 4, 6 and 8 I used the same questions as in grade 2 during the interviews. Many students explained with feeling and insight defoliation as a part of the decomposition process. Therefore I found it important to know more about their thinking about defoliation and asked the students: 'What makes the leaves fall from the trees at autumn?'In one interview in grade 4 the students were also asked what would happen to different things on the soil surface such as leaves, wood, paper, a plastic cover, an iron nail and jam jar. In grade 5 I interviewed the students about decomposition in a sealed box and in a sealeded aquarium both with plants, brown leaves and a few invertebrates.

During the interviews in grade 2, a child made a spontaneous addition to his answer that the leaves become soil: 'Well, the more soil there is, the bigger the planet will be.' I found this comment interesting and questioneded other children and adults in order to find out whether people other than a 9-year-old child had such an opinion. I got such diverse answers and explanations to the phenomenon that I decided to use the following question in the interviews in grade 4, 6 and 8: 'What would happen to the size of the planet earth if all leaves turned into soil every year?' I wanted to know whether more students in the class were of the same opinion. During the interviews in grade 4, 6 and 8 I therefore asked them what would happen to the planet Earth, if all the leaves turned into soil.

**Interviews about the role of the flower**

I had got the possibility to interview the children at the age of 10y about plants in a meadow during a school-camp. The interviews were carried out in early June in a verdant meadow with many different flowers. I asked the children: 'Why do flowers have colour?' This question was then followed up by:?' The children exposed a rich diversity of interesting ideas. At the beginning of the autumn semester the children investigated flowers of different kinds and were taught about reproduction of plants. I interviewed the students at school with the same questions at the age of 11y and 13y and then at 15y with the question: 'What is the importance for a plant to have a flower with colour?' During these interviews, I always had wild flowers in a vase or in a box front of the interviewee.

**Interviews about the students' ideas about there own thinking**
After the last interview at the age of 15, I let each student listen to what they said four years earlier. I then asked them a ) to make comments on their ideas at 11 years of age and explain why they said as they did, b) to try to describe how they had developed their ideas after 11 and c) to describe what they thought had been of greatest importance in the development of their ideas.

**Description and analysis of the interviews**
All interviews were tape-recorded and transcribed before the analysis started. I got a rich material of transcribed interviews In many cases, it was necessary to both read and listen to the interviews during the analysis. Different forms of flow charts were used to illustrate the conceptual development and make the analysis clear. I found that concept maps as they were described by Novak and Gowin (1984) could be very useful for my purpose.

In a twelve-year longitudinal study of science concept learning, a research group at Cornell University had obtained many transcriptions of interviews. In order to handle these data the research group developed the technique of concept mapping (Novak & Musonda, 1991). Concept maps have also been a very useful educational tool to improve meaningful learning and teaching at different levels. In meaningful learning, it is necessary for both the learner and the teacher to know the 'conceptual starting place' (Ausubel et al., 1978).

Concept mapping has been developed to tap into the learner's cognitive structure and show both the learner and the teacher what the learner already knows. The concept maps represent relationships between concepts used by the students to explain different phenomena during the interviews. In this context, a concept is defined as a regularity in events and objects designated by some label. A concept map visually represents the pathways used by the students to describe and explain the phenomena (Novak & Gowin, 1984; Novak, 1998).

By comparing concept maps of interviews at different ages, a picture of conceptual development can be developed. The relationships between the concepts can be followed, for example how assimilation of a new subordinate concept can change the meaning of a superordinate concept. I have found Ausubel's theory of meaningful learning to be a useful theory for the analysis and description of the interviews and the students' learning.

After the interviews in grade 4, I organized an investigation in groups, in which the subjects were the fragmentation of dead organic material by woodlice and a discussion on how plants could survive in a sealed box. Otherwise I did not influence the ordinary teaching. The students also started to cultivate plants of different kinds in the classroom after the interview in grade 4. After grade 6 (13 years), the class continued its schooling at a secondary school with more subject-oriented teaching in biology and chemistry.



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## THE STUDENTS' IDEAS ABOUT CONDITIONS FOR LIFE AND GROWTH

At the beginning of the first interview before the introduction of thecultivation of plants in a closed box in grade 3 I asked the 25 ten-year-olds what plants need to grow. 24 of the 25 students said water, 17 sun or light and 5 of them mentioned air or oxygen. When the box was introduced, the number of students that thought air to be necessary increased from 5 to 21 and nearly all of them mentioned soil and water. 13 students mentioned either sun or light as important conditions for life in the box. Many students expressed doubts as to whether the plants would survive in the closed transparent box. Two students accused me of killing the plants. Some students urged me to open the box now and then to give plants air/oxygen and water. The challenging effect was clear.

The students thought that the plants must take in matter of different kinds from the environment but did not describe the passing of matter from the organism to the environment. The living organism was the 'end station' for matter flowing through the ecosystem. Initially, many students expected the plants to die in the sealed box. They had constructed an 'end station model' in their minds to explain how air, oxygen, water and other resources were consumed. Other students thought that the air was useless because it was rotten or old and some that the air had dried and disappeared.

The teacher heard the children discuss the plants' chances of survival and possible sources for all the water that covered the walls and the lid inside the box. Therefore, she introduced a 'cycle model' to explain why there could be so much water although they had not seen it when they started the experiment. Many students picked up that 'cycle model' and started to dicuss the plants possibility to survive from new perspective. As a result of that intervention most of the students constructed their own ideas about the water cycle. Many students then used their 'cycle models' as prototypes to explain how organisms could survive in the sealed boxes and maintain life-supporting resources such as air, oxygen, carbon dioxide, water and nourishment. That does not mean that their explanations were scientifically correct. In most of the interviews the students argued that the plants needed sun or light and soil in order to be able to survive in the sealed boxes. What was different was their description of the role of oxygen and carbon dioxide and the cycles in the box. An analysis of the development of 25 students' ideas about conditions for life and growth from age 10 to 15 can therefore be grouped into the following three categories depending on their description how the plants got oxygen, carbon dioxide or what they called air:

I. Alternative ideas about the role of oxygen and air.
II. Towards a limited understanding of the role of oxygen and carbon dioxide
III. Towards a more complete understanding of the cycles in the box.

### I. Alternative ideas about the role of air and oxygen.

In this category of students we can find those who did not talk about the role of carbon dioxide as an important resource for the plants but argued that the prescence of oxygen or air were an important prerequisite for life in the sealed box together with soil and water.

In order to be able to explain from where the plants got oxygen and air, four students said that the resources that the plants needed came from the soil. They argued that also oxygen and air came from the soil. Two students mentioned it a couple of times during the interviews, while Stina and Emil mentioned that oxygen came from soil in every interview from 10 to 15 years of age. The idea appears to be strongly consolidated in their thinking. Already at 10y Emil said



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that the plants got oxygen from the soil and at 11y that the plants could grow better in soil than on wet filter paper because they got oxygen from the soil. At 15y he talked about the need for air, not oxygen. When I asked him where the plants got the air from he said: *'Doesn't the soil take up the air and then the soil gives it to the plant and the grass?'*. This statement indicates that he meant that the plant absorbed the air through its roots. There are other statements in the interviews with the students that could mean that they considered oxygen or air to be absorbed by the roots in the same way as water and nourishment.

Ten students also argued that the plant could survive in the box because they needed so little oxygen that it never would be used up or that air or oxygen could be available through the water cycle. Hanna was one of the students that stated that the plant could get air or oxygen through the water cycle. The development of Hanna's thinking is described on page 25. Anders said at 12 years of age that the plants got the air they needed from the water film on the lid. See page 33. Some students' ideas about the steam containing air or oxygen seemed to be due to the experience of their own breathing and one of them also referred to their own breathing. Linda talked in every interview about the importance of the condensation? At 10y she said that the plants got oxygen from the condensation and at 11y that the steam consisted of old air. She descibed condensation as a result of the plants breathing at 13y and as a life supporting resource at 15 years of age. Eric argued at 11 years of age that the quality of air was renewed through the water cycle: *'The air disappears down into the soil and there is more nourishment. Then it goes up again. Then it goes up and down, up and down'*. Eric seemed to have assimilated the concept cycle to his cognitive structure already at 10y and then used the idea in every interview with him to explain how the plants could survive in the sealed box. But he integrated 'an air cycle' with the water cycle only at 10 and 11 years of age. Many students seem to have a core idea that you can recognise in all the interviews with them through the years. 6 students in this category of ideas argued at 15 years of age that the plants in the sealed box got oxygen through there own production.

**II Towards a limited understanding of the role of oxygen and carbon dioxide**

The four students that belong to this category had a vague idea of the role of oxygen and carbon dioxide in the sealed box. For example, they could not even at 15 years of age explain explain from where the carbon dioxide came. Already at 10 years of age Betty talked about the need for carbon dioxide. Betty also said that plants could transform carbon dioxide to oxygen at 12y and added that oxygen could be transformed to water. When she was asked where the water inside the lid came from, she said: *'Well, it's made of oxygen moving towards the glass lid. Well, there will be water condensation because oxygen is transformed.'* At 15 years of age Betty declared that the plants got what they needed as result of cycles in the box. Barbara did not talk about cycles but argued through the years that the plants got what they needed because so little was used up. At 15 years of age she included carbon dioxide. Louise talked on the other hand about cycles but mentioned the role of carbon dioxide only at 13y.

At the age of 15 Sofia said that the green plants transformed carbon dioxide to oxygen but she could not explain where the carbon dioxide might come from: *'They give off oxygen. And then perhaps it is transformed to carbon dioxide again. It goes round.'* Before 15y she did not say anything about that process but described at 12 and 13 years of age how the plant got its oxygen from the soil and through the water cycle. In all the interviews about the conditions for life in the plastic boxes, Sofia described the water cycle in an illustrative way that could provide for many of the plants' needs. Her ideas were always associated with dew on the leaves. At 11y she explain how the plants could survive in the box: *'Well, first you poured in water. Then in the morning, there sort of will be dew on the leaves and then when it is a little* *warmer in the box, it rises up towards the floor. And then it is raining down when there is too much.'* At 15y she explained how the plants got water: *'They give off water. You had watered the soil before you planted them and had sealed the box. They absorb the water. Then there is dew on the plants that evaporates. It rises. It is therefore it is condensation there. And then it runs down back into the soil.'* This is a one example among many others that illustrates how the students use a similar way of describing and explaining a phenomena at different ages. The students also found the water available for the plants through the water cycle in the box. It seemed to be important for the students to see the water appear on the lid and on the walls inside the box instead of only accepting that there was water in the soil. Besides that, Sofia also thought at 13y that the plant got oxygen through that cycle.

**III. Towards a more complete understanding of the cycles in the box.**

The seven students in this category described at 15 years of age a more or less complete understanding of the relationship between oxygen and carbon dioxide in the sealed box. They could also explain where carbon dioxide came from. Their conceptual development towards that idea over the years appeared to be different. Sven, Morgan and Thomas developed their understanding step by step from the 10 to 15 years of age. They talked already at the age of 10 and 11 about the need of carbon dioxide and from where it came. Thomas suggested for example at 11 that the carbon dioxide came from the worms in the soil. All the students in this category argued that oxygen was transformed to carbon dioxide. They did not talk about a chemical reaction where oxygen and carbon dioxide was involved. Morgan said: 'The plants use carbon dioxide and them transform it to oxygen. But then when they die and rot, there is combustion when creepy crawlies and sort of eat them. Then all the oxygen is used up and transformed to carbon dioxide. And it goes like a cycle.' The students used an everyday expression that carbon dioxide is transformed to oxygen which is scientifically incorrect and can be charaterized as a transmutation (Andersson, 1991). The students looked upon it as a process with an input of carbon dioxide and an output of oxygen.

The other four students in this category did not talk about carbon dioxide at all before the age of 15. Lisa said that there were enough resources in the box because the plants used very little: *'Have you had them at a window? Well, then they got light. They have air that is in there, 'cos it remains there. Then they have a little water and nourishment. A little disappears piece by piece.'* Oscar argued that the resources disapperaed but suggested that the plants got the resources they need by cooperation with each other. See page 22. Tove said at 12 years of age that they got oxygen and other resources from the soil. The six students in this category often talked about cycles, especially Tove who finshed her description with: *'It is something like a cycle. It is like a mini earth'*.

## THE STUDENTS' IDEAS ABOUT DECOMPOSITION

Twenty-three students were interview about decomposition at 9 years of age. Only one of them mentioned that an organism was involved in the decomposition. An analysis of the interviews at 11, 13 and 15 years of age showed that the twenty-nine students' ideas about decomposition could be grouped into the following three categories:

I. Ideas that do not contain a description of organisms eating the leaves expressed during all three interviews.

II. Ideas about no organism eating at the age of 11 and with organisms involved in ideas at the age of 13 and 15.

III. Ideas about organisms being involved in the process expressed at all three interviews.

**I. No organisms eating the leaf**

Seven students describe in all the interviews a process with no organisms involved. Instead the students describe psysical factors and the age as causing the decomposition of the leaves. There are such features of their ideas that seem to play an important part of the interviews both at the age of 11, 13 and 15. As an 11 year old Sten described for example how leaves blow down into the soil and rot, as a 13 year old how they blow away and then rot and at the age of 15 that the leaves blow into pieces. The wind was an important part of his ideas and was completed with descriptions of how leaves were trampled into pieces or how the soil took them up.

In other interviews the process could be the charateristic feature. Stina described different ways of fragmentation at 11, 13 and 15 years of age. At 11 she described how the leaves were trampled into pieces, at 13 how creepy crawlies could bite them in pieces and at 13 how leaves withered in pieces. Emil said at 11, that the leaf grew down into the soil and was crumbled, at 13 that it was crumbled under the soil and at 15 that it went down into the soil and was crumbled.It seems that there is a model of looking at what is happening with the leaves on the ground that is very stable through the years even if it finds expressions in different ways. It seems also to be very resistent to any change.

Already at an earlier interview Anders related his description of decomposition to compost and this was repeated in all the others inteviews even if he described different processes. Such a detail as the possibility to throw eggshells on the compost heap comes back when he discusses soil and decomposition. At 9 he said that the leaves were destroyed. Here follows a segment of the interview at 11: *"I think they rot in some way and then there is nothing left, is there. Some people gather them up and make a compost heap and they lie there and get mouldy."*

It was difficult for him to find a clear explanation to the fact that it rotted in the compost and said that it was something within the leaves that was the reason why they rotted. In the same way as his experiences of compost heaps had helped him to develop his ideas, they gave him such challenges that he hesitated in drawing the conclusion that soil could be the final result of the decomposition of leaves. At 15 he said: *" I don't really think that they're turned into soil. It's more I think that they fall into tiny, tiny bits that are mixed with the ground, so that they say they have become soil."* See page 35. Common to his thinking at the different interviews is that soil in itself is important for the decomposition. An early experience of an everyday phenomenon like a compost can play an important role in a students' mind when his is struggling to understand processes in the environment.

**II.Towards a process with organisms involved**

This category consists of 9 students' ideas which describe a development towards an explanation at the age of 13 and 15 that the leaves become soil after being eaten by organisms.

Linda and Ruth described at 11 how the leaves rot and become soil by going and sinking down into the soil. As 13 and 15-year-olds both described how the worm's faeces will be soil. As an alternative they described how the leaves could be soil by crumbling without any influence from the worm. Ralf and Gunnar decsribed at the first interview how the leaves became soil by being torn to rags. At the age of 13 and 15 both of them had left the idea of any kind of fragmentation. instead they adopted the idea that animals like worms and snails decomposed the leaves to soil.

While Gunnar and Ralf represent students that as 13- and 15-year-olds have broken with their earlier ideas, Hanna represents a completely different development. Instead of breaking with her earlier ideas she modified them and added new characteristics to the old ideas. But you can recognise the same feature through the years. At 9 she described the following idea. *"They dry out in some way and shrivel up. Then when they are completely dry, it is enough for it to rain just once more for them to become just small bits."* As 11 year old she had revised her previous ideas by saying that the leaves rot away by trampling from animals. It was still a mechanical process without any influence from organisms. At 13 she still had an explanation of how the leaves were broken down by the rain and the sun, but she had added that the animals ate the fragmented leaves.

At the age of 15 Hanna had taken another step away from the mechanical fragmentation when she describes how the leaves are eaten and become soil. When she was asked about a alternative process she desribed something very similar to that she described as a 9-year-old: *"It must be when it dries up. Then when it rains, it is mixed up with some mud. Then it dries and becomes soil. Or also some animals come and eat it. Then their excrements will become soil."* The constructions had been simplified. New knowledge had been added to the structures Hanna had described six years earlier. There must have been a powerful experience during childhood in order to exist in spite of all influences while growing up. See page 29 and 38.

Four students described as 11-year-olds how animals participated in the processes by making holes, eating the leaves or pulling them down into the soil. It was however not clear that the biomass passed through the animals. As 13-year-olds they evidently declared that the leaves became soil by animals eating and through the excrements from the animals.

**III. Organisms involved in the decomposition**

In this category we find students' conception of organisms using the leaves as food described in all the three interviews. There was a tendency at the age of 11 and 13 for the students to start their decriptions by saying that the leaves rotted before they went on to describe the process. Lisa described rotting as a prerequisite for the animals to eat the leaves. As 15-year-olds several students were more willing to talk directly about the animals' activity. Annie belonged to the exceptions. She used rotting as a starting explanation at every interview.

Several students could describe an alternative to decomposition by organisms when they were asked about an alternative. Mary mentioned every time that the leaves also could rot to soil by being dissolved. She belonged to a category of students that described nearly the same process on the different occasions. Their ideas could be built up round a special factor that caused the decomposition such as insects, water and ageing. Such a factor seemed to be so strongly established that it controlled the students' explanations. The end result soil, good soil and nourishment were very important in Betty's explanations and came back both at the age of 13 and 15. The idea emerged for first time at 11: *"Well, if you say of the one hundred per cent, there will be fifty per cent rich soil and then five per cent that is nourishment and the last fortyfive per cent beomes soil."*

Sofia presented diverse explanations during the interviews. She claimed a varied idea at 11 when she explained how the leaves were sucked down into the ground and eaten by beetles,



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bacteria and that sort of thing. Then she presented a more simplified explanation and never mentioned anything about bacteria at 13 and 15.

Four students in the class developed at 15 years of age their ideas towards the conception of microorganisms causing the decomposition. Let us look at Oscars development towards a more complete understanding. As nine year old he said that the soil ate the leaves. At 11 he described how the leaves were fragmented by the animals to small pieces which disappeared down into soil. He seemed to consider that matter of the leaves was conserved as soil: *"Small animals bite and eat the small pieces of it. Then it just disappears. Then the animals do a number two and it becomes soil."* At 13 years of age he also desribed the alternative that the leaf can be soil by lying and rot. At 15 he understood that microorgansims took an active part in decomposition: *"Well they are lying there and sort of small animals come, microscopic creepy crawlies. And it will become soil 'cos it is organic material here."* Later in the interview he explained how the organisms ate the leaves and how they became soil. See page 24.

In contrast to Oscar Morgan had the same idea at 11 and 13 years of age that decomposition could take place if the leaf was just lying on the ground. At 11 he completed the basic idea with new knowledge about microscopic activity and with an anthropomorphistic view of the process: *"Some of them can just lie and lie. They will be broken down by the nature, 'cos it is the nature itself that built it up. It is bacteria that have broken it down."* At 15 he explained it by Protozoa, bacteria and worms eating it.

At 15 Sven and Thomas described the process as a result of an activity of soil invertebrates, fungi and bacteria. Sven said that both a rich soil and a gas was the result of decomposition. He was the only one that described a gas concept when he explained the result of decomposition. At 11 13 Sven said that the leaves turned to soil by worms eating them or by moisture and rotting.

**THE STUDENTS' IDEAS ABOUT DEFOLIATION**

The students explanations of defoliation as answer to the question: "What makes the leaves to fall from the trees in autumn?", have been brought together in the following three categories:

Category A. Elements of anthropomorphic or teleological explanations such as they have not strength to hold on or the leaves must fall because they were old, it was time to fall or to make room for new leaves.

Category B. Changes in the physical environment like wind, temperature and light.

Category C. Changes in the supply of resourses from the tree such as sap, water, nourishment and oxygen. See table 1.

| Name | Age | | |
|---|---|---|---|
| | 11 | 13 | 15 |
| Alexander | AC | AB | BC |
| Anders | AB | AB | ABC |
| Annie | A | A | AC |
| Barbara | B | AB | AC |
| Betty | C | BC | C |
| David | - | B | A |
| Ellen | AB | AC | AC |
| Emil | AB | A | AC |
| Erik | BC | C | AC |
| Gunnar | BC | BC | BC |

| Name | Age | | |
|---|---|---|---|
| | 11 | 13 | 15 |
| Hanna | AB | ABC | AC |
| Helga | AB | AB | A |
| Johanna | BC | C | C |
| Josef | C | BC | - |
| Linda | C | C | AC |
| Lisa | B | BC | BC |
| Louise | AB | C | C |
| Mary | AC | A | ABC |
| Morgan | ABC | ABC | BC |
| Oscar | A | ABC | AC |

| Name | Age | | |
|---|---|---|---|
| | 11 | 13 | 15 |
| Paul | AB | AB | C |
| Ralf | B | ABC | AC |
| Ruth | A | AC | A |
| Sofia | ABC | A | ABC |
| Sten | B | B | C |
| Stina | AB | A | C |
| Sune | B | - | B |
| Sven | AC | AC | BC |
| Thomas | ABC | ABC | ABC |
| Tove | BC | AC | ABC |

Table 1. Different features in students' explanations of defoliation at 11, 13 and 15 years of age (n=29).

In many cases the students combined different reasons of defoliation when they explained the phenomenon. Explanations of defoliation as a result of physical causations were more common at the earlier interviews. Many students mentioned the wind at the age of 11 and 13 but only two at 15. At that age ideas about physical causation were replaced by ideas about lack of resources coming from inside with nourishment as the most common resource mentioned. All the ten students that mentioned lack of resources at 11 had the same idea at 15 years of age while only seven of the nineteen that explained defoliation as a result of physical facors at 11 years of age had the same opinion at 15.

There were more explanations with anthropomorphistic or teleological features at the age of 13 than at the age of 11 and 15. Twelve of the sixteen students that used anthromorphic reasoning at 15 also used it at 11 and 13 years of age. Seven students did not use such reasoning at any time during the interviews. There was a tendency at the earlier interviews to descibe the leaves as individuals. This could possibly be the reason why many students used human characteristics describing the defoliation. Several students changed from "leaf-centred" ideas at 11 and 13 to more 'tree-centred' ideas at 15 years of age. Morgan, Sofia and Sven presented explanations at the age of 15 that a biologist would accept. They also expressed 'tree-centred ideas' at 11 and used anthropomorphistic or teleological ideas when they developed their understanding. On the whole it seemed to be a help for many students to use anthropomorphistic or teleogical ideas in order to be able to develop and describe thinking.

Shortage of nourishment was mentioned as a cause of the defoliation by eight students at all the three interviews. Otherwise very different features in the interviews survived from the first interview to the other two. Very often there seemed to be a core idea in first interview that



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can be recognised in the following interviews. It could be explanations about shortage of water, cold weather, blowing, ageing or strength to hold on. Let us look upon some segments from interviews with Oscar which can illustrate changes over time from 'leaf-centred' to 'tree-centred ideas, from physical efforts to physiological needs. Changes that can be found also in other interviews with other students.

Age 9: *"It doesn't get any water. Or it has no muscles left to be able to stay on the branch"*

*Age 11: "They don't have the strength remain sitting there. They must jump off."*

*Age 13: "They fall at autumn and they want much sun. Well, perhaps the tree has not the strength to carry them any longer. It has enough to do getting nourishment themselves, and it drops the leaves."*

*Age 15: "Well, it is ...... during winter the tree cannot give nourishment to the leaves and itself, so it drops the leaves. It closes the supply of nourishment to the tree, doesn't it. Then they die and drop."*

**THE STUDENTS' IDEAS ABOUT THE SIZE OF THE EARTH**

The children's ideas from their answers to the question: "What will happen to the size of the planet Earth if all leaves turned into soil every year?" are divided into following seven categories of ideas:

Categories of ideas

A. Do not know.
B. Change in size. Description of the result.
C. Change in size. No description.
D. No change in size. Matter disappears.
E. No change in size. Matter is redistributed.
F. No change in size. No explanation.
G. No change in size because of organism activity or cycle of matter.

See table 2!

| Name | Age | | | Name | Age | | | Name | Age | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 11 | 13 | 15 | | 11 | 13 | 15 | | 11 | 13 | 15 |
| Alexander | E | E | G | Hanna | B | B | B | Paul | - | C | G |
| Anders | E | D | B | Helga | B | B | B | Ralf | B | - | C |
| Annie | D | C | D | Johanna | F | F | G | Ruth | C | C | G |
| Barbara | A | G | G | Josef | - | B | - | Sofia | E | B | G |
| Betty | C | C | G | Linda | C | A | B | Sten | D | D | E |
| David | - | G | G | Lisa | D | E | G | Stina | E | C | C |
| Ellen | B | D | G | Louise | A | F | G | Sune | - | C | B |
| Emil | E | B | B | Mary | E | F | D | Sven | C | C | G |
| Erik | E | B | B | Morgan | F | G | G | Thomas | C | C | G |
| Gunnar | G | F | B | Oscar | B | B | F | Tove | G | E | B |

Table 2. Children's conceptions of what happens with the size of the earth as a result of defoliation at age 11 (n=26), age 13 (n=29) and age 15 (n=29).

Ideas about an increase of the size of the earth belong to category B and C. In category B the students also describe the result of the increase. 23, 28 and 31% of the students are represented in this category in the three interviews. The students claim that the earth grows bigger by formation of new layers or changes in the topography. Oscar said at 11 years of age: *"Well, within some millions of years it will perhaps be jagged instead of being round, because it will be so high that it will stick out from the Earth."* In the children's minds the whole biomass is conserved as soil.

It is only in category B where the same two children are represented during all the three interviews. Four students belong to this category both at 13 and 15 years of age. Three of the nine 15-year-olds in category B had two years ealier the conception that the Earth's size did not change. Six of the fifteen students in category B and C at 13 years of age are represented in category G as 15-year-olds.

Category B and G dominate the picture at 15 years of age. In category G there are conceptions that explain the Earth's unchanged size by organisms' activity or as a result of the cycle of matter. The following segment comes from an interview from a 13-year-old student in category G: *"Well, there will be more soil coming. But in fact a part of the soil disappears up into the trees. They absorb goodness, water and sort of. So there will not be more soil."*

he had the idea that the organisms' activity limit the amount of soil, although he described a common misconception that plants get their food from the ground.

While the percentage part has been quite stable in category B over the years there was a high increase from 10 to 49% in category G between the second and third interview. This can be a result of teaching basic ecology about six months before the last interview. Seven and six of the fourteen 15-year-olds in category G thought at 11 and 13 respectively that the the Earth grew in size. Only three students were represented in category G also as 13-year-olds.

Also category D, E and F contain conceptions that the size of Earth does not change in size. Half of them seemed to have an intuitive idea that the Earth did not be bigger. Therefore they tried to construct explanations of how soil was redistributed in some way. Here is Eric's explanation at 11 years of age: *"It will be pressed together. If there is a cavity, it will be filled until it is full."*. Four students from this group are at 13 years of age represented in category B and C with the conceptions that the Earth changes in size. Three of those stay there even at 15 years of age.

About half the class claimed at 15 that the Earth did not become bigger because of activity from any kind of organism. Two years earlier the students were represented in very different categories. Only Sven described the conception that their gases were produced as a result of decomposition.

The students had everyday experiences that soil was the end result of the decomposition in nature. Possibly that ideas also was strengthened by common sense and the language. On the other hand the students seemed to have an intuitive idea that the Earth could not become bigger. It is in the struggle between those two ideas that the students formulated their answers to the question about the changes of the Earth's size.

## STUDENTS' IDEAS ABOUT THE ROLE OF THE FLOWER

During the interview with the 24 children as 10-year-olds about flowers in the meadow, there was a common attempt by the children to see the 'purpose' of the flower. This 'purpose' could be described in relationship to humans, to other organisms and to the plant itself. The childrens' ideas as to why plants have flowers can be described in five categories of ideas: I. Five students noted the fact that plants had flowers but did not explain why. II. Nine students argued that the plants existed for the sake of human beings in order to be fine and beautiful. III. There were four students that said that the flowers only existed as food for insects. IV. Three students said that the flower gives resources to the plant by catching sunshine and water and giving energy and nourishment to the plant. V. Three descriptions touched upon the role of the flower as a part of the reproductive system of the plant.

The childrens' ideas as to why flowers have colour can be grouped into four categories: I. Four children said they did not know. II. Eight children gave a variety of explanations as to why the plant had colour. One child said that somebody had painted the flower and another that it depended upon where it lives. III Something purposeful from a human point of view. IV To attract insects. Even if pollination is not referred to, there are signs that six children have certain ideas concerning this mechanism.

The development of 27 students' ideas about the role of colour on flowers can be described as the following four categories of ideas:

I. Anthropomorphic and human centred ideas.
II. Ideas about plants getting protection and resources.
III. Towards different ways of mixing pollination and seed dispersal.
IV. Towards a more or less complete description of pollination.

### I Anthropomorphic and human centred ideas

Three students continued to use anthromorphic and human centred ideas during all the interviews compared with six students at the age of 11y. Ruth and Stina said even at 15 years of age that the purpose of the flowers' colours was to make them more visable and beatiful. Anders had a more detailed description of his ideas which appears in the following segments from the interviews with him at 11, 13 and 15 years of age as an answer to the question why the flowers have colour:

11y

*'I think the flowers have ..... cos they have colours to make you think they are nice and want to have them indoors. It gives you something to embroider the table with when you have guests. Then the food on the table and then you embroider the table with some brightly coloured flowers.'*

13y

*'I think there is a thought behind it just like we as human beings, that I want to look nice and that I don't want .... So if you know to put on something, just as human beings put on things. We comb our hair and so on. So I think the have nice colours so that people and others think they are nice. Just like we want other people to think that we..., that I look nice. That's what I think.*

15y

*'Well, actually I've wondered about that too, but I think it's like a human being, they need all this growing around them and the leaves. Life's a bit nicer and not so boring. It is like human beings. We live in our houses. We plant plants and have other things 'cos it makes it nicer. I think that .... what plays a big part for them to have a flower is that the leaves are not alone. The flower is company for them which makes it nicer for them to grow up. Perhaps it makes them stay on longer 'they're having a nice time.'*

**II. Ideas about plants getting protection and resources.**

Ellen is one of the three students that are represented in this category. She launched the idea that the flower makes it possible for the plant to get nourishment from the wasp. But she had at 13 years of age also thoughts that the wasp could do something more of importance. As a 15-year-old she did not say anything about insects. Here follows two segments of the interviews with her at 13 and 15 years of age:

13y

*'Cos otherwise ... For example then if the wasp comes, it must give the flower nourishment or it must do something else.... Otherwise the plant dies.'*

15y

*'Well, there are stamens and pistils in it. And then, the petals protect them in some way.'*

Sten said at 10 and 11 years of age that the purpose of the colours of the flowers was to look nice and at 15y that the plant got oxygen through the flower.

**III. Towards different ways of mixing up the description of pollination and seed dispersal.**

All the 12 students represented in this category of ideas, described at 15 years of age how pollen or seeds were transported by insects and dropped down to the ground where a new plant then would grow. Only one of the students in this category talked at 10 years of age about insect having something to do with the colour of the flower. Six students expressed, as 11-year-olds, the idea that insects were attracted to flowers and could disperse pollen or seeds. One student said: *'There is something that fastens on them. Then they fly and drop a little of it and then it'll grow.'* another student said at 13 years of age: *'Such insects come. And perhaps it is so .. , then it perhaps disperses such pollen. It disperses it so new will come.'* These quotations are typical for this category of ideas. I think the two processes pollination and seed dispersal have similar features that cause confusion for the students. Both the pollen and the seeds develop in a flower. The two concepts are also both involved in the plants reproduction.

**IV. Towards a more or less complete description of pollination.**

Six of the eleven students in this category expressed already at 10 years of age a description of how insects were attracted to flowers because of the colours and how the insects transported pollen from one flower to another. Four students described at 11 and 13 years of age how the plants attracted inscets but mixed the two processes pollination and dispersal of seeds in their descriptions. This was a part of their development towards a more complete understanding of the phenomena. Oscar had a rather curious way towards a complete understanding. Here follow some segments from the interviews with him about the colour of the flower . You can see how he used clear expressed anthropomorphic and human centred ideas to explain the role of the flower at 11 years of age. You can still find such features in his explanation at the age of 13y. (I=Interviewer; S=Student)

11y

*'In order to attract animals that can then suck nectar from inside there so that they can reproduce or perhaps they can boast to the other flowers and make themselves beautiful and so on in the same way as women powder themselves and so on. If you have them in a garden, perhaps you water them very much more cos they are so pretty.'*

13y

*S: To attract bees and and such so it can grow better.*

*I: What does it mean that it can grow better?*

*S: That there will be a bigger family. It will be more diluted and not extinct. Nobody wants to have anything to do with an ugly flower but you can try to plant a pretty flower more and so.*

*I: What role do the bees play?*

*S: They make it flower. Well, they suck out something. And there is a scale or something like that inside the flower of which they can make honey. And they spray something else in or something like that and it flowers in any case.*

15y

*It's in order to attract the wasps. And then they suck the nectar or something and so the stuff gets stuck, pollinin...... No, I don't know what it is called. Perhaps that is what it is called and then they take it with them and so it goes on to the next flower. The flower can't be fertilized from the same stamen there down in the seed, it must sort of change flowers. These stick to the wasp and are carried on and go down into the seed. And a new embryo is formed in there which falls out or when it withers, it stays there.*

**Oscar's ideas about conditions for growth**

Before the box was introduced, Oscar mentioned that a plant needed soil, sun, roots and worms to be able to grow. It is obvious that the possibility of cultivating plants in a sealed transparent box challenged Oscar's as well as the other students' ideas about conditions for life.

After the introduction of the box, Oscar still mentioned that a plant needed soil and some creepy-crawlies which could make the soil better; he assimilated the concepts of oxygen and air to his cognitive structure to explain what a plant needed to survive. He constructed a 'use-up-model' in his mind to explain what would happen in the box and claimed that the air was not only used by the plant. The air would moulder away and die. *'It disappers into the the other air,'* he said while pointing into the box. He also said that the plant would rot.

When, after three weeks he saw that some plants had withered, he interpreted it as a lack of air. He thought that the grass was growing well because the plants shared oxygen with each other. Even during the following interviews up to the age of 13 he utilized the 'use-up model' to explain what happened with air and oxygen. At the age of 11 and 12 he explained how oxygen was sucked down into the plant through the leaves and the flower. Oscar also argued that oxygen could be replaced by other resources such as nourishment from the soil.That led him to the conception that the plants could get oxygen from the soil.Through subsumption he assimilated alternative concepts as resources to maintain life under the superordinate concept plant.

At 10, Oscar launched the idea that the plants could survive by sharing resources like oxygen. Also at 12 he argued that some plants could survive through some kind of 'cooperation' though he then introduced the idea competition between the: *'Perhaps they cooperate. So half of them die and the other half takes their part and then they gain a little in that way."* He still thought that the resources were used up. Oscar used some kind of anthropomorphic reasoning to explain how some plants could live in the sealed box. Concerning the plants in the sealed aquarium, he did not mention the need for oxygen or air. He explained why they could grow underneath the water by expressing the following brief teleological explanation.: *'They are made for the bottom of lakes.'*

Oscar was willingly using anthropomorphic and teleological reasoning in order to understand and describe different phenomena in nature. He did not say so much about the need for water. At 11 he described a 'cycle model' when he explained where the water inside the walls of the box came from. When he described the conditions for life at 13 he also involved the plants in the water cycle by saying: *'It is the plants that take in water from the soil. Then it sweats and there is steam.'*

In the sixth grade (13 years) Oscar had expanding his knowledge about the human body. It thus seems natural for him to use recently assimilated concepts and argue that the sunlight made it possible for the plants to produce vitamins, like vitamin D. He had not mentioned anything about sunlight in the interviews at 10-12 years of age. He subsumed light under the superordinate concept life and this, perhaps, could be of some help in the development of a deeper understanding of the conditions for life. See figure 1.



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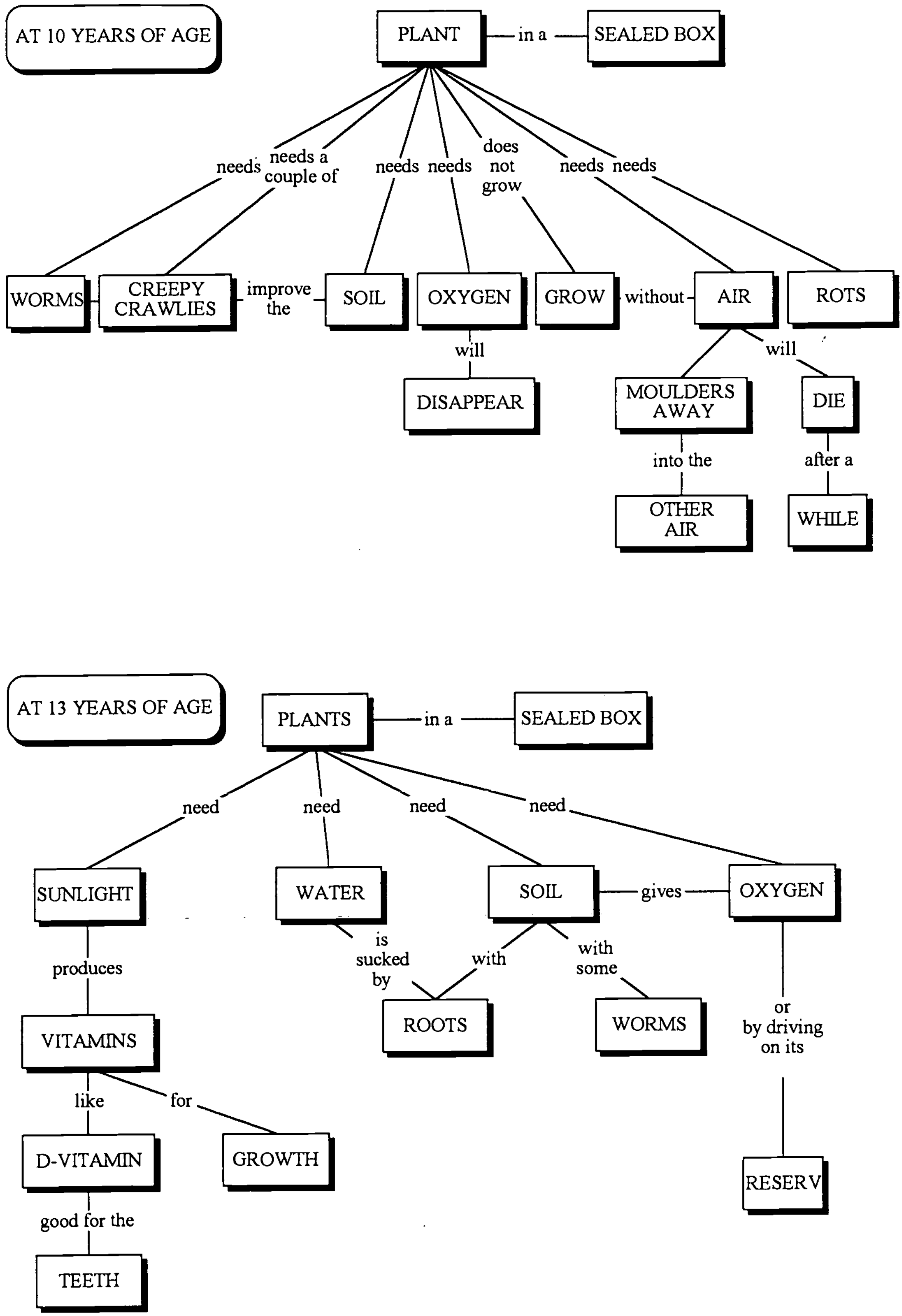


Fig. 1. Concept maps drawn from interviews with Oscar about conditions for growth at 10 and 13 years of age.

Also at the age of 15, he mentioned sunlight, together with water and oxygen, as necessary resources for plants in the sealed box. When I asked him about the importance of sunlight, he answered that it had to do with the photosynthesis and the plants' production of sugar. Then he realised that the plants needed carbon dioxide. Through progressive differentation during the last two years, he developed a new meaning for the plants' need of different resources. Oscar had now assimilated the concept photosynthesis to his cognitive structure through superordinate learning. The concepts sunlight, carbon dioxide, oxygen and sugar can be described as subordinate concepts under the superordinate concept photosynthesis.

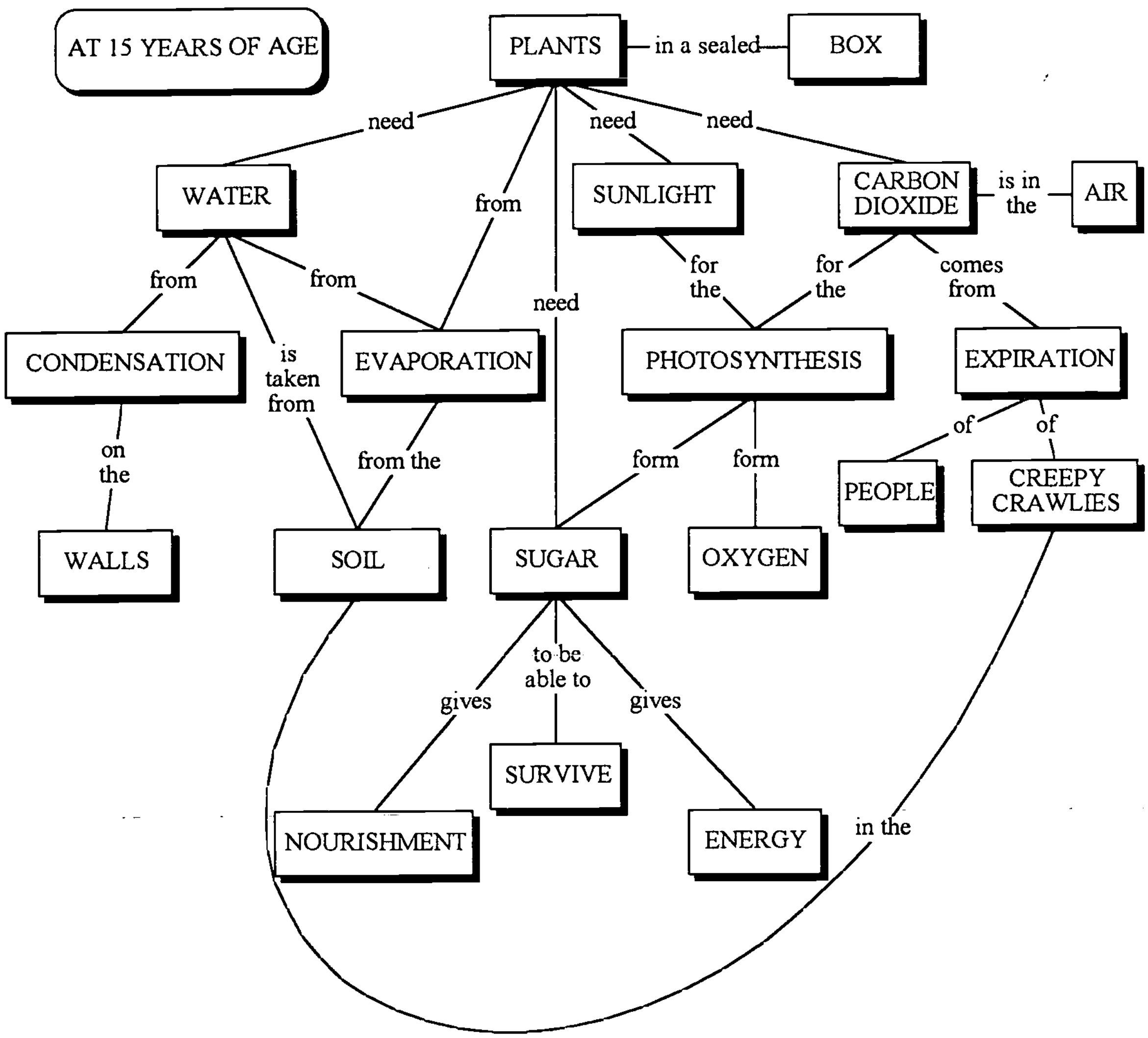


Fig. 2. A concept map drawn from an interview with Oscar about conditions for growth at 15 years of age.

Oscar found it however difficult to explain where the plants got the carbon dioxide from. He had assimilated that concept to human expiration, probably as a result of teaching. But this could not be the full explanation in this case, as the plants were growing in a sealed box. Later in the interview, he offered the suggestion that carbon dioxide could come from the breathing of small animals in the soil. An integrative reconcilation had occurred. See figure 2.

During every interview after the age of 10, Oscar mentioned that the plants needed to have small animals like worms in the soil because those organisms would improve the quality of the soil. Such ideas perhaps made it easier for him to connect soil processes to photosynthesis. His ideas about the role of the soil in boxes had changed from alternative conceptions to scientific explanations through meaningful learning. Also the superordinate concept water cycle had got a clearer meaning by assimilation of the concepts evaporation and condensation.

**Oscar's ideas about decomposition**

At nine years of age Oscar expressed his thoughts about decomposition of leaves on the ground through simple causual reasoning - one thing makes something happen. Disappearance was the main concept he used. He described a variety of ways in which the leaf disappeared by flying up into the sky, disappearing down into the ground, or into the snow or by 'mouldering away'. For Oscar "disappear" did not mean that matter did not exist any longer but that it was not possible to observe: *"Well, it disappears, so to say. It is divided into small pieces, I think, in order to be soil."* He claimed that moulder away to soil means fragmentation into small pieces.

Mouldering/rotting would, later on, function as a subsumer for other concepts in his cognitive structure. We can follow how he developed the concept "mouldering" up to 13 years of age. Through subsumption, new ideas were assimilated to the concept of mouldering. For example animals ate the leaves and contributed in that way to mouldering and soil formation. At 13 he distinguished between activities of different animals, worms and insects. Through progressive differentiation he developed a more diverse description. At 15, he replaced the concept of mouldering with a process with different organisms involved.

But still he claimed that decomposed organic matter was conserved as soil. This idea became problematic when he met the question what will happen to the planet Earth if the leaves falling down every year will become soil. At the age of 11 he said that the Earth would grow, even if would take time: *'Well, within some millions of years it will perhaps be jagged instead of being round. Because it will be so high that it will stick out from the Earth.'* Even at 13 he thought that the Earth would grow bigger but you have a feeling that he is not very convinced: *'Your eyes can hardly see it, but after some millions of years there is perhaps another meter.'* At 15 years of age he is struggling hard to find a reason why the Earth did not grow bigger: *'That it would keep on expanding all the time and become a great, huge planet. No, it doesn't. The soil must go somewhere..... I don't know where it goes.'* If Oscar had the possibility to assimilate the concepts respiration and microorganism to his cognitive structure, he would have been rewarded for his struggling. If we look above how he solved the problem with carbon dioxide in the sealed box, we will find that he was not so far from the solution of the problem, in realising that the soil is not the ' end point' for decomposition of organic matter. His ideas about decomposition were restricted to terrestrial environments. He could not explain what would happen to leaves lying in water. *"I think it will be allright. It will be wet and dark and keep lying there."*

Through integrative reconcilation, the concepts of nourishment and nutrient got a new meaning as a resource for trees which as a result of decomposition could keep their leaves. "Sunlight" had the meaning of being a necessary resource while at the same time, it would be a problem for the trees by causing dryness.

Oscar's ideas about defoliation developed from a leaf-centred idea at the age of 9 and 11 to a tree-centred idea at the age of 13 and 15. At the same time, he left behind his clearly expressed anthropomorphic ideas. At 15 however, one can still trace a residue of the anthropomorphic ideas from an early age. See page 15.

**Hanna's ideas about conditions for life**

At the first interview without introducing the box, Hanna claimed that a plant needs soil, water and sun to be able to grow. She also made a human centred statement that you need to have seeds in the garden, though plants just grow in the woods.

When the idea to grow plants in a sealed box was introduced, her conceptions of conditions for life were challenged. She added air to the other three resources she had mentioned before. She described a 'use-up-model' concerning for the plants' use of air and water to maintain life in the closed environment. Hanna claimed that the plant was the 'end-point' for both water and air and that there would be no more after some time. She had assimilated the plants' need for air to her cognitive structures by relating it to her conception that a candle cannot burn without air. An integrative reconcilation has occurred. Hanna also described the consequence of lack of air and water and predicted that the plants would wither and rot to soil in the closed box.

In spite of Hanna's earlier prognosis plants grew very well in the box. When she saw how wet it was in the box three weeks later, she did not mention anything about shortage of water. But she still claimed that there was no air left. She still applied a 'use-up-model' of thinking but now only for air because she could not deny that there was water inside the walls. Hanna concluded that this was due to lack of air in the box. Otherwise, she thought that the air had dried up the water. She said: *'It doesn't get any air and then steam rises up there and then it gets wet in the box. And there is no air in the box to dry it up. So it stood there and got mouldy.'* She perhaps had an everyday experience that wet things like clothes dried in air. Perhaps Hanna also had an experience that the effect of drying was larger in windy weather when she really could feel the existence of air.

There was mould in the box which confirmed Hanna's earlier statement that the moisture could not dry up because of lack of air.She also realised that the mould on the soil and plants had to do with the moisture: *'Well, if you say like this that at first it gets a bit brown there where the mould is and then there's moisture and steam. It'll be almost like a little cloud and it becomes attached to it.'* She had a rich store of concepts that she used to make the situation meaningful to her, even if her conclusions were incomplete and wrong from a biologists point of view.

At the interview six months after the cultivation in the box had started, Hanna described how the plants had withered. She did not explain however, it by sticking to her earlier statement that moulding and rotting depended on shortage of air that otherwise had dried up the wet environment in the box.

Hanna developed a new idea as an explanation of how the plants could survive in the box. Besides the 'use-up-model', she developed a 'cycle-model' in order to be able to explain why some plants could still grow in the box. She had assimilated the water cycle to her cognitive structure as a superordinate concept for other concepts. Hanna realised that water was conserved in the box and argued that the water cycle in the box made it possible for the plants to get air: *'We planted those before when there was air and then we poured water on them and then when the steam made some air, so they could breathe and grow.'* Later during the interview she confirmed that air came from the water by the water cycle, but this seemed to be a quality of the water or a substitution for air according to the following segment from the interview.

*I: Do you know anything now that you didn't know when we started the experiment?*
*S: Yes, that it could grow without air.*
*I: What is the explanation of that?*
*S: There was water and they got their moisture and nourishment from that instead.*

She still also applied a modified 'use-up-model' and claimed that the steam would lose its quality during its cycle in the box. Sometimes she seemed to think that air was synonymous with steam. In other cases she used the concept air as a quality of the steam or water. She had not assimilated air as a substance but as quality. Therefore, as can be seen in the following example, she used what she saw and assimilated steam as air to her cognitive structure.

*I: How can you see that the air is moving or how do you know it?*
*S: Because it is the only possibility, nearly, because if it stays up there, then the plant and this grass down there doesn't get anything. When we looked at it for the first time, when we put the plants in there, it was only down there. Therefore it must have been able to go down again, up again, down again in order to make it possible for them to grow.*
*I: Is it the same air all the time?*
*S: No, it gets thinner, and sometimes there's more steam and then there will be less air. Soon there won't be any air left only steam and then it will wither away completely.*

Hanna's ideas were challenged by the circumstances that the plants still were growing in the sealed box after six months. In order to be able to grow, the plants' needed resources. She thought that all the resources had the same quality of maintaining life and were therefore all mutually exchangeable.

When Hanna as an 11-year-old described what a plant like a snowdrop needed to grow, she mentioned soil and rain as she had done a year before but she did not mention sunlight. She also claimed that the plant needed air and nourishment. Her cognitive structure concerning a plant's need had gone through a progressive differentiation. Perhaps the discussion about the plants in the boxes a year before had challenged her ideas and facilitated the assimilation of new concepts. When the box was introduced, she still claimed that air was formed by the water cycle. She combined the use of a 'cycle-model' with a 'use-up-model' and argued that the quality of the air was impoverished during the repeated water cycle. She said that it was the sun that made the whole process work. Even when she saw the dry conditions in the open box with sweet violets, she used anthropomorphism and her 'cycle-model' of thinking and explained why the violets in the closed box were taller and looked fresher: *'They perhaps like the climate and the exchange of air.'*

Another year later, she said that the plants needed sun and water to grow in the box. She then described how she thought the plants got air through the water-cycle. There were a couple of invertebrates in the box during that interview and she thought that they also got their resources of water and air through the water-cycle.

At 13 years of age she mentioned that the plants in the box needed oxygen available from the beginning of the cultivation. Again she described the sun as a 'driving force'. According to Hanna the plant needed light in order to become green, which she claimed was a sign of health. She also made the teleological statement that soil was necessary because otherwise, the plants did not have a place where their roots could grow.

Two years later Hanna spontaneously mentioned the need for light, water and oxygen. Through integrative reconcilation, the concept of water got a more diverse meaning: - for the plant to grow in the box - for the absorption of nourishment - for the 'production of oxygen'. She described the role of the water in a way which made evaporation to be a prerequisite for water to be obtained by the plants. She said that the soil could hold an extremely small amount of water which could be utilized before evaporation started. She mentioned the plants' need for oxygen but did not say anything about air or carbon dioxide.

**Hanna's ideas about decomposition**

At 9 years of age Hanna described the decomposition of the leaves on the ground by using pieces of experiences from everyday life. She let birds and hedgehogs take the leaves and use them for their purposes. For Hanna, the leaves disappeared and were no longer possible to see. See figure 3. I have found that this is a usual way for children in the early years to explain a process that they do not understand. However, Hanna had another, more detailed explanation that had more to do with the decomposition process itself. Here follows a segment of the interview with her:

*I: Well Hanna, what happens to the leaves in autumn when they land on the ground?*

*S: Perhaps birds take them and build nests with them. And some of them sink into the mud when it rains.*

*I: What will happen to them in the mud?*

*S: They dry out in some way and shrivel up. Then when they are completely dry, it is enough for it to rain just once more for them to become just small bits.*

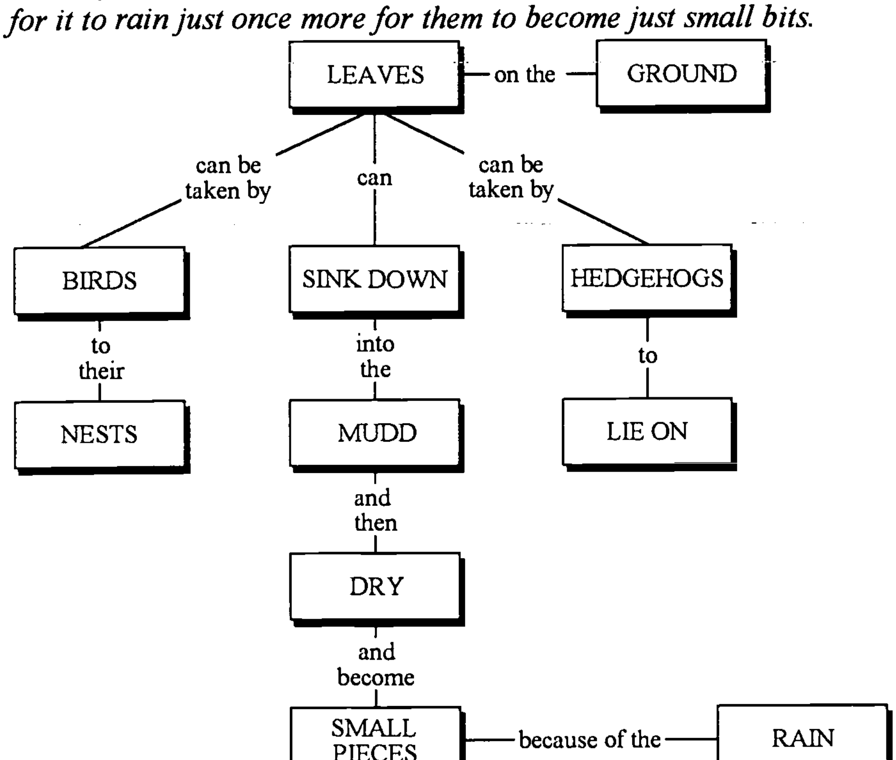


Fig. 3. Concept map drawn from interviews with Hanna about decomposition at 9 years of age.



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This idea must have built upon a powerful experience. It was so deeply integrated in her cognitive structure, that we can follow it all the way up to the age of 15. She assimilated new concepts into the old core concept which then got a new meaning.

At 11 years of age, Hanna assimilated the concept "rotting" that seemed to be a subsumer for other concepts concerning decomposition. Animal trampling was also assimilated. However, she considered the animals to be only involved in a mechanical fragmentation. In the first part of the interview, she did not say that soil was the end result of the process. When she was later asked the question about how soil was formed, she described the same process as before and with soil as the 'end point'. During the first interview in grade 2, she said that soil had always existed. As we can see on the following concept maps, she seemed to have the idea that there were two kinds of soil: the real, true or darker one and the one that consisted of products from decomposition.

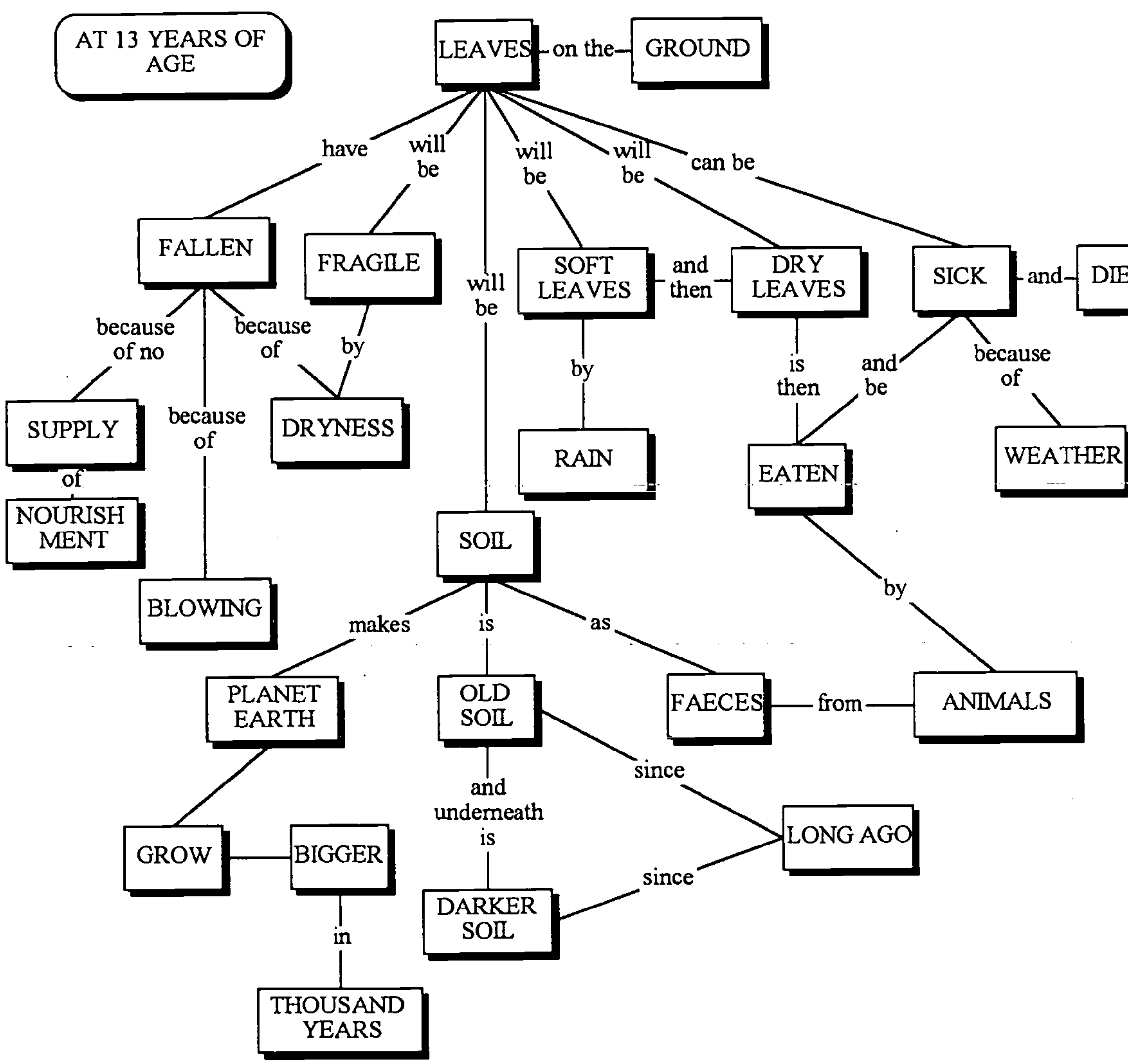


Fig. 4. Concept map drawn from interviews with Hanna about the composition at 13 years of age.

At 13 she took another step and assimilated animals' eating to the other concepts under the superordinate concept "rotting".The whole process got a wider meaning through inegrative



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reconcilation. She still started her explanation however by presenting the same idea as in the earlier interviews, namely that leaves were broken down by drying, raining and drying again.

Already at 9 years of age, Hanna argued that there was soil that had always existed. When she was 11 she expressed some uncertainty about how soil was formed. As a 13-year-old she said that soil was soil and that there was a darker soil under the soil that consisted of rotting material. Hanna underlined that this was soil that had been formed many years ago before we existed. Hanna seemed to talk about inorganic material that had been formed by erosion and accumulation. See figure 4.

When Hanna was 15 years old, she described the decomposition as two alternative processes. One process encompassed the core idea which we can recognise from the first interview about decomposition at the age of 9. The alternative idea describes how organisms are involved in the process. The two processes were seen as being partly integrated.

In the following segments of the interviews about decomposition of leaves we can follow how Hanna described her ideas from 9 to 15 years of age.

Age 9
*'Some of them sink down into the mud when it's raining. The dry out in some way and shrivel up. Then when they are completely dry. It is enough for it to rain just once more for them to become just small bit.'*

Age 11
*'I think they mould away. The will dry out ... then an animal is coming, trampling them and they become broken. It will become small, small pieces and then the real soil is pressing them down and they will be a lump and then it is raining and the sun is shining and it becomes soil.'*

At 13
*'They dry out and perhaps it rains so that they become soft. Then they dry out again. Then in the end they become ... and animals start eating them. Then you get soil of it.'*

At 15
*'It must be when it dries up. Then when it rains, it is mixed up with some mud. Then it dries and becomes soil. Or also some animals come and eat it. Their excrements will become soil'*

As an answer to the question about whether soil formation every year would influence the size of the Earth, she said at the interviews at the age of 11-15 that there would be more soil every year and at 11 and 13 that the Earth would grow bigger. At 11 she said: *'Well, it will be wider in some way. It's built up in some way'.* Two years later she said that it would take many years because it expands so little every year and added: *'I hope it will go faster; we are already too many on the Earth.'* She thought that soil was the end point for decomposition and that more soil would mean that the land area would increase.

She was a little more uncertain at 15 and said that the Earth ought to grow bigger but she seemed to have an intuitive feeling that it could not be so. She suggested that the earth's crust was sinking and that people were digging and using much soil and added: *'It can't be more than half a teaspoon f rom each leaf.'* After she had been reminded that there were many leaves falling down every year, she said: *'Well, the animals eat some, don't they, but of*



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*course it will be soil of their excrements.'* She was on the right track by trying to find an explanation to her intuitive idea but had not assimilated microbial activity and respiration to her cognitive structures.

Hanna willingly used anthropomorphic ideas to explain why the leaves fell in autumn as in the following sentences from the age of 11: *'Cos it's windy then and it becomes colder. It's not the climate they're used to. Then they haven't the strength to hang on any longer.'* At 13 and 15 years of age she talked more about the lack of resources like water and nourishment.

**Alexander's ideas about conditions for life**

At the age of 10y Alexander described the plants' need for resources to grow in the sealed box by mentioning resources like nourishment, soil, water, air and oxygen but also roots and and pot. Nourishment seemed to function as a superordinate concept for different needs that were necessary in order to maintain the plantlife. *'Well, it is water. The stuff they eat and so on. Well, water is nourishment for them like food is nourishment: just as food is nourishment for us.'*

He applied a 'use-up model' to what would happen in the sealed box, by saying that the water would disappear by drying up and that the oxygen would disappear by the plants' breathing. *'They breathe it in. Then they must have new nourishment in order to live. They can't live on the same nourishment all the time.'* He said that the water would dry up and go down into soil and then 'turn into oxygen'. See figure 5!

After three weeks and after six months when he saw that there still was water in the box, he abandoned the idea that the water would dry out. However, he still thought that the air was used up, with the result that the plants withered. When he was 10 years old, Alexander had thought there was a problem in the box being sealed by a glass lid; it appeared to prevent the water from evaporating. However, one year later, he interpreted the sealing as an advantage, because it prevented the conditions in the box from becoming too dry for the plant. He did not say anything about the need for oxygen or air.

At 12 years of age Alexander argued that both water and oxygen were adequate but then he added that the air must be exchanged. He realised that the water came from the soil that had originally been put in the box from outdoors. At the ages of 13y and 15y he continued to use a 'cycle model' in talking about the cycle of water in the sealed box.

At the age of 12y, he also argued that the plants needed soil, with worms, that could facilitate mouldering of the leaves and in this way improve the qualitaty of the soil. He also mentioned this process at the ages of 13y and 15y.

Alexander explained at 12 why the animals could survive in the sealed box as follows: *'They need air, don't they. They get it from .... 'cos plants are like humans, aren't. They breathe it out.'* Concerning the conditions for life in the aquarium, he thought that the plants there did not need any air because they could live under the water. He had not yet assimilated the air as a substance that could be dissolved in a liquid. Therefore, he could not think that water in the aquarium could contain any air.

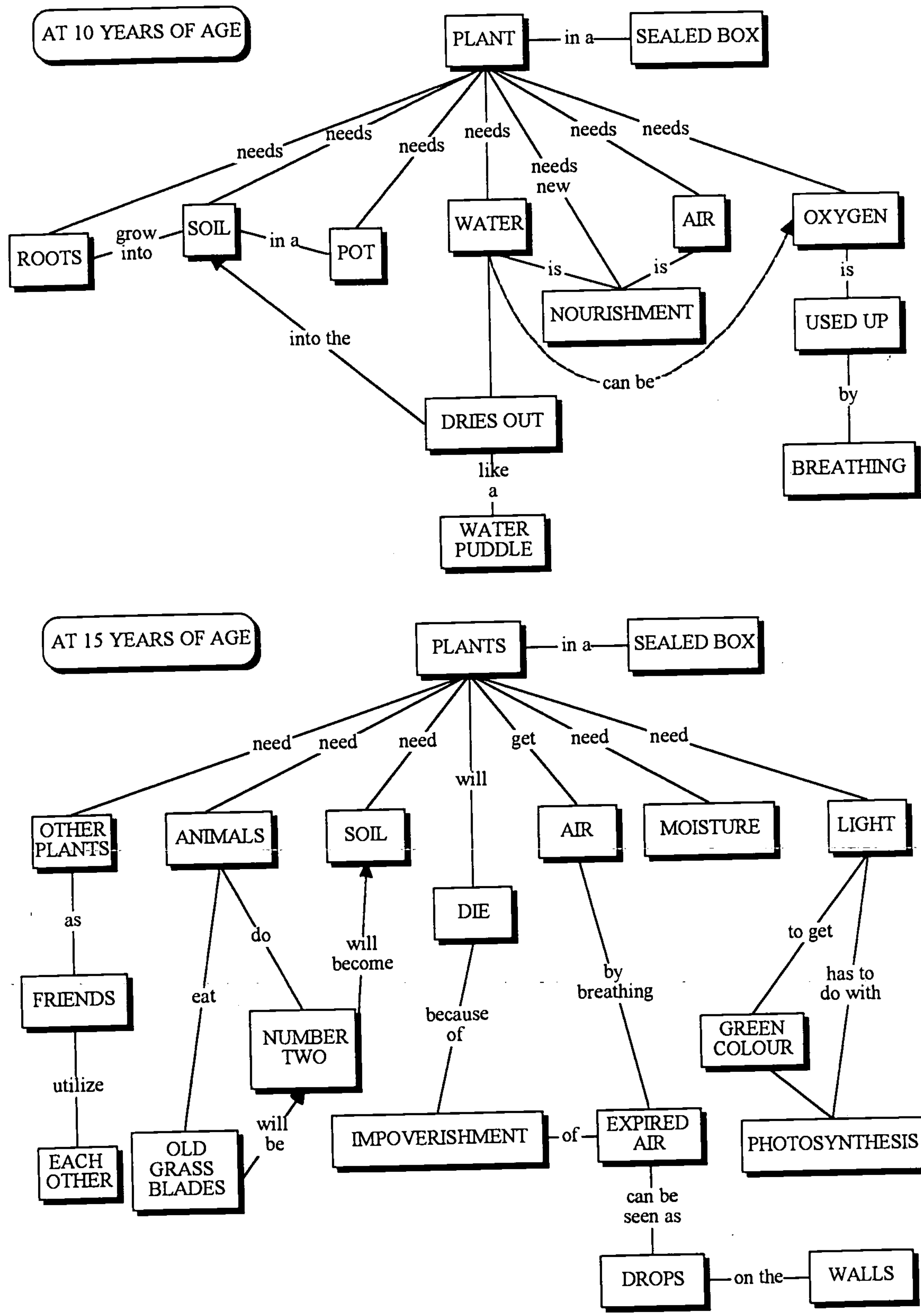


Fig. 5 Concept maps drawn from interviews with Alexander about conditions for growth at 10 and 15 years of age.

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At 12 years of age he argued for the first time that a plant needs light. He mentioned an anthropomorphic reason for this, namely 'to be awake'. Alexander gradually assimilated other characteristics to the subsumer light and at 15 the concept light had been integrated as a subordinate concept under the superordinate concept photosynthesis.

Alexander seemed to have problems in understanding the whole spectrum of needs. As an 11 and 13 year old he did not say anything about the need of oxygen and air. He had not progressed sufficiently to differentiate the need and exchange of such resources as oxygen and carbon dioxide. During the interview at 15y, he struggled to understand and describe how the plant could breathe and survive in the sealed box. Here follows a segment from the first part of the interview: '*I am not at home in that stuff but they breathe in the same air once more, don't they. They breathe out and that is what they have here. There are drops inside the glas here, aren't there. I think they so to say breathe in the same air.*' When I asked him how he thought this could happen, he answered; '*No I suppose, they can't that many times. I suppose they die at last.*' He had problems to think of air as a substance in a gaseuos state. Therefore, he used his own experience of having seen water drops condense as result of expiration. I think this is an experience that could be a reason for several students in this study to think that air could be transmuted to water or vice versa. See figure 5!

**Alexander's ideas about decomposition in nature**

At 9 years of age Alexander said that the leaves on the ground disappeared under snow and that they would rot to soil next summer because they were old and got mouldy. As an 11 year old he was talking about something that was happening down in the soil where the leaves rot to soil. He described how the leaves were pulled down into the soil and eaten by animals. The subsumer 'rot' had got a new meaning because new concepts like 'grub' and 'eating' had been assimilated to Alexander's cognitive structure.

At the age of 13y and 15y Alexander said that the leaves rot through a process where worms and other animals ate them and that the animals' faeces became soil. It was no longer a process that was hidden under the snow or down in the ground. Alexander also gave the concept 'soil' a wider meaning. He thought soil not only consisted of sand and excrement from animals but also of twiggs and roots. Through all the interviews from 9 to 15 years of age, it looks as though he considered soil to be the 'end-point' of decomposition.

When he was 15 I asked him if the yearly defoliation and decomposition of leaves would influence the size of the planet Earth, he said that it did not. This seemed to be an intuitive idea that he explained at 11 years of age by the small amount of material. At 13 years of age, he suggested that the new soil was redistributed: '*No, it will be like fifty fifty. A little falls into the water or something like that.*' At 15 years of age Alexander said that the Earth could not become bigger of the following reasons: the earth's crust was pressed down; plants absorbed a part of the soil; the excrements from animals did not contain all the food. Thus, the activity of organisms in the soil played an important role in Alexander's thought. A progressive differentiation was going on. If he had got the possibility to assimilate the concepts 'microorganism' and 'respiration', the whole matrix of concepts had changed through integrative reconcilation.

From 9 to15 years of age, at all the interviews about the decomposition process, Alexander said that defoliation was caused by deminishing resourses, which could be sap, nourishment, water or oxygen. His explanations are strongly characterized by anthropomorphic reasoning.

At 11y he said: *'They don't get oxygen, they don't get as much nourishment. And their muscles or what you call it, become weaker and weaker and they drop off.'* At 13 he talked about about diminishing strength as a result of getting no resources from the frozen ground. Also,at 15y, he found that cold weather was the reason of defoliation.

**Anders' ideas about conditions for life**

Anders argued at 10 years of age that the plants needed soil, water and nourishment in order to be able to grow. He said that nourishment was something that people spread in the gardens while plants out in the woods did not need any nourishment.

When the experiment with the sealed box was introduced, he claimed that the plants needed soil, water and air, but now he did not mention nourishment. He described a 'use-up-model' for air and argued that there was no more air when the plant had consumed it. He said: *'The flower takes it up and then it is used up.'* He thought that the plant was the 'end point' for air and not a part of a cycle.

Three weeks later he had assimilated the concept oxygen to the plants' needs and it seems to be a compensation for air. He thought that some plants in the box had died because of shortage of oxygen and that mould had developed from water for the same reason. Anders described the water cycle in the box in a way that meant that the cycle was a prerequisite for the water to be available for the plants. When he saw the grass and moss grow in the box even after six months, he said that it was the light that had made this possible. He thought that both the grass and the moss had started to be brown and that it would rot to soil.

Even as an 11-year-old Anders claimed that a plant needed soil, nourishment and water to grow. After the introduction of the box, he mentioned that nourishment, water and air were necessary resources for the plants in the box. Compared with one year earlier, he now found that nourishment was something that came from water and soil. Even now Anders described the water cycle as if it made water available for the plants after condensation on the lid and on the walls. He did not see water in the soil and therefore had difficulty to understand that it existed there until it became visible through the water cycle. Concerning the air in the box, he applied a 'use-up-model' and described the roots of the plants to be the 'end point' for the air which the plants had taken in.

Again as 12-year-old, he applied the 'use-up-model' and explained that water and air with its oxygen would be finished. Anders claimed that the soil could give the plant both nourishment and mecanical support from the soil. In the same way as before, he thought that water became available for the plant through the water cycle; but now he also let air be available through the water cycle. He thought that the water film inside the lid contained air that both the plant and the animals utilized. By referring to his own breathing he showed what could be the origin of his conception.

I: Anything else they need to be able to live down there?
S: Yes, and air. That's what we need too.
I: Where do they get it from?
S: Well, they use some air from what is on the lid.
I: What do you mean?
*S: Well, the grass and the plants use just as much air as they need to start with. Then the animals use a bit of it.*



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Even as a 13-year-old Anders tried to explain the plants' survival in the sealed box by saying that they got their oxygen from water, from the water bubbles inside the glass lid. Now it was evident that he referred to his own breathing when he said: *' There will be steam when you breathe on it.'* Anders showed a human-centred idea that life demands oxygen and this was now confronted with the idea that the plant breathes out oxygen.

He now claimed for the first time during the interviews that the plants needed sunlight but he had no deeper idea about it. In that case he described the following anthropmorphic and human centred idea: *'Cos ... They can ... I think they must be able to live but they won't be very nice to look at. I think they get sort of ......, they shine up just as the light when it sees light. Then it'll be allright and then it'll be happy and shows its good points. Shows its colour, I think.'*

Anders argued at 15 years of age that the plant in the box needed nourishment, moisture and oxygen that was in the air. He claimed very clearly that the plants used the moisture that was formed in the box. That means that he still had the same idea that the water cycle was necessary to make water available. See figure 6.

He also still had the idea, full of contradictions, that the plant needed oxygen which came from the plant and from the soil. At the same time he applied a 'use-up-model' to the circumstances in the box and said that he did not believe that the plant could survive in the box because the oxygen would be used up.

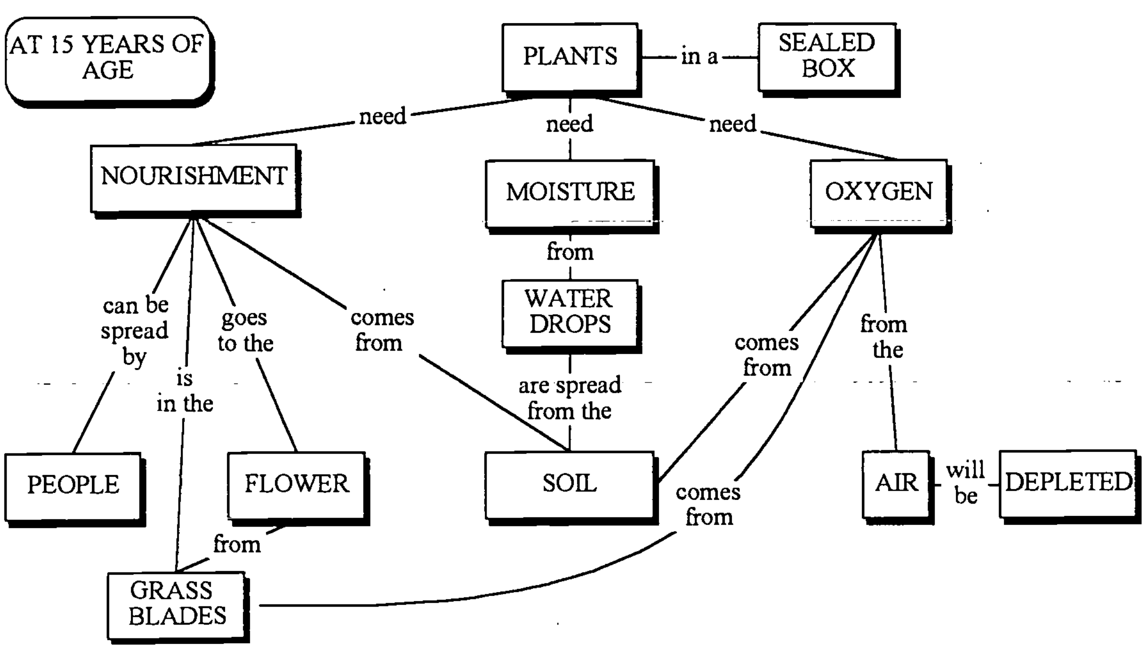


Fig. 6. A concept map drawn from interview with Anders about conditions for growth at 15 years of age.

**Anders' ideas about decomposition in nature**

At all the interviews about the decomposition process from 9 to 15 years of age, Anders claimed that the leaves got rotten or mouldered to soil without mentioning anything about organisms being involved in the process. Oscar seemed to have had an important experience of composting already when he was 9 years old. He claimed for example that eggshells and



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coffee grounds on a compost heap rotted to soil as well as the leaves. He mentioned the eggshells at all interviews about decomposition up to the age of 13.

When Anders was 11 years old, he described how old and new soil were mixed and that it took four years for the compost to turn into soil. As a 15-year-old, he had also assimilated the concept "forest" to the subsumer "mouldering" when he realised that the same process was going on in the forest as in the compost heap.

His early experience of composting seemed to both enrich his cognitive structure and limit further development. He looked upon the process as a mixing process after a fragmentation of the material like the one he described at the age of 11 and without any organisms to be involved. He went so far that he hesitated to call the end product soil. Here follows one segment of the interview at 15 years of age:

*'I: How does it become soil? Do you have any thought about that? Here you have leaves and there's some grass.*
*S: Well it goes into sorts of very small bits. Then they're on the ground out in the woods. Then it is mixed up with soil. It is like compost. You have some soil on the bottom and it stays there becoming smaller and smaller bits. I think it is the same with the leaves, that are mixed up and then there'll be more and more of it. I don't really think there'll be soil but I think there will be tiny, tinyl bits that are mixed up with ground. Then you say it has become soil.'*

The decomposed matter was conserved as soil. Anders explained this by saying that it disappeared to soil. Instead of talking about organisms that made the leaves moulder, he claimed from 11 to 15 years of age that it was water. Even if his ideas seemed to be limited in same way, he had assimilated new concepts to his cognitive structure at 13 and 15 years of age through subsumption. The subsumer "soil" got a wider meaning when clay, sand and stones were connected to it.

His experience of composting could not help him to understand what happened to paper, plastics, iron and glass on the ground. He said that it disappeared in different ways. For example, when he found that the glass jar could not fly away, he said that it would blow down into a pond and sink into the mud. To let something go to a place where you cannot observe it, is a way young students use to solve a problem to which they have no solution. They often use the word 'away' to illustrate what they mean. In some cases students use the word "disappear" implying that the object does not exist any longer rather than that it cannot be seen.

The consequence of Anders' conception that the leaves continued to exist as small fragments after the decomposition process, meant problems for him when he should explain how the size of the Earth was influenced by the yearly decomposition of leaves.

At 11, he said that the whole Earth would be filled with soil when he described how the soil was moved out onto the flower beds. Again the experience of composting was important. When Anders tried to explain the phenomenon when he was 13 years old, he said that he did not think the Earth would grow bigger, since not everything that fell down would become soil. He implied it would fly away. He solved the problem in the same way as two years earlier.

At 15 years of age, Anders accepted the consequences of his idea about the decomposition process and explained how the Earth grew bigger: *'I think the Earth will grow bigger each*



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*year. It expands and one thin layer is added and so on, 'cos there are a lot of leaves and that sort of thing that disappear. And it expands and it is added ... the Earth is round, isn't it and a layer is added each year. Therfore, I think that the size of the Earth increases because of ... it doesn't need be only soil, but soil is only a part of it.'* Then he added some ideas about expansion of the Earth because of a geological process. See figure 7.

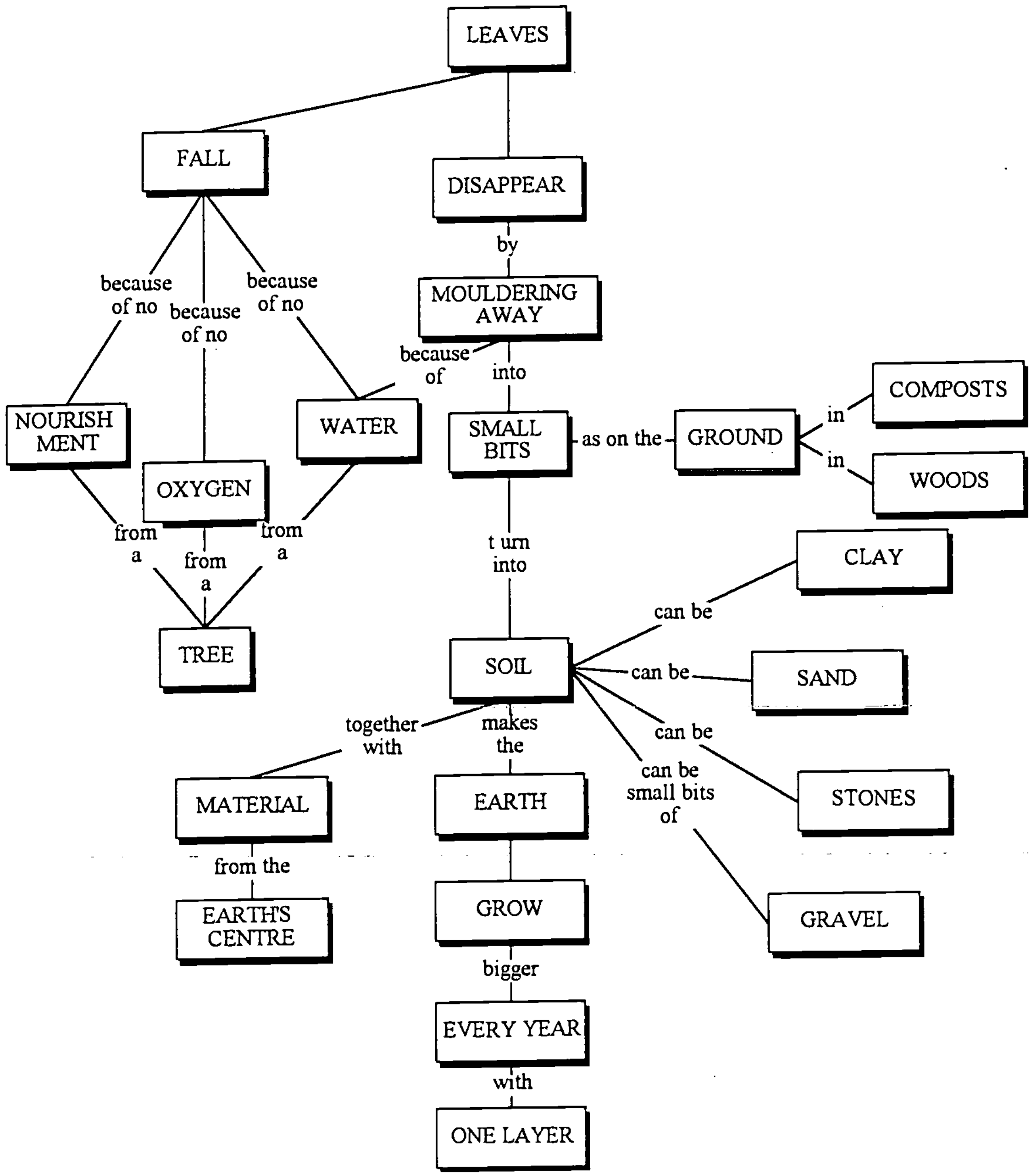


Fig.7. A concept map drawn from an interview with Anders about decomposition at 15 years of age.

Anders interpreted at 9 that it was shortage of water that made the leave fall to the ground. Two years later he said that the leaves fell because it was windy in autumn and that it was a preparation for new leaves to develop. At 13 years of age Anders talked about causes like the wind, less sunlight and less water. Two years later he had assimilated several concepts to the superordinate concept "defoliation" which made the whole process more meaningful to him

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even if it is not scientific correct. He still believed that the tree needed oxygen that it got from the ground.

Anders explained the defoliation in the following way and with a slight touch of anthropomorphism: 'They blow down 'cos even if they are small, they are quite strong and they are stuck to the tree. It gets cold and the tree doesn't get enough nourishment and oxygen from the ground and perhaps the tree's a bit dry. It's drier and the ground is frozen.' It looks like that the studies in ecology a couple of months earlier had helped him to assimilate consequences of the frozen ground but may have also have strengthened the misconception that all the tree's resources.



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## THE STUDENTS' IDEAS ABOUT THEIR OWN LEARNING

Already two years after the first interviews, students came to me and asked to listen to what they had said about the processes at the beginning of the study. Several of them showed as 15-year-olds great interest and in some cases enthusiasm to listen to the interviews from four years earlier. Many students made spontaneous comments when they heard the interview on the tape and said that their ideas of today were very like what they had said at 11.

When they explained how their understanding had changed through the years, nine girls and two boys said that the difference had to do with how their thinking had changed. This group of students consisted both of children who had expressed well differentiated ideas as well as of children who had not developed their understanding very much. Three in the former group explained how they had developed their understanding, from mostly listening to what others had thought, towards a more independent thinking of their own.

Johanna, Sofia and Hanna belong to that group of eleven students. Their descriptions of their own conceptual development shows that they have started to think about the process of learning. Johanna described her development in the following way: *'At that time I only thought about things, like piece by piece, but now I have put them together.'* Sofia claimed that her knowledge at 15 years of age consisted of a framework that she had developed at an early age and then coloured and built upon. She thought she came back to that framework all the time. Hanna talked very much about a child's development and maturation and how she had got another language: *'Well, the world grows all the time. You learn to think in new trajectories, a little more logical. It isn't so small as when you are a child. And there will be more anxiety.'*

The other students in the class explained how they had learnt from experience at school and outside school, without saying anything about the development of their thinking. Three students with a well differentiated understanding at 15 years of age, argued that learning is a process which you yourself are responsible for.

When I asked the students what had contributed to their knowledge, 24 of the 28 students mentioned teaching at secondary school but six referred to the primary level (7-13 years). Oscar claimed that it was school only that had helped him to develop his understanding. The students often described separate occasions that had contributed to a better understanding. 15 students said that conversations and other experiences together with parents and sometimes grandparents had been important.

23 of the 28 students could describe concrete experiences, often in detail, that had contributed to the development of their ideas. Many episodes were from the ages of 5-10.

Anders had a very clear experience from early childhood when he followed how a neighbour worked with his compost heap. We can trace that experience in the interviews all the way up to the age of 15.

We can also follow the characteristic feature in Hanna's description of the decomposition process from age 9 to 15. She explained why she described it in that way. Near the house where she lived were two big birch trees from which lots of leaves fell every autumn. There she had recognised how the leaves gradually decomposed on the muddy ground.

Annie described at 11 years of age how sand in the soil was formed: *'Small stones are peeled and cut into pieces and then you grind them to sand.'* This idea was developed during summertime when her family stayed in a summerhouse near a quarry where she had seen how they worked with the rocks.

The question of how the decomposition of leaves every year would influence the size of the Earth was the question that caused most confusion for the students even at 15 years of age. Most students could not give a differentiated explanation of the problem. Many alternative explanations were given. Sofia explained why she thought that all the leaves would not be soil and therefore not contribute to an increase in the Earth's size. She mentioned at 11 that leaves could instead be decomposed in a compost heap or burnt up. At 15 she said that those ideas had developed when she saw the activity in the compost heap at home and when she experienced how trees and leaves were burnt up on a big bonfire every year on the 30th of April.

**DISCUSSION**

The children in this study had continuously more-or-less developed their understanding during the years of the study. To make the understanding of the processes meaningful, the students assimilated different concepts depending on what they had assimilated before and how their cognitive structure was organized. Therefore, the cognitive structure concerning the processes studied developed an idosyncratic nature. Many students could themselves describe concrete experiences which they had assimilated and then used as subsumers for other concepts. There are, however, some common features in several students' explanations.

In order to understand what was going on with the plants in the sealed boxes, the students assimilated a 'use-up-model' that meant that the plant was the 'end-point' for the different resources. The idea was strongly established and retained even up to 15 years of age. It worked well as a way for the students to explain their observations, and was supported by everyday experiences, for example the way in which we water plants without being able to see how water also leaves the plants. For some students, the closed box stimulus meant that the plant would eventually die because of lack of water, air or oxygen. If the concept "transpiration" had been subsumed to other concepts under the superordinate concept "plant" and perhaps introduced practically, the students might have been able to look upon the plant as an organism delivering water to the environment rather than as an endstation.

When the 'water cycle' was introduced or brought up again, the students assimilated the 'cycle model' to their cognitive structure and used it to explain the movement of different resources. The 'cycle model' made the processes in the box meaningful to the students throughout the years up to the 8$^{th}$ grade, even though the explanations were sometimes scientifically incorrect. Several students developed their understanding of the cycles continuously. I would argue that other concepts such as transpiration, evaporation and condensation could have been introduced at an early age at school, facilitating the development of a deeper understanding.

The students had assimilated the concept "steam" under the superordinate concept "water cycle". When they tried to describe what happened with other resources in the box, they did not differentiate between steam and air or oxygen but used the steam as something that could contain both air and oxygen. Their interpretation made the situation in the box meaningful. If the concepts "air" and "oxygen" had been introduced, it might have helped them to develop a deeper understanding of the conditions for life.

An important change of the understanding of the decomposition process occurred when organism activity was assimilated but for the students, the soil was still an 'end-point' for decomposition. When the students assimilated the activity of microorganisms under the superordinate concept decomposition the process got a complete new meaning which made it possible to understand that soil was not the end point for decomposition. It gave them the possibility of assimilating water, carbon dioxide and minerals as the major end products of the decomposition process.

Concerning the decomposition process, I claim that it would be possible to introduce not only the concept microorganism but also carbon dioxide and oxygen as gases at early primary level. Many students are familiar with the words at that age and it would be possible to introduce those concepts in connection with a study of the development of a compost heap.

As 15-year-olds the students explained how they picked up what they heard and saw in everyday life. In this way, they assimilated very different concepts to their cognitive structure. Some of them also claimed that common sense and language were important for the development of their understanding. Several students underlined that they often referred to the function of their own body when they tried to understand other biological processes.

I think all experiences the student have had are an important resource in an education strategy that tries to help student to understand. The prerequisite is that the students get the chance to show and discuss their experiences and conceptions.



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## CONCLUSIONS

By comparing concept maps of interviews at different ages, a good picture of conceptual development can be obtained. It is possible to follow how the relationships between the concepts can change, for example how assimilation of a new subordinate concept can change the meaning of a superordinate concept. If we identify such changes and analyse them in order

to see why they occurred, we can use that knowledge:
to improve teaching and learning in cases where meaningful learning did not occur,
to create new learning strategies for the introduction of new concepts.

We need to decide which main concept might be needed by the students in future. Children's thinking in relation to such concepts can be starting points for the creation of educational strategies that challenge their ideas. They can then assimilate the new ideas into their existing knowledge frameworks and enhance meaningful learning. Perhaps we should drop some traditional concepts and experimental settings in order to create new approaches that concentrate on main concepts and based on a good understanding of young children's thinking.

Another resource that can be used much more is to let children study their own learning in order to help them to learn how to learn. That means that we must give children experience of how their ideas can change in the learning process. I have found that children are very interested in their own learning. Each child's conceptual development has its own story, and that story can be used as resource for both the learner her/himself and for the teacher. Even if the the cognitive structure is idosyncratic there will be some categories of features that can be used in education. There appears to be a metacognitive capacity in children's minds that have not been fully utilized.

It thus appears that for a successful science education in the early ages we need
- to identify a limited amount of important concepts,
- to identifiy children's ideas in connection to those concepts,
- to work out educational strategies to facilitate meaningful learning,
- to help children to learn how to learn,
- to create an atmosphere that give the children opportunities to recognize, discuss and reflect over their ideas,
- to show children that we find their ideas interesting and valuable.

I argue that in the early years at school there are great possibilities to improve the total result of school education. Meaningful learning in science should not only focus upon the learner's thinking. Feeling and acting are also important.

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