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Paper Title: Pupils' Understanding of Ecological Processes and Their Conceptions of Matter
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Abstract: This paper reports on a longitudinal study of pupils' understanding of ecological processes, with emphasis on how their conceptions of matter influence the development of their understanding those processes. A class of 25 Swedish pupils is being followed from age 8 to 15 in an interview study using the revised clinical method.

The pupils' ideas were challenged by cultivating plants in closed transparent boxes, and investigating leaf litter. Initially, the pupils expected the plants to die, and constructed a 'use up model' in their minds to explain how water and air were consumed. When they saw plants survive they used a 'cycle model' to explain how the organisms maintained life-supporting resources. Some pupils thought that water, air and oxygen were formed during the cycle. Many pupils thought that soil is the ending place for matter in decomposition, with the result that the Earth would increase in size. Other pupils constructed explanations as to why the size of the Earth does not change, such as matter disappearance, displacement, modification, transmutation and chemical/biological interaction. Pupils' ideas about the transformations of matter can be explained by their limited conception of the gaseous state.

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PUPILS' UNDERSTANDING OF ECOLOGICAL PROCESSES AND THEIR CONCEPTIONS OF MATTER

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BACKGROUND

In connection with an intensive debate on the advisability of building a refuse disposal unit in the town of Kristianstad, Sweden, the public started to discuss what would happen to recidue from refuse incineration.There was limited knowledge of what actually happens to refuse in general. Many thought that the matter would disappear, except for a small residue of ash. There was no recognition of the existence of, for example, waste gas. We are justified in asking whether this is the kind of knowledge which citizens should acquire at school.

As a secondary school teacher in biology, I have encountered many students who were unable to express, in their own words, how biomass builds up and breaks down, or where matter comes from and where it goes to. This is even true of students who have worked with concepts such as photosynthesis and respiration. Could this lack of understanding be due to the fact that our teaching has not been based on the students' own thinking about different phenomena? Has knowledge been reduced only to "school knowledge", without having challenged the students' everyday understanding?

If we, as teachers, want to help pupils to obtain more extensive knowledge of the environment, we ourselves must know more about children's ideas about different phenomena, in order to learn about the pupils' starting points of learning. Only then shall we be able to create teaching situations in which the children's ideas will be challenged.

In order to get to know more about the development of pupils' understanding of ecological processes I started a longitudinal study in 1988. I followed a group of 25 pupils from 9 to 15 years of age, that is between grade 2 and 8 of a Swedish comprehensive school. A part of this study based on a 9-12 y age group is published in my doctoral thesis (Helldén, 1992).

PREVIOUS STUDIES OF PUPILS' IDEAS OF TRANSFORMATIONS OF MATTER IN NATURE

Let us look upon three examples from biology where the understanding of the concept of matter could be problematical.

1. The organism maintains 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.

These three examples of gas exchange processes cannot be seen by the ordinary observer. Children take it for granted that everything that you cannot observe does not exist (Driver, Guesne & Tibergien, 1985). In that case, the pupil constructs her own explanation in order to understand and describe the phenomenon.

Several studies have shown that it is difficult for many pupils to imagine that a plant assimilates a gas to be raw material in building up the plant. Instead, they think that plants obtain their food from the soil through the roots (Simpson & Arnold, 1982, Roth et al, 1983, Andersson & Eliasson, 1987).

Russell & Watt (1989) found that many 5-11 year old children thought that the plant's germination and growth was a result of different parts being folded up. It was not unusual that the children thought that growth itself generated new matter, for example, during the development of an egg, or a plant from a seed.

Children's difficulties in understanding decomposition have been documented by Smith and Anderson (1986). They found that the children were generally aware of the fact that dead organisms decay and rot. However, many of them did not recognize water and carbon dioxide to be products of decomposition but only recognized soil and soil minerals as decomposition products. Some pupils viewed dead organisms as simply rotting away. They did not recognize that the decaying material was converted into other materials that became parts of the environment.

Seqeira and Freitas (1986) found that amongst 10-13 y old pupils very few had the idea that organic matter was converted into mineral nutrients. For many pupils decomposition meant that materials were eaten, worn out, gone into pieces, were rotted or disappeared up into the sky.

Leach et al (1992) described how problematic it is for the children to understand decomposition. They found children's ideas to be very context specific, and there was no evidence that these pupils had a general theory to explain decomposition in a variety of contexts.

I think we can learn a great deal from research on pupils' conceptions of matter and the transformations of matter which are studied in physics and chemistry when we want to describe pupils' ideas of matter exchange between the organism and its environment. Andersson (1990) has given a description of five general categories of conceptions based on a large amount of material collected from the many published research reports.

These five categories are 1. Disappearance. 2. Displacement: a substance can appear in a given place simply because it has been displaced. 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.

METHODS

As a result of a pilot study, and projects undertaken by student teachers investigating pupils' conceptions, I have found that clinical interviews give the best information on children's ideas.

The interviews in the present study were carried out at a small school surrounded by mostly private houses in Kristianstad, a town in south Sweden. The children were interviewed over the years at different occasions from grade 2 (9 years) to 5 (12 years) of the Swedish comprehensive school. In grade 2 there were 25 pupils (12 male, 13 female), in grade 3 there were 26 pupils (11 male, 15 female) and in grade 4 and 5 there were 29 pupils (14 male, 11 female).

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 the pupils 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 .....?"

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

During the interviews about decomposition, I placed on a table in front of the interviewee, soil, brown leaves and litter from a deciduous forest, and used this as a point of reference.

CHILDREN'S IDEAS OF CONDITIONS FOR LIFE

The pupils thought that plants and animals must 'take in' matter of differnt kinds from the environment but did not express the passing of matter from the organism to the environment. The living organism was the end station of the flow of matter through the ecosystem. Initially, many pupils expected the plants to die in the sealed boxes. They constructed a 'use-up model' in their minds to explain how air, oxygen, water and other resources were consumed. When they saw that plants survived, the pupils constructed ideas about the plants' utilization of the resources in the sealed box. On the whole, the following four ways were used to describe this.

I. Matter as a life-supporting resource is consumed gradually. Most pupils thought that there were sufficient resources of water and air in the box at the beginning of the experiment. They thought that the resources were then consumed, or lost their life-supporting quality. They could express it in the following way: *"If they have used the air a couple of times, it is too old and there is no nourishment and no oxygen left." "The air will be thinner and thinner and at last the plant will fade."*

II. The resources come from a supply. Several pupils thought that the soil was a supply of resources of nourishment, water, and oxygen needed by the organisms. They used a 'cycle model' to explain how the resources were renewed: *"The air disappears down into the soil to get more nourishment. Then it moves up again. Then it moves up and down, up and down."* Others thought that the plants got carbon dioxide from the soil.

III. Matter is renewed, modified, transmuted or disappears. Most of the pupils solved the problems concerning the plant's need by conceptualising what are, in chemistry 'forbidden' transformations. Water vapourised and the condensed water on the inside walls of the sealed box made the water visible and challenged the pupils' thinking at an early age to develop a 'cycle model' in their minds. This can be called a modification. One of the pupils said:*"Well, 'cause it will be some steam that moves up and then it forms some water and then it falls down."*

Some pupils had the idea that fresh water, air and oxygen were formed by the water cycle. Such an idea can be characterized as a transmutation, i.e. one

of the 'forbidden' transformations. One pupil pointed at the plants in the box and described her ideas in the following way: "*Then it will be condense. If this goes up and it rains down again, then it makes air; so they get air.*" Another pupil described how water was transformed into oxygen when it dried.

Other pupils used another way to explain the changes by saying that matter disappeared. *"The air disappeared into the old air." "Water disappeared by drying up."* The reason why pupils used transmutations and disappearance to explain the transformations of matter can be explained by their lack of a conception of the gaseous state. They did not understand the evaporation and condensation of water but observed the result (Bar, 1989). They used what they saw to explain the conditions for life in the sealed boxes and applied a 'cycle model' that they had incorporated into their minds at an early stage of their development.

IV. Organisms produce the necessary resources. In grade 4 and especially in grade 5, some pupils tried to explain how oxygen was produced by the plants and that there was a gas exchange between the different organisms. Such conceptions presuppose that matter can be transported between different parts of the ecosystem. Many described this transportation as a cycle or as parts of a cycle. The water cycle has been the prototype for this thinking at an early stage in their cognitve development..

IDEAS ABOUT DECOMPOSITION IN NATURE

Several pupils in grade 2 (9 years) answered questions about what happens to leaves on the ground that disappeared, by saying that leaves flew up into the sky, would blow away or were rained away. According to their conceptions, matter was not conserved. Other pupils suggested that the matter was broken up into smaller and smaller pieces until they could not see anything of the leaves. Even here, the pupils did not understand the conservation of matter. They thought the leaves were moved down into the ground during fragmentation. Oscar said: *"The soil eats the leaves."* In other cases the children thought that the work of the soil invertebrates was only a fragmentation. All pupils except one thought that food only was transported through the human body. According to those conceptions, matter did not pass through any change of phase.

In grade 4 (11 years), pupils thought that paper would become soft and was to be mixed with the soil during decomposition. Nails would rust into a powder. One pupil thought that plastic became liquid and disappeared down into

the ground and another one thought that glass became converted into ice. These two conceptions can be seen as transmutations.

Most of the 11 year olds thought that leaves, grass, wood and paper were converted into soil. This process was seen as taking place with or without organisms. Because they could not observe any exchange of oxygen, carbon dioxide and water with the environment during the decomposition process, they thought that the biomass was conserved as soil. In their conceptions, soil therefore became the 'end point' concerning decomposition in nature and not a stage within the cycle of matter.

When the pupils were asked what would happen to Earth if every year, all the leaves were decomposed into soil, one third of the class thought that the Earth would increase in size. Other pupils imagined Earth to be something like a container. They did not think that the size would change, because all new soil would fill hollows or be compressed. Some pupils in the class thought that the size of the planet would not increase because matter would disappear, for example by blowing away. Others thought that the unchanged size would depend on matter being burned up or eaten by animals. It seemed that many pupils had an intuitive feeling that earth could not increase in size and therefore they constructed a number of explanations for this phenomenon.

THINKING ABOUT CYCLES

The pupils' ability to think that movement of matter was a part of a cycle was developed at an early stage at school. They constructed ideas about a model describing the water cycle. When the ten year olds saw the water covering the inside walls of the sealed plastic boxes I challenged their ideas. Each pupil constructed her own idea about the water cycle. Most of the pupils then used their 'cycle models' as prototypes to explain how organisms could survive in the boxes and maintain life-supporting resources such as air, oxygen, water and nourishment.

The The pupils described two types of 'cycle models'. One model described a cycle outside the world of organisms and was the first one they developed in their minds. In this model, water evaporated from the soil, was condensed on the the inside of the sealed boxes and trickled down into the soil again. Some children described a similar model for the cycle of air and oxygen following the water. Another model described how the organisms were

involved. In this model, water evaporates from the plants, is condensed and trickles down to the soil and is sucked up by the plant.

Grade 3 pupils who had just begun cultivation of organisms in the sealed, transparent boxes, could not believe that the plants would survive because of lack of water and other resources. When they saw how the plants were growing in the boxes, many of them constructed explanations with the help of a 'cycle model'. They thought that water became obtainable through evaporation and condensation and that air or oxygen were formed through that process. I repeatedly challenged the children who consequently repeatedly reformed their ideas. Their thinking then developed in different ways. For one pupil, both water and oxygen were formed through condensation; and for another, air forced its way down into the soil so that it would get more nourishment, - they thought the condensation on the walls of the sealed box was 'nourished-air'. The children had not developed any complete conception of the gaseous state. They could not see the water vapour but could see the result of condensation. In the same way they could not see air and oxygen. They used the condensation of water as a model and some of them constructed an idea that the water film on the inside of the walls of the box contained both air and oxygen: *"You can see air here on the walls!"* The daily conversation about the sealed boxes in the classroom surely stimulated the development of their thinking about the processes in the boxes.

Only a few pupils in grade 3 (10 years) described an exchange of air, oxygen and carbon dioxide between the organisms in the box. At the beginning, some pupils thought that the plants got their carbon dioxide through the expiration of man. When a couple of pupils saw that the plants survived in the sealed boxes after six months, they constructed the explanation that the plants produced oxygen for each other. One pupil in grade 4 (11 years) said that carbon dioxide could come from the earthworms in the soil. Gradually, the children developed their knowledge about the origin of oxygen and several pupils thought that the plants themselves could emit the oxygen, they and the animals needed.

At the end of grade 4, more children also began to describe decomposition as a part of a cycle. One of the pupils said: *"First leaves have appeared and then they have grown. Then they move down into the soil and moulder away and then they become nourishment again to plants."* In connection with the next interview she had the following explanation why Earth did not increase in size as

a result of decomposition: *"There is something like a circulation. It just moves round. Plants and animals die and then ..."*

During the grade 5 (12 years) interviews about life in a sealed box and aquarium, again I challenged their thinking about cycles in nature. Several pupils still described the condensation as a necessary part of the water support in the sealed box and one pupil said that the the water cycle was necessary for both water and oxygen production. One fourth of the class presented ideas about production of oxygen and carbon dioxide, partly as a result of routine teaching by their class teacher. Ideas about exchange of gases between plants and animals had been further developed.

Their conceptions of matter and its transformations caused problems when the pupils tried to understand interplay and cycles in a closed aquarium. Pupils who had said that the animals in the sealed box got oxygen from the plants, found it difficult to realise that gases like oxygen and carbon dioxide could be obtainable from water. Instead they said that the animals used the content of the air bubbles in the water or snapped up oxygen at the water surface. The pupils had constructed an idea about decomposition in a terrestial environment that made it possible for the plants to take in decomposition products through their roots. They thought that these products were dissolved in water. It was difficult for them to associate this knowledge to the 'cycle model' concerning terrestial conditions that they had constructed before.

The pupils had gradually built up their understanding of the interplay in an ecosystem and developed their conceptions about the flow of matter in this ecosystem. This flow was described as a cycle or as a part of a cycle. The 'cycle model' that was introduced at the age of 8 concerning the water cycle, became very useful to the pupils when they constructed their conceptions of the exchange of resources between the organism and its environment.

DISCUSSION

The pupils' possibilities to construct 'cycle models' to explain the flow of matter in nature have limitations. The transformations of matter between solid, fluid and gaseous state are parts of the cycles that deal with conditions for life, growth and decomposition. For a child, it is difficult to understand the presence of a gas. Therefore, they construct their own conceptions as in the following explanation of how a plant breathes: *"It has small tubes in the leaves and when the wind is*

blowing it will get air there. Then it comes into the whole plant. In that way the plant can breathe."

The children did not see the water vapour but interpreted condensation as something which must have a source. They got help to construct a model from the cycle of water. Then they developed that model as an alternative model involving air, oxygen and carbon dioxide. Many pupils said that the film on the walls in the box consisted of water and air or carbon dioxide. Those interpretations were logical from the children's point of view, although they were scientificly incorrect. The 'cycle model' became a help to understand a phenomenon, on the way to a more complete understanding of the flow of matter.

The children comprehended the plant to be the 'end point' for matter; for example, because they could not observe water leave the plant as water vapour, the plant was therefore the end point. For the same reason the children comprehended the soil to be the 'end point' for decomposition in nature. They could not observe water and carbon dioxide leaving the soil as a result of the decomposition of carbohydrates. Use of the 'cycle model' would be a useful teaching strategy to help pupils understand the interplay in the ecosystem. Such a strategy implies that we

- challenge pupils conceptions of matter, especially the gaseous state
- give the pupils experiences which will make it easier for them to develop their understanding of the cycles of matter in the future.

The questions that have been discussed in this paper are very relevant to important questions in environmental education. Also, much effort has gone into irrigating cultivated plants in areas where most of the water leaves the ground through evaporation before it has been used by plants. It is possible that too little has been done to counter this problem. One explanation could be that we cannot observe the large amount water leaving the ground as a part the water cycle.

The natural greenhouse warming is mainly caused by water vapour and carbon dioxide. Carbon dioxide leaves the ground as a result of respiration and combustion. These gases trap reflected radiation from the Earth, keeping the planet warm enough for life to flourish. The burning of fossil fuels and deforestation has released still more carbon dioxide into the atmosphere. Together with release of methane and nitrous oxides from human activities, this has probably caused global warming (Kupchella & Hyland, 1989). This is another phenomenon that can be difficult to understand because students cannot observe

the large amount of gases leaving the ground. A teaching stategy that can help pupils to develop a better understanding of the carbon cycle and the cycles of other elements would give them a better understanding of important environmental issues in the future.

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