Pupil’s ecological reasoning with help of modeling tool

Tiina Nevanpää
Institute for Educational Research
P.O. Box 35
FI-40014 University of Jyväskylä
+358 14 260 3226
tiina.nevanpaa@ktl.jyu.fi

Nancy Law
Faculty of Education
University of Hong Kong
Pokfulam Road
+852-28592550
nlaw@hkusua.hku.hk

ABSTRACT
Ecological concepts, and in particular population dynamics, has been found to be among the most difficult topics in biology. Some researchers pointed to students’ relatively weak mathematical background as the main source of learning difficulties. This paper reports on an investigation of pupil’s (n= 73) reasoning about the ecological phenomena by using an iconic modelling tool, WorldMaker. The simulations eliminated the need for understanding of mathematical equations, and made the ecological concepts much more accessible to some children. However, many of the pupils reasoned from an anthropocentric perspective that obstructed their ability to predict ecological phenomena which requires systems thinking.

Keywords
Population dynamics, ecological reasoning, simulation, modelling.

ACM Classification Keywords
K.3.1 [Computers and Education]: Computer Uses in Education - Computer-assisted instruction (CAI)

INTRODUCTION
Nature conservation and maintaining biodiversity are amongst the most important socio-scientific issues faced by many societies and are given increasing importance in many basic school science curricula. While cultivating appropriate attitudes and values are often crucial objectives in such curricula, informed decision-making often requires an understanding of the scientific principles and concepts involved [7]. Understanding population dynamics (e.g. food chains, food webs, ecosystems, competition, pyramids of numbers, ecological niches, natural population fluctuations and extinction) is prerequisite for understanding the functioning of nature and natural systems.

This topic is, however, very difficult for pupils to understand. According to previous studies, people have misconceptions or alternative conceptions in ecology regardless of their age and background (e.g. [3, 5]). People have difficulties in understanding the ecosystems and their functioning [6, 1, 2]. In general, pupils have difficulties understanding ecosystems as organized wholes, but they consider them as collection of organism. One reason explaining difficulties in understanding population dynamics is the complexity of the mathematical models involved and the students’ relatively poor mathematical training as the key obstacles to learning [4, 1]. Another significant difficulty encountered in the teaching of population ecology relates to the fact that direct experimentation is often not possible, and even for the simplest laboratory experiments in this area, the processes are often very tedious [13]. Thus abstractness of ecological phenomena makes it difficult for pupils to change their knowledge structures and to construct the scientific explanation.

Ecology related misconceptions proved to be highly resistant to change and thus traditional teaching is not very effective. Computer-based modeling environments that help students to visualize and explore the behaviour of ecosystems without going into the complex mathematics involved have been developed [1, 8, 13].

In many of these modeling environments the user still have to be able to comprehend the nature of mathematical modeling, as well as understand how the specific mathematical model is conceptualized and interpreted. This requires a level of mathematical sophistication and conceptual understanding that are not generally accessible to children or the non-mathematically oriented public. In this study an iconic modeling tool, the WorldMaker [9, 10] used to support the development of understanding of ecological phenomena. The learner can construct a simulation of an ecosystem without understanding the complex mathematics involved. Thus the simulation reduces the working memory load and cognitive overload (see [12]). The learner is able to follow the fluctuation of population size of different species and organisms by means of iconic world grid and statistical graphing tool. The iconic world grid consists of 2-dimensional grid in which the user can follow the movement and interaction of different species. The graphical tool allows the user to gain a real-time display of how population of different species change as the simulation evolves. Thus WorldMaker allows the user to conceptualize and visualize ecological processes...
both at the microscopic level of random interactions and a macroscopic view of the changes at the systems level. It is in a way like a microworld, in which the learners are able to demonstrate inquiry based learning.

The purpose of this study is to examine whether iconic modeling tool can support pupils to construct the scientific explanation of certain complex ecological phenomena and concepts, in this case carrying capacity, inter and intra specific competition and predator-prey relationship.

THE RESEARCH SETTING AND METHODOLOGY
The research was conducted in the classroom settings in central Finland. The school was selected for its convenient location and willingness of the principal and the teachers to allow the researchers to conduct the study within their classrooms. However, the school represents a typical Finnish elementary school in general. Altogether 73 pupils from grades 5 and 6 (aged 11-13 yrs) participated the study. Pupils were used to work with computers as part of their school work but they did not have much experience of learning games. Pupils had the basic knowledge about the ecological principles, i.e. about different species, food chains, photosynthesis. However, the main focus of teaching is not on systems level at these grades, thus the understanding the ecology at the population level is limited.

Pupils participated in two sessions of 90 minutes of learning activities, with a space of one week between the two sessions. The learning activities were designed as group tasks of 2-3 pupils in the computer room. The children were given learning task through the computer screen as well as through structured worksheets. One researcher took the role of a “guest teacher” for experimental sessions. However, the guest teacher’s role was mainly to frame the learning tasks and to give instructions on how to use and operate the WorldMaker simulations. The guest teacher thus supported and facilitated the learning processes and construction of knowledge without teaching pupils in a traditional sense as the pedagogical design has it’s basis on inquiry- or problem based learning.

There were two major learning objectives in the design of the learning tasks in the first work session. Firstly, it was important that the children could master a basic understanding of the WorldMaker simulation. The second objective was to help the children understand the concept of carrying capacity, the notion that food is the limiting factor in this very simplistic ecology.

In the beginning of the first session the guest teacher discussed with the pupils briefly about the abundance (population sizes) of different plants and animals in nature. The children were then given the task to work in groups as ecologists to solve some problems related to the ecosystem and that they could use WorldMaker as a tool to help them in solving the problems. The guest teacher then gave a short introduction to WorldMaker (10 minutes). From then on, the pupils worked mainly with their group mates by following the instructions given by the WorldMaker and answering the questions on the worksheets. The ecosystem pupils encountered in the first session was a simple one with just rabbits, grass and soil. The complexity of ecosystem was increased during the second session as pupils were able to introduce new species: foxes, hunters and hares. The learning task was to understand the relationships between different species and the new equilibrium of the ecosystem.

The primary empirical data collected in this study consisted of the group worksheets completed by the children during sessions 1 and 2, and the individual worksheets completed in session 2. A video camera was set up during the two learning sessions to capture the discussions of the children when they were interacting with the simulations. The data was analyzed qualitatively by means of content structure analysis.

FINDINGS AND DISCUSSION
Simulations created by WorldMaker seemed to have helped some of the children to develop some rather sophisticated ecological reasoning.

Children’s reasoning about carrying capacity
Before using the WorldMaker simulation 8 groups of 24 indicated that they expect some kind of limit to the rabbit population due to limited amount of food. After the simulation nearly all of the groups (22 out of 24) were able to point out that the drop in the number of rabbits was because of the lack of food. They saw it very clearly both from the graph as well as from the grid where they see the green grass turning into brown barren soil. However, this ‘knowledge’ gained from experience with the simulation in itself was not sufficient to help all of the children to appreciate the concept of resources as a limiting factor in determining the population of different species in any ecosystem.

Children’s reasoning about predator prey relationship
Pupils were all aware that the foxes are predators and that, when released into the rabbit population, they would kill the rabbits. In fact all of the children mentioned either that the foxes would kill or eat the rabbits and/or that the number of rabbits would decrease. However, just knowing that foxes are predators is not sufficient to predict the outcome of adding predators to an ecology – there is a need to go beyond what happens at a local, individual level of an animal to reason about how such local interactions would extrapolate and impact on the entire population – and eight of the children (out of 64) did not write anything beyond this. All the other children predicted that the number of rabbits would decrease, but 40% of them did not mention anything about the magnitude of the decrease. Of all the predictions about the magnitude of the decrease, the most popular one (made by 14 children) was that there will be no rabbits left! Three of the children predicted that only a few
rabbits would be left and three of them predicted that not only all rabbits would be gone but that all the foxes will also die because the foxes would then have no more food.

The children’s responses indicate that simply knowing that one animal species predates on the other is very different from knowing the predator-prey relationship as an ecological concept. The children’s naïve reasoning leads them to an exaggerated expectation of the environmental impact (damage) of predators and a lack of understanding about the environmental dangers that many of the large predators face. One major difficulty that the children have is their unfamiliarity with the concept of feedback. So their understanding of the predator-prey relationship is purely as a food chain and not that of a food web.

**Children’s reasoning about competition and niche**

The question about the impact posed by the introduction of hares proved to be the most difficult for the children and attracted the most diverse range of responses. About two-thirds of the children indicated awareness of the issue of food being a constraint and possibly a focus for competition for the two animal species. This was expressed mostly in the form of ‘the hares will eat the rabbits’ food’, ‘the grass will decrease’, ‘there is not enough food’ or ‘the food would run out’. This was a great improvement on the first session when about a third of the groups anticipated unlimited increase in the number of rabbits and only about a third of the groups were able to point out that food was the limiting factor when they were asked to explain why they observed the rabbit population reaching an equilibrium size in the simulation.

**Did iconic modeling tool help the children to understand population ecology?**

The children’s engagement in ecological explorations of the simple rabbit-grass ecosystem using WorldMaker appeared to have helped the children to appreciate the idea of food as a limiting resource that determines the optimal population size of animal species. Apparently, this realization helped a quarter of the children to predict that direct competition for food would make hares the most serious threat to the rabbit population. This is a remarkable achievement considering that only one out of 24 groups was able to predict and explain why the rabbit population would reach an optimal equilibrium size. Furthermore, of the 5 groups that arrived at the prediction that competition would pose the greatest threat to the rabbit population, 4 groups were able to predict correctly how the population would change when hares were introduced. Thus these children seemed to be able to extrapolate the conceptions of food as a limiting resource from intra-specific competition situation to an inter-specific competitive environment and make predictions about global population changes in the latter situation correctly.

However, making such an extrapolation proved to be too difficult for most of the children as 15 out of 24 groups did not understand idea of inter-specific competition. Furthermore 11 of these groups were unable to predict what kind of effects the introduction of hares would have on the rabbit population, even though some of them (3 groups) explicitly stated that hares and animals are eating the same food. This indicates how hard it is to link observations and predictions at the local level with those at the population level.

It is noteworthy that for those children who were not able to grasp the significance of food as a determining ecological constraint on population size through the first simulation on carrying capacity, interpreting and making sense of the outcome of the simulation on inter-specific competition proved to be also difficult. None of the groups that predicted predation or hunting to be the most serious ecological threat was able to predict the outcome of inter-specific competition correctly.

Another difficulty children had was predicting the impact of predation and hunting. The majority of pupils who predicted predation to be a more severe threat to the rabbit population expected the number of rabbits to decrease drastically when foxes were introduced. It was observed that most of the groups who initially predicted either predation as the greatest threat changed the simulation test for the impact of hunting, and vice versa. Furthermore, the pupils were able to provide more realistic predictions for their second trial. For example, when foxes were added in the second trial, 5 out of 8 groups stated that the effects of predation would not be substantial and only 3 of these 8 groups expected foxes to eat all the rabbits.

Predicting the behaviour of a multi-species ecosystem by adding, foxes, hares & hunters simultaneously to the ecosystem proved to be too difficult for nearly all of the children, even after observing the behaviour of the system when each of the three species were added to the Rabbit Paradise alone. Six (out of 23) groups expected the extinction of all other species except for the hunters. Another three groups predicted hunters and foxes as the only survivors. These answers indicate that pupils were not able to construct the idea of equilibrium of ecosystem or transfer the idea of food as a limiting resource to the multi-species situations. Thus pupils still had problems in understanding how the concept of dynamic population equilibrium would hold in a multi-species ecosystem.

The above observations indicate that the two level representation of ecological systems using WorldMaker helped children to visualize and establish a preliminary understanding of limited resource (food) as a key ecological constraint on population sizes and helped some children to construct correct predictions on relatively simple population ecology problems. However, the extent of the benefit varied greatly across different children. Furthermore, unaided exploration in the simulation environment was insufficient to help children achieve a basic understanding of more complex situations.

**CONCLUSIONS**

There are a number of important concepts in population ecology that are core to understanding ecosystems and
environments impacts on our ecology. As such these concepts should form part of a science curriculum for literacy and informed citizenship. However, past research has also shown that many of these concepts are difficult even at the undergraduate level because of the difficulties involved in understanding associated mathematical models and abstractions involved [14].

This study found that using simulations built using an iconic modelling tool, WorldMaker, young children between the age of 11 to 13 were able to make sense of some rather sophisticated ecological concepts such as carrying capacity, predator-prey relationships, population fluctuation and inter-specific competition. The simulation environment was easy to use and attractive to the children. Most of the children in this study found the environment stimulating and helpful. Some referred to the simulation process as play, indicating their liking for the tools and the learning process.

WorldMaker provided easy scaffolding support for children to bypass the difficult mathematics and develop an understanding of the ecological concepts involved. The statistical graph in WorldMaker provided a good visualization that helped many children to conceptualize the feedback loops between different species. Such visualization seems to have helped about a quarter of the children to develop rather sophisticated ecological reasoning, including the prediction about the serious consequences brought about by inter-specific competition. Most of the children seemed to have achieved some understanding of population ecology based on the concept of food being a most important constraining factor.

On the other hand, there were some children who tended to reason from anthropocentric i.e. from individual perspectives and found it difficult to relate to the statistical graphic representation. Apparently, providing access to a dual representation, iconic and statistical, of the ecosystem is not sufficient to help some children to visualize the connection between local interactions of species as individuals and population changes as consequential global behaviour. There were ample examples of children giving correct reasoning at the local level, for example foxes eating rabbits or hares competing with rabbits for the same food, but unable to give the correct prediction about the impact at the population level. These children need to be able to change their perspective from anthropocentric considerations to thinking at the system level. This study also reveals that cognitive scaffolding through visual representations alone was inadequate in helping some children to make this perspective shift. More research is necessary to further understand the cognitive and metacognitive aspects of such perspective shifts. However, there are some results suggesting that metacognitive scaffolding strategies can be very helpful especially for low ability children [14].

REFERENCES
