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READING NATURE FROM A BOTTOM-UP PERSPECTIVE

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Abstract This paper reports on a study of ecology teaching and learning in a Swedish primary school class, (age 10-11yrs). A teaching sequence was designed aiming at helping the students to *read nature* in a river ecosystem. The teaching sequence had a bottom up approach in the sense that it took its starting point on a common key organism- the freshwater shrimp. From this species and its ecology the perspective was broadened to involve studies of the interrelations between organisms and finally to the relation between the biotic and abiotic factors. A large part of the instruction took place outdoors. The main objective for the study was to follow students developing ecological understanding. Each student was interviewed early, in the middle and late in the teaching sequence. The interviews were semi-structured and resembled the construction of a concept map. Students were asked to describe and link a large number of objects on a tray. The objects related to the river ecosystem and comprised a large number of living organisms together with non living objects such as water, air and pictures of the sun and of humans. The task for the student was to identify the objects and to describe the ecosystem by linking them up in as many relevant ways as possible and explain their reason for the linking. These tray interviews were translated by the researchers to concept maps which graphically represent the researchers' interpretation of the interviews. Concept maps together with a revised SOLO-taxonomy are used to illustrate students developing ability to read nature. Results indicate how students relate several abstract processes and correlations back to the key organism studied early in the teaching sequence.

1 Introduction

The ability to *read nature* is central in this work and has been described in another paper (Magntorn & Helldén 2005) but needs a brief explanation here as well. We see it as an important aspect of ecological literacy where ecology is seen as a scientific field with a tendency to amalgamate with other disciplines and form interdisciplinary fields such as environmental education. The phrase ecological literacy is a re-conceptualisation of the phrase *environmental literacy* which Orr (1992) refined to *ecological literacy*. According to Orr ecological literacy primarily constitutes ”knowing, caring and practical competence” and . "How people and societies relate to each other and to natural systems, and how they might do so sustainably". Ecological literacy is ideally about developing a rich knowledge base and multifaceted beliefs and/or philosophies about the environment which lead to ecological sustainability. Returning to our phrase *reading nature* we see this ability as an important aspect of ecological literacy. Its focus is on ecology and the context is outdoors. This literacy has to do with an ability to recognise organisms and relate them to material cycling and energy flow in the specific habitat which is to be read. It has to do with the natural world that we face outside and the tools we have are our experiences from previous learning situations both in and out-of-doors.

The ecosystem to be read is a river and we have followed a year 4 class (age 10-11 yrs) when they studied the ecosystem. Together with the teacher we have designed a teaching sequence spanning 7 lessons from February till May where most of the teaching was conducted outdoors. The teaching sequence had a bottom-up design where we started with focussing on the fresh water shrimp and a few other common organisms in the river. Finding and naming the organisms together with close studies of their morphology and their adaptations to life in running water was followed by studies of their interactions directly or indirectly with the other components, both biotic and abiotic, of the ecosystem.

2 Objectives

In this project there are two main objectives. The first objective has a methodological approach where we present a type of interviews resembling the construction of a concept map. Students are asked to link living and non-living objects from the river in as many ways as possible. All the objects are presented on a large tray and students are asked to use a hierarchical structure when they link their objects to an ecosystem as in a concept map. Students' "tray interviews" have been interpreted by the authors as concept maps illustrating students' ability to read nature. The other objective has to do with students' learning and how they can relate their ecological understanding of a key stone species to the understanding of the function of the ecosystem.

3 Background

Research on students learning and understanding of ecology suggests that developing an understanding of ecosystems and their functioning is difficult. Leach and colleagues did a cross sectional study of 5-16 year old students and their understanding in ecology and they found that student ideas of the function of the ecosystem is not seen as an interrelated whole, i.e., photosynthesis, respiration and decay are not viewed as cycling of matter in ecosystems (Leach et al. 1996). A review of the literature suggests that students do not have a good grasp of the complexity in food webs, of energy flow or of the dynamics and structure of ecosystems (e.g. Adeniyi, 1985; Gallegos et al, 1994; Hogan & Fisherkeller 1996; Grotzer & Bell Basca 2003). Studies have also found that students often find ecology education as cut off from real life and not appealing to them since they are not familiar with the species and dynamics presented (e.g. Magro et al 2001). With the bottom-up design young students' knowledge of organisms and how they live in their environment is central and when Lock et al. (1995) asked a sample of 12-14 what sort of living things they would expect to find in freshwater frogs, tadpoles and fish were commonly mentioned but few made reference to plants or invertebrates. Other studies have shown that students have great difficulty in the classification of invertebrates (e.g. Kattman 2001). Since many of the invertebrates found in a river are larvae becoming flying adults it is also important to know the difficulties young students have with life cycles where they tend to forget the egg stage and the cyclicity of the life stages (Shepardson 2002).

4 Research design and methodology

Important for our research design has been Ausubel's theory of meaningful learning (Ausubel, 1978) supplemented by Novak (1998) who stresses the importance of the interplay taking place between emotions, personal relevance and context when people learn. The one who is learning is actively extending her existing concepts or defining new ones. This also means finding new connections between those already given and the new ones as well as finding new structures and sustainable theories. When meaningful learning occurs, the relationship between concepts become more explicit, more precise and better integrated with other concepts and propositions. This involves what Ausubel calls *progressive differentiation* of conceptual and propositional meanings, resulting in more precise and/or more elaborate ideas. In our study a relevant example might be the understanding of the role of the sun developing from being restricted to a source of light and heat, to after instruction also being the energy source for all the living organisms in the river.

We believe, supported by e.g. Duit, Treagust and Mansfield (1996), that interviews can give reliable information about students´ ideas. We have positive experience from older students i.e. university students and secondary school students making their own concept maps on ecological topics but with younger students concept mapping can be too difficult and time consuming (Kinchin 2000). Therefore we designed a new interview method, the tray interview, based on ideas from Mellgren (2004) where students make a kind of concept map by linking a number of given objects on a large tray. They were asked to describe each object and to link it with as many other objects as possible and explain how they were related. The objects on the tray were real objects from the river such as a large number of different living invertebrates, representing herbivores, decomposers and carnivores, and both the adult and larval stages of dragonflies. There were also live aquatic plants and brown half-eaten leaves together with a picture of a salmon. Non living components were represented as gravel and rocks from the river bottom together with a glass of water, a dish with air (representing air or oxygen or carbon dioxide) and a picture of the sun and of a human.

Our impression is that the students generally find these interviews challenging as if they were a game, and their motivation for solving the task is high. Each student was interviewed early, in the middle of and after the teaching sequence (see figure 1). Each interview has been analysed by the researchers and interpreted as concept maps. This graphical illustration of students' development has been supplemented with an analysis of the interview according to the SOLO-taxonomy (Biggs & Collis, 1982).

Concept mapping with its graphical structure has been recognised as a powerful tool for helping students understand the notion of complex models such as ecosystems (Kinchin, 2000) and research has shown the importance of getting acquainted with the concept maps in order to make them a useful metacognitive tool for the learning pupil (Novak, 1998). Although these graphic representations can reveal the complex webs of students' ideas, when ideas are taken out of the context of students' wordings and reduced to conceptual labels the labels become open to a variety of interpretations and meanings that may not accurately represent the meanings or richness of students' ideas. This is why the tray interview with possible immediate follow up questions can reduce this limitation. Research has also found that students often find it difficult to make this concept maps and that the difficulties not necessarily have to do with their understanding of the topic studied but rather that the instrument suits some students better than others (Schmid & Telaro, 1990). For the younger students we believe the advantage of an "oral" concept map is even greater than with the older students.

5 The teaching sequence and data collection in outline

The teaching was carried out in a Swedish year 3-4 class of 23 students aged 10-11. The school is a public school in a middle class community and the 23 students ranged from high to low achieving. It is important to say that the instruction was conducted by a teacher from the local nature school together with the ordinary class teacher. All the interviews were conducted by one of the researchers. There was continuous negotiation between the researchers and the teachers about the content and the design of the teaching sequence. The river, where all the outdoor teaching took place, is situated on walking distance from the school. The overall teaching sequence comprised 4 phases spanning 7 lessons of varied duration from 80 to 200 minutes (see figure 1). Space constraints make it necessary to present details of the sequence as a short synopsis.

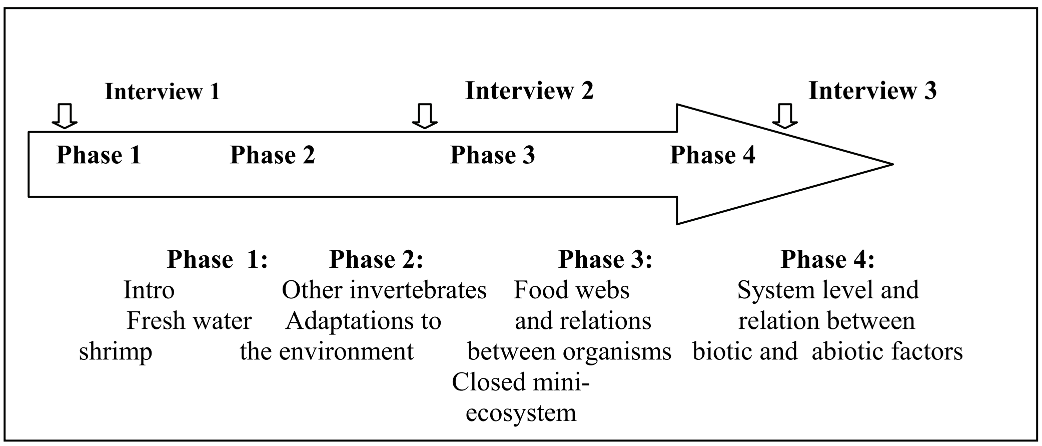

Figure 1. The teaching sequence together with the three tray interviews are illustrated above.

Phase 1: Autecology (i.e. the ecological relationships of a particular plant or animal species) of the freshwater shrimp. After having collected them in the river they studied them thoroughly and discussed their autecology.

Phase 2: Taxonomy and autecology of different invertebrates. The children collected different organisms in fast and in slow sections of the stream, studied their adaptations to the environment and the taxonomy of the different organisms. Herbivores and predators were determined according to their morphology and behaviour i.e. large eyes, large mouth parts and rapid animals are often predators. Life cycles were discussed and sealed ecosystems were constructed and discussed according to the roles of plants animals and abiotic factors such as light and air.

Phase 3: Students were introduced to food webs and food pyramids and related these models to the organisms observed in the river. Synecology (i.e. the ecological relationships of a community) was discussed. A litterbag experiment was conducted where the children put fresh water shrimps (Gammarus sp.) and water louse (Asellus sp.) in small net-bags together with green and brown leaves. The bag was then put into the river and after a week it was collected and studied in order to find out that the animals preferred brown leaves and could be considered decomposers in the ecosystem.

Phase 4: Systemic view of the ecosystem was discussed where students were introduced to photosynthesis and energy flow in the ecosystem. The relation between abiotic and biotic factors were discussed and investigated focussing on the importance of high water flow for aeration of the water and the importance of trees both for the main food source and for the shadow keeping water temperature low and subsequently oxygen level higher. The importance of a varied bottom substrate for a higher diversity of life was discussed together with the direct and indirect human impact on the river ecosystem.

In conclusion the teaching started of with the taxonomy (naming) of the common species and particularly the freshwater shrimp and its autecology. This was followed by the autecology and life cycles of the common invertebrates and synecological models were introduced such as food chains and food pyramids. Finally a systemic view of the ecosystem was discussed where the biotic and abiotic factors were linked in many different ways. Reading nature has to do with recognition of the authentic structures and objects in the ecosystem and the ability to link taxonomy, aut- and synecology to a systemic view.

6 Framework according to SOLO

The SOLO taxonomy (Dart & Boulton-Lewis 1998; Biggs & Collis 1982), was designed to be particularly relevant to school and university learning environments, with the central feature being a focus on the structure of students' responses after a teaching sequence. It offers a model for characterizing levels of sophistication of children's developing explanations, and it was used as our basis for the analysis of the children's tray interviews. The principles on which explanations were assigned to the various levels mainly hinge around the sophistication of causal notions between structures, such as plants, animals and non-living objects, and functions in the ecosystem. The SOLO taxonomy focuses on sophistication and does not necessarily equate with conventional scientific ideas. Hence, we have added an aspect of correctness to our definition of the five SOLO levels regarding the ability to read the river ecosystem. The levels of our revised SOLO taxonomy are described below. They are developed in direct relation to the topic- reading nature. This ability is related to age and experiences and, of course, a biologist reads nature differently to a primary school student. Our levels are adapted to a concrete symbolic mode where a person thinks by the use of a symbol system such as written language or number systems. Thinking in this mode requires a real world referent. This is the most common mode addressed in learning in the upper primary and secondary school. The levels are also directly related to the aim of the teaching sequence and distinctions between the levels are made from the analysis of student interviews. The teaching sequence is designed to start with

1. **Prestructural.** The responses are often inadequate and the student is frequently referring to irrelevant aspects. Species knowledge is non-existent or very limited. The autecological (i.e. the ecological relationships of a particular plant or animal species) relations are trivial single step relations such as fish need water to swim in or all animals need the sun to be able to see. No synecological (i.e. the ecological relationships of a community) relations are described. No functional aspects describing the key processes of photosynthesis, cycles of matter and flow of energy is mentioned.

2. **Unistructural**. Single aspects of the task are picked up, but the task itself is not attacked in an appropriate way. The student is reasoning in the relevant mode but only single step relations without any mediating description of a sequence of causally linked events or relations. Species knowledge covers a handful of common organisms. The autecological relations are often single step relevant relations, in the first hand, describing the freshwater shrimp and its features such as feeding, breathing and reproduction. No synecological relations are described. No functional aspects describing the key processes of photosynthesis, cycles of matter and flow of energy is mentioned. This level of explanation indicates fragmentary understanding without any attempt to make a synthesis or systemic analysis of the ecosystem.

3. Often all the items are involved but only in one step relations but the objects can have single relations to more than one object.

4. **Multistructural**. Causal chains are given in the explanations, linking two or more objects together and referring to relevant ecological theory. There is no attempt, however, to raise the explanations and linking to the level of a generalization. Species knowledge covers at least the seven most common organisms. The autecological relations are often single step relevant relations, but also chains of relations involving organisms on several trophical levels (i.e. levels in the food web). Adaptations to water flow are mentioned. Life cycles of some of organisms are described but without linking to ecological effects. No functional aspects describing the key processes of photosynthesis, cycles of matter and flow of energy are mentioned. No process discussions or abstract relations are discussed.

5. **Relational**. Relational explanations extend relevant points to a general principle, or interrelationship between factors. Species knowledge covers at least the seven most common organisms. Autecological relations of organisms belonging to different trophical levels are supplemented with the synecological principles of a food pyramid. Other synecological relations described are the life cycles of some organisms and its effect on the ecosystem over the whole year. The sun is often mentioned early in the interviews. Students do not relate to abiotic factors or human influence on the river on a systems level. Plants growth depending on light and producing oxygen is mentioned and energy in the form of food in the food web is often discussed but no discussion about cycles of matter and no synthesis about these processes are made.
   Different life cycles are discussed.

6. **Extended Abstract**. The coherent whole is generalised to a higher level of abstraction. The students discuss ecology as in the relational level but also refer abstract relationships between biotic and abiotic factors such as photosynthesis or human effect on the ecosystem such as the morphology of the river banks, light conditions and pollutants. Species knowledge covers at least the most common organisms. Autecological relations of organisms belonging to different trophical levels are supplemented with the synecological principles of a food pyramid. Other synecological relations described are the life cycles of some organisms and its effect on the ecosystem over the whole year. Students give more than one explanation or cause for processes in the ecosystem and they can refer to feed back causality in ecosystems such as the importance of both decomposers and plants. Autecology about a few key species can be referred to ecological principles which are linked. "The salmon is actually containing old dead leaves since they eat animals which have eaten leaves" Generally mentioning how the flow of energy and cycling of matter occurs in the river as well as in other ecosystems.

7 Results and analysis

According to our revised SOLO-taxonomy we can see a strong development over the course (see figure 2.) The diagram illustrates how most student have a very limited ability to read nature prior to instruction. Most students in the second interview can relate to the autecology of the freshwater shrimp and the life cycles and adaptations to water flow of many of the invertebrates but they have difficulties relating the facts to a whole.

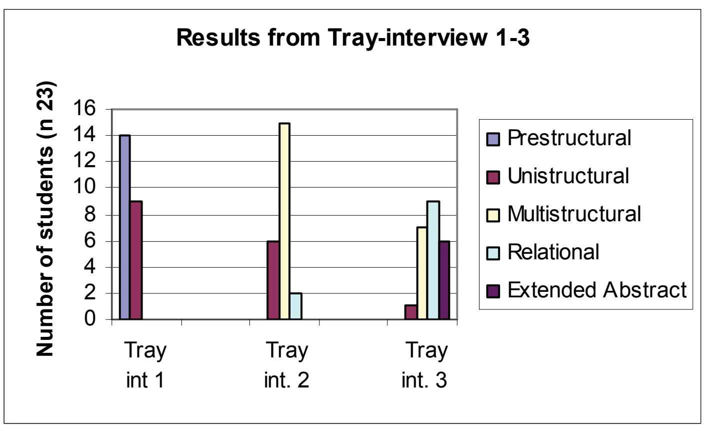

Figure 2. The diagram illustrates students' SOLO levels in tray interviews 1-3.

In the third interview students still start by describing the freshwater shrimp and its autecology but they often add synecological and systemic relations. 15 students can read the river on at least a relational level where they link the organisms to the function of the ecosystem. The diagram gives a very superficial illustration of students' development and we have therefore chosen to include the concept maps from the three interviews of one of the students, Anna. The teacher with 30 years of teaching experience describes Lisa as "an average student, quite lazy but she is good at logical thinking".

In the first interview, prior to instruction, student's ability to read nature was very limited. The relations between items on the tray were often single step and trivial. Species knowledge was with a few exceptions restricted to fish, dragonfly and molluscs. This is different from similar studies on terrestrial ecosystems where f.ex. bugs, butterflies and spiders often are recognised by young students (Hogan & Fisherkeller 1996, Shepardson 2002). Having names for the common organisms is an important part of reading nature.

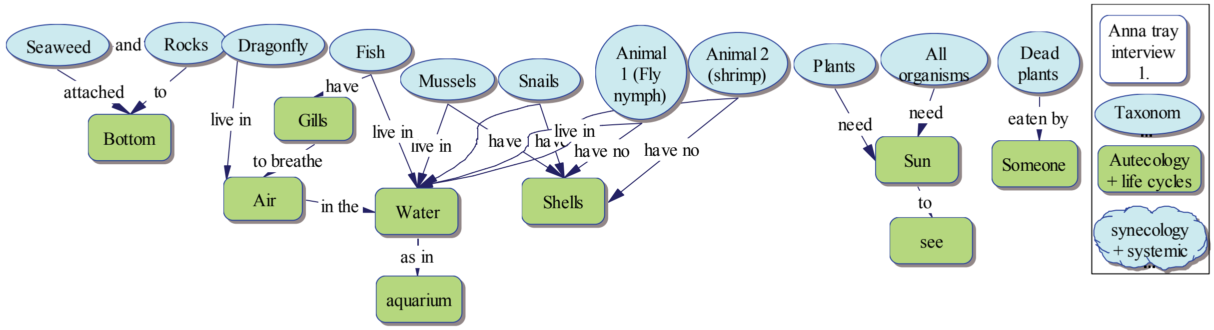

Figure 3. Anna's tray interview 1. The concept map contains concepts marked with different symbols representing taxonomic level (ellipse), autecological level (rectangle) and (cloud) systemic and synecological level. She was categorized as prestructural according to our revised SOLO-taxonomy.

Our experience together with many other researchers is that students often refer to personal experiences of ecological processes in terrestrial ecosystems such as earth worms turning dead leaves to soil (Hogan & Fisherkeller 1996, Helldén 1995) or they discuss food chain relations between predators and prey i.e. who eats who. This kind of reasoning often relates to episodic memories (White 1988) which are important for linking experience with relevant propositions and intellectual skills. In the first interview Anna only recognised dragonflies, mussels, snails and seaweed. She related the mussel and the snail because they both had shells. The dragonfly was linked to air since it flied and the plants to the gravel since they lived in gravel. Sun gave light for seeing and water was to live in and fish had gills to breathe and she said they breathe air as in an aquarium. Her reading of the ecosystem is poor and it seems that without proper names for the organisms and without knowledge of their autecology Anna cannot describe the ecosystem and generalise about processes in nature. References to episodic memories of relevant experiences prior to instruction were almost absent. She was categorized as prestructural according to our SOLO-taxonomy.

Prior to the second interview students had been catching and studying the freshwater shrimp and collected animals in the fast and slow streams. Naming and adaptations together with life cycles were what most students discussed in the second tray interview. The shrimp was naturally the key organism and most students discussed its feeding and its morphology and adaptations to a life in the river. Many students had names for several animals and now they could discuss their abundance and their roles in the ecosystem but no discussion took place on a systemic level including abiotic factors or cycles and flow. Knowledge about a few animals, particularly the shrimp, and practical experience of catching and studying the animals help all students to discuss the ecosystem on a taxonomic and autecological level. Anna was focusing on the freshwater shrimp and related autecological concepts and also synecological links between plants and freshwater shrimps. Most students including Anna were categorized as multistructural according to our revised SOLO-taxonomy.

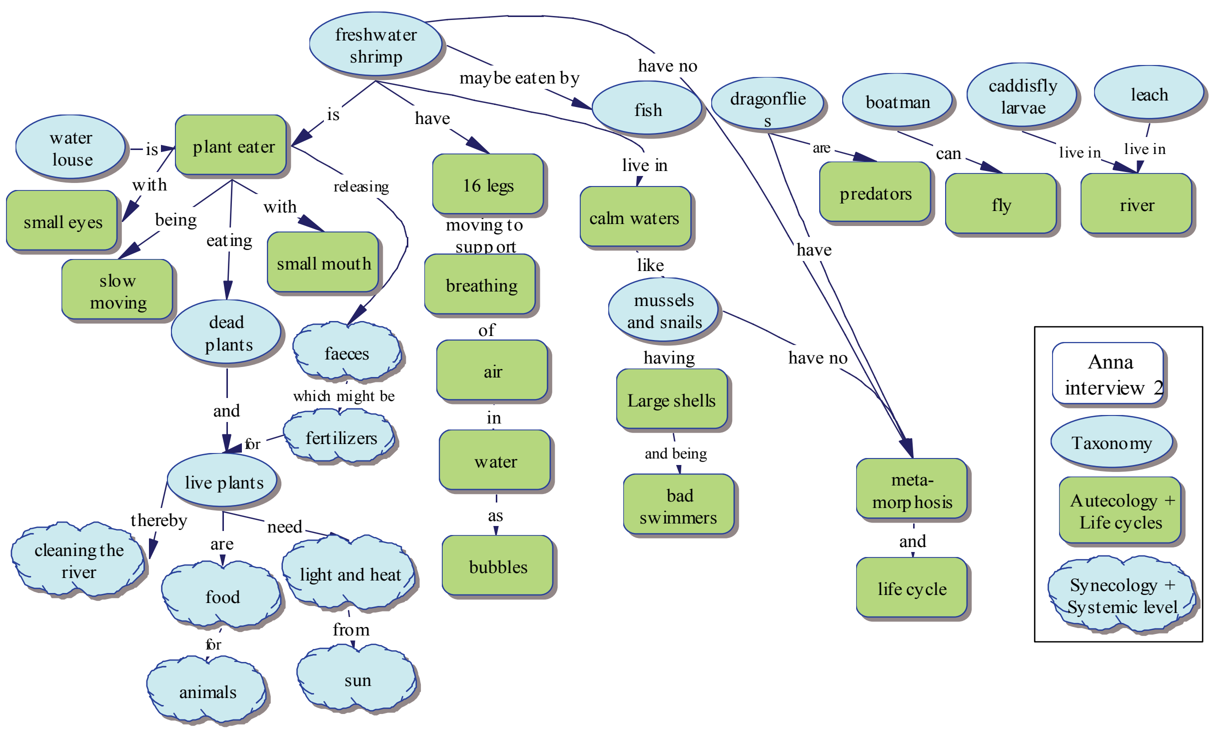

Figure 4. Anna's tray interview 2. The concept map contains concepts marked with different symbols representing taxonomic level (ellipse), autecological level (rectangle) and (cloud) systemic and synecological level. The freshwater shrimp is her starting point and she relates it to several autecological features.

In the third interview students had experienced feeding experiments, models of food chains and food pyramids related to the animals found in the river. Photosynthesis and oxygen production was discussed together with a discussion about human impact on the river and how one can measure the water quality according to biological parameters. As in interview 2, most students started by describing the shrimp. Some still focused on the taxonomic level where they knew the species names but relevant systemic reasoning was absent or poor and they did not reach further than the multistructural level. Most students, though, linked the organisms to their habitat and related them to abiotic factors such as oxygen and light and referred to the whole ecosystem. Anna could recall the names of many of the organisms but most of all she had a systemic view on the ecosystem and included the photosynthesis and bacteria and anoxic conditions. Anna interpreted what she had experienced over the whole course and she generalised her understanding to the river ecosystem but also to general ecology in any ecosystem. She is categorized as extended abstract according to our revised SOLO-taxonomy. In her tray interview (Figure 5) she referred to several of the episodes (episodic memories are marked with a * in the concept map) during the teaching sequence. These episodes together with the taxonomy and autecology of the organisms seem to be her way of constructing an ability to read nature.

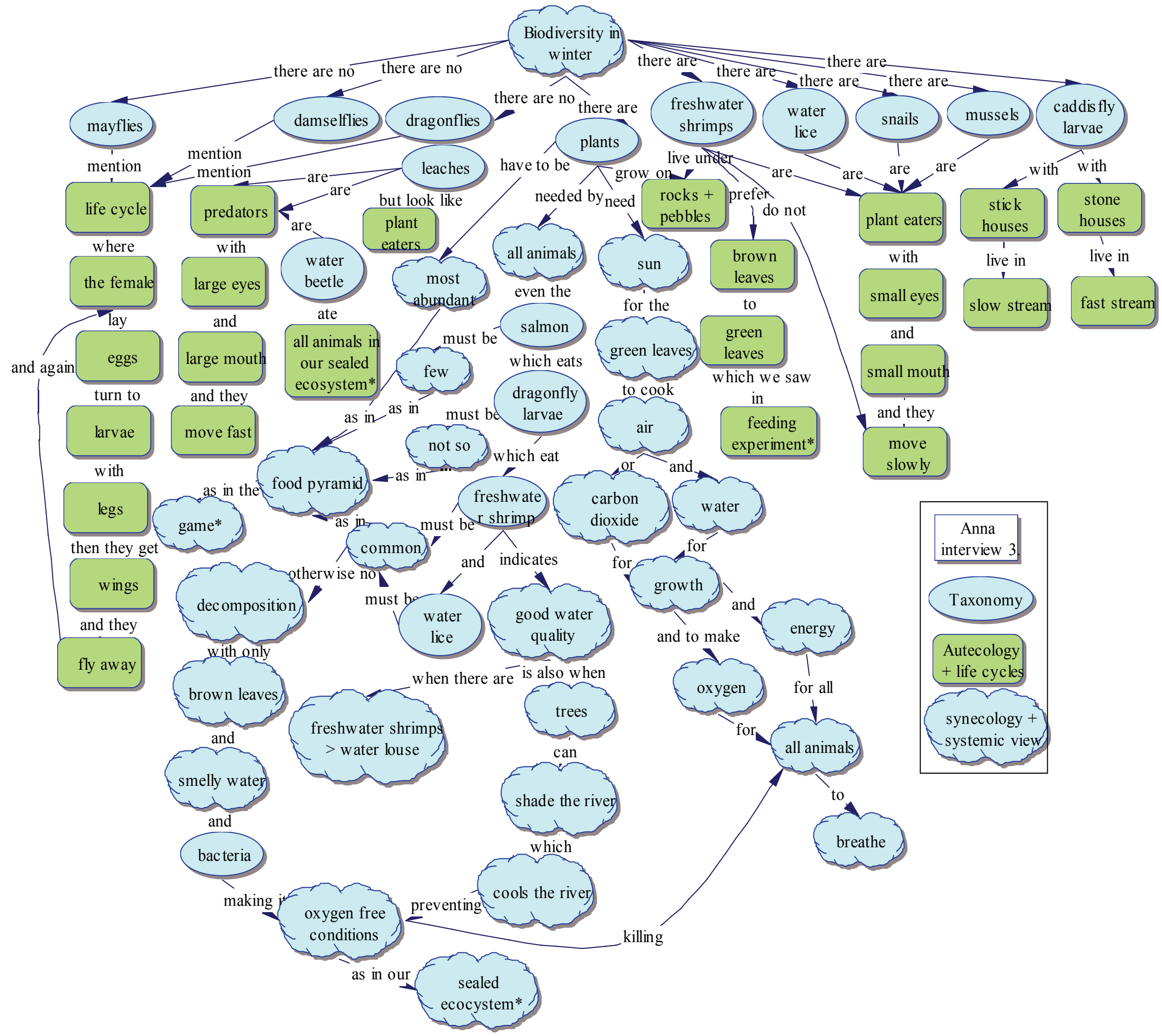

Figure 5. Anna's tray interview 3. The concept map contains concepts marked with different symbols representing taxonomic level (ellipse), autecological level (rectangle) and (cloud) systemic and synecological level. Concept marked with an * refer to episodes during instruction.

8 Summary

Developing an understanding of ecosystems and their functioning is difficult (Leach et al. 1996) and students often find the theory abstract and not related to real examples from nature which students can relate to (Magro et al. 2001). In this project we have implemented a teaching sequence focusing on a key stone species, a freshwater shrimp, and tried to build an ecosystem understanding based on the ecology of this organism. We have found that the recognition of one species and the knowledge of its autecology is helpful for the students when they discuss the whole ecosystem functioning. A majority of the students can relate the freshwater shrimp to systemic levels of ecosystems understanding. Memorable events such as outdoor activities and challenging experiments seem to be important for the meaningful retention of knowledge since many of the students often refer to these when they read nature. In this study we have also found the tray interviews to be very fruitful for eliciting students understanding of the ecosystem functioning and its parts -whole relation. The resemblance to concept map construction with its metacognitive component has been important and since the young students do it orally it eliminates the sometimes tiresome writing. Tray interviews have been interpreted by the researchers to concept maps which have been analysed in relation to the SOLO-taxonomy which we find to be a promising way of analysing students' ability to read the river ecosystem.

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