Students' Systemic Reasoning of Food Webs at Lower Elementary level (Grades 1-4)

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Abstract

The framework for the new National Science Education Standards identified ecology as a key topic in the life sciences (NRC, 2011). Several studies have investigated students' ecological reasoning in upper elementary, middle and high school, but there is paucity of research that investigates students' reasoning at lower elementary level which is what we attempt to do in this study. Taking a systems approach to the food web, 40 students from grades 1 till 4 were interviewed in order to investigate students' reasoning and find out the consistency of their thinking. The results showed that students' causal reasoning about the food web system was classified into four levels with the first considering aesthetic or anthropomorphic reasoning and the last being branching causal reasoning that considered the influence on several branching food chains. Those categorical levels were similar to the ones identified with elder students. However, students' levels were not consistent with the various interview questions, rendering the influence of some populations more important than others. Those results have practical implications for construction of appropriate instructional approaches to foster students' systemic reasoning at early grades.

Introduction

Ecology is a main topic in biology that students learn in schools. The framework for the new National Science Education Standards identified ecology as a key topic in the life sciences (NRC, 2012). Parallel to that, the framework identified system reasoning as a crucial practice that applies to ecological systems. Ecology allows us to perceive the macroscopic picture of species interaction and biotic-abiotic interactions. As such, systems reasoning in ecology is a key socio-scientific practice for scientific literacy in that reasoning about ecosystems influences decision-making concerning environmental issues (Hogan & Weathers, 2003; Mohan, Chen & Anderson, 2009). This study investigates elementary students' systemic reasoning in ecology; particularly how they view the influence of a change in one factor in the food web on an entire ecosystem.

Literature Review

Various empirical studies have investigated students' misconceptions and reasoning about the influence of various organisms on others in a food chain for middle or high school students (e.g. Griffith & Grant, 1985; Hogan 2000; White 1997). In most of those studies the stu-

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dents were given written assessments or interviews and were asked questions to predict the effect of a change of one population on the other. The results showed that students' causal reasoning usually remained at a low level, meaning that they only recognized simple predator-prey relations within one food chain. However, for the most part, the literature does not investigate young students' ideas about ecosystem at lower elementary[3] and there are few studies that investigate the coherence of younger students' ideas when thinking of the various factors which make up the ecosystem. One reason for that may be the fact that even middle or high school students sometimes showed simple reasoning about food webs, so there may have been an assumption that younger students can only exhibit very simplistic reasoning. However, Carey (1985) states that, "Human beings are theory builders; from the beginning we construct explanatory structures that help us find the deeper reality underlying surface chaos" (pp. 194). This means that even students at a younger exhibit understanding that follows a logical coherent reasoning. In this study, we investigate lower elementary students' (Grades 1-4) understandings of and reasoning about ecosystems. The rationale behind this study extends to several dimensions. On one hand, it provides a baseline about elementary students' understandings which can inform curriculum development and instructional methods. In addition, this work contributes to learning progression conversations in that it helps us understand the various sophistications, constraints and affordances of students' reasoning.

Theoretical framework

When considering ecosystems as the subject of study, the word "system" becomes crucial. An ecosystem is a biological organization that has properties and interrelations at the system level. Although one could study a particular species or population, thinking how populations interact with other populations and other biotic and abiotic factors in the system is what characterizes a view at the system's level. The biologist Von-Bertalanffy (1975) discusses the theory of open systems in biology. He mentions that the key word in biology is "organization" which produces a whole that is different from the sum of its parts according to Aristotle. When comparing closed and open systems, Von-Bertalanffy mentions that equilibrium can only be reached in a closed system, whereas the open system can only reach a "steady state" which is a state of disequilibrium but the one that keeps the system functioning through the flow of materials. Whereas a closed system can reach an equilibrium state where no energy is required to preserve it, an open system depends on continuous flow of energy to preserve its "steady state". Those features of a system require reasoning in a systemic manner. Chandler & Boutilier (1992) propose a reasoning model that applies to open systems and they call it "dynamic system reasoning". They proposed four properties for systemic reasoning: (1) systemic synthesis: i.e., understanding that a change in one component affects others; (2) systemic analysis: i.e., there are critical elements (like water molecules or sun) that are essential for the system (e.g., hydrologic system) to work and they are different from incidental elements (e.g., storms); (3) circular connectivity: which is the opposite of systemic synthesis where the students are asked to make the system from the independent elements; (4) dynamic recycling: i.e. molecules do not exit from the system but instead keep cir-

[3] Leach et al. 1996, worked on this but their results remained very general

culating in it. When examining whether students' systems reasoning was ontologically different from Piaget's formal operational reasoning or whether it is a kind of reasoning that develops at the "heels of Piaget's formal operational reasoning", they found out that there were significant statistical differences between the two kinds of reasoning. That is, students' performance on the dynamic system reasoning task was a separate "ontogenic" category. In this study, we take a systems approach to investigating students' "systemic synthesis" when presented with a food web system. We attempt to categorize the various kinds of reasoning students have when thinking of food webs and whether this level of reasoning is consistent when thinking of the effect of the various populations. Therefore we pose the following research questions:

1- How can elementary students' reasoning about disturbances to ecosystems be characterized?
2- Are elementary students' reasoning levels consistent across various population changes that can affect the system?

The Method and Data Analysis

Our main data source for this study came from semi-structured interviews. Forty students in a Mid-Western suburban school from grades 1 to 4 were interviewed about their ideas of the ecosystem (N=40 students, 10 from each grade). The interview contained several questions, one where a food web ecosystem (figure 1) was presented and there were several "what would happen if" questions. Those kinds of questions followed by probes (such as "Why do you think so?" or "Do you think something else will happen?") allowed us to look at students' causal reasoning about the system. All interviews were transcribed verbatim and then the transcripts were checked against the recording. We had an iterative process of several rounds of coding: we first started by looking at students' answers, took a small sample and used constant comparative method (Strauss & Corbin, 1998) to derive general codes about students reasoning in the system. After deriving initial codes, we went back to the data and recoded students answers accordingly and then went back to refine our codes and code in an iterative process.

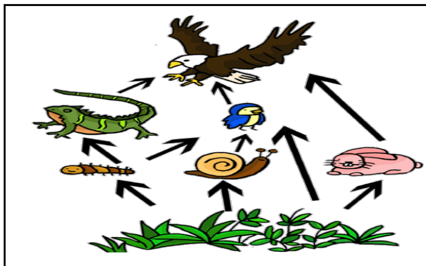

Figure 1: Food Web System

Results and Discussion

The results of our analysis showed there were several categories by which students reasoned in a food chain system. We classified those categories from the simplest to the most sophisticated: the simplest being those that did not recognize any affect or recognized an aesthetic or anthropomorphic effect, and the most sophisticated being those that recognized the branching effect in the food web. Those categories were similar to the ones in the other research for elder students, such as middle school students (Hogan, 2000). Due to space limitation we illustrate the categories and sample answers in table 1 below.

Table 1: Various Reasoning levels of the food web system

Categories of reasoning that cut across the different questions	*Q1*: **What would in environment system above happen if all plants died?**	*Q2*: **What would happen if all eagles disappeared?**	*Q3*: **What would happen if all the worms disappeared?**	*Q4:* **What would happen if you add so many rabbits?**
Level 1: Answers are not related to organisms' interactions (includes **aesthetic, anthropomorphic**)	*The air will not be good and we will not be able to eat vegetables (G1)*	*We will not see it again (G1)*	*The nature will become not beautiful (G3)*	*It would be boring because it wouldn't be nice to look there because we see the same animal (G4)*
Level 2: **One-way linear causal** reasoning involving two population of one food chain	***No such category for this question from any grade***	*We need eagles because sometimes they help up from small birds to come to our house or something (G3)*	*The lizard won't be able to live (G4)*	*It will help the eagle it will eat more and will be easier for it; it will only help the eagle because all animals here don't eat the rabbits. (G4)*
Level 3: **Two-way linear causal relationship** involving more than two populations along the same food chain	***No such category for this question from any grade***	*The tiger cannot live because it eats the eagle, and other animals do not die (G4)*	*The lizard won't eat them and the worms won't eat grass anymore (G3)*	*They will eat all the grass so no more grass and the hawk will eat them all (G3)*
Level 4: **Branching complex causal reasoning involving** populations along different food chains	*All animals cannot live because those that eat grass will die and then eagle eats lizard so it would die (G4)*	*I'm sure lots of animals would be happy, because they would not be eaten by the eagle, but snail would still be eaten (G4)*	*The food chain would not work, it would get ruined, because chameleon cannot eat grass, maybe it will look for another animal to eat or other kinds of caterpillars and worms(G4)*	*We won't have a lot of carrots and we won't have a lot of rabbits* *I: why will they (rabbits) die if they're a lot* *S: because some other animals will eat them (G3)*

Students across all grades (from grade 1 (G1) to grade 4 (G4)) gave answers that depicted different levels of sophistication for all the three questions regarding the consumers (whether removing or adding the consumers). However when the question concerned the producer (plants), students' answers across all grade levels were either anthropomorphic, or displayed reasoning that branched to think of more than one food chain; thus recognizing that the change in plants supply can have influence on the whole food chain. This finding suggests that students thought of plants as a different category than consumers, which is most probably linked to their previous knowledge about plants from various sources and its importance in the environment.

In order to answer the second research question, which tried to find out whether students' levels are consistent for all the questions, we analyzed each student's answers and compared which level he or she had for each question. We found out that students did not have the same levels for the four questions. For example, a student who is at a high level when answering the producer question may not score as high when answering the consumer question. We illustrate this point by two examples (Table 2) which were at level 1 and level 2 of the producer level, but had different levels for the consumer questions.

Table 2: Examples of two students with various levels for different questions

Categories of reasoning that cut across the different questions	Q1: **What would happen in the system above happen if all plants died?**	Q2: **What would happen if all eagles disappeared?**	Q3: **What would happen if all the worms disappeared?**	Q4: **What would happen if you add so many rabbits?**
Student1	*It wouldn't be good, first it would be less oxygen, and it wouldn't be cool enough, it would be hot because there wouldn't be too much shade and plants are nice to see and plants give good smell (level 1)*	*If it disappears we will have a lot of worms on the trees because birds often eat worms (level 2)*	*The birds will run out of food and we will have less birds because birds eat worms and our trees will have more fruits because there are no worms to eat the fruits (Level 3)*	*It would be boring because it wouldn't be nice to look there because we see the same animal (Level 1)*
Student 2	*Animals that eat plants will not have food and the eagle will not be able to eat them (Level 4)*	*I don't think a lot of things will happen, because it's up and it can eat them all(Level 1)*	*The food chain would not work; it would get ruined, because chameleon cannot eat grass, maybe it will look for another animal to eat or*	*It will help the eagle it will eat more and will be easier for it; it will only help the eagle because all animals here don't eat*

			other kinds of caterpillars and worms. the chameleon will die and then other birds and other animals will die (Level 4)	*the rabbits. (Level 2)*

The two illustrative examples show that students' reasoning is not consistent when thinking of the effect on different populations of the food chains. Whereas Student 2 realizes the influence of plants on the other animals which also affects the top carnivore (eagle), this student does not realize that the top carnivore (eagle) will also have influence on the animals below it (e.g. bird or rabbit). On the other hand, student 1 could only think of the aesthetic importance of plants, but was able to think at level 3 for the importance of worms when she recognized that worms influence the birds that eat them and the trees as well. These two illustrative examples were chosen from the same grade level (Grade 4), in order to show the difference of thinking even at the same grade level. However, students at all the 4 grade levels showed this inconsistency when thinking of the influence of various populations on the system. We conclude that students' reasoning about the whole system is influenced by the organisms that they think are crucial. Therefore, similar to Gotwals and Songer (2010), we found that it would then be difficult to pin down students to specific level of causal reasoning because that seems to be changing depending on the population they are thinking of.

Implications and General Interest

The above results indicate that students from early elementary classes can reason about species interrelations at various levels of sophistication similar to students at middle or high school level. However, the results also show that students can be selective in their reasoning, meaning that the level of sophistication depends on which population is more crucial from the point of view of each student. This study showed that students at younger age could learn about the ecosystems and this pushes us to think of a systemic instructional approach useful for teaching younger kids about complex open systems. The empirical findings should be interesting to engage NABT members in conversations at the practical level, in particular at the level of designing appropriate instruction that helps students reach the desired learning goals of ecological system's reasoning. Research into system's reasoning helps the community to think of ways that foster student's reasoning of complex structures essential to thrive in a "diverse" and "global" society that depends on understanding how change in one element of the ecosystem influences entire system.

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