LEARNING PROGRESSION OF ECOLOGICAL SYSTEM REASONING FOR LOWER ELEMENTARY (G1-4) STUDENTS

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A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Curriculum, Instruction and Teacher Education

2012

ABSTRACT

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In this study, I utilized a learning progression framework to investigate lower elementary students (G1-4) systemic reasoning in ecology and I related students reasoning to their sources of knowledge. I used semi-structured interviews with 44 students from first through fourth grade, four teachers, and eight parents. The results revealed that a hypothetical learning progression begins with anthropomorphic reasoning as the lower anchor and ends with complex causal reasoning as the upper anchor for students in this age. However the results showed that many students revealed mixed-level reasoning - meaning that they can reason at different levels in the same context. Very few students were able to use scientific terms and even those who did use the terms were not able to capture the scientific meaning of those terms. The results also revealed that students' accounts about scenarios in the various categories of systemic reasoning were inconsistent. Finally, the results concerning sources of knowledge revealed that students acquire their ideas from various sources, the media being the most frequently mentioned source, followed by books, personal experiences and parents. Those results have implications for defining the learning progression in general, for the validation of the hypothetical learning progression and for practical development of curriculum and instruction. With regard to defining the learning progression, the presence of mixed-level reasoning opens the discussion whether learning progression levels should be strictly pure levels or should include combinations of various levels to identify students' reasoning. With regard to validation of the hypothetical

learning progression, the inconsistencies of students' answers and low correlations across various categories of systemic reasoning suggest that the categories used in this study were distinct. Finally the results of students' sources of knowledge has implications for designing a curriculum that capitalizes on students interests such as media and general books and scaffold students to move them up to scientific reasoning.

ACKNOWLEDGEMENTS

I would like to thank my advisor, Dr. Amelia Wenk Gotwals for her support throughout my graduate school program at Michigan State University. She has been a wonderful mentor and advisor and a great inspiration to my work.

I also would like to thank my dissertation committee members, Dr. Andy Anderson, Dr. Suzanne Wilson, and Dr. Samantha Caughlan for their guidance and their precious advice during important moments of my graduate school program.

Moreover, I would like to thank the teachers and principal at the elementary school where I collected data for their generous time and support of my work. In addition, I would like to thank the parents of the students for their time and generous information and most of all I would like to thank the 1st through 4th graders whom working with was a real pleasure and fun.

Finally, special thanks to Ignat Soroko whose support, love and care made it possible for me to finish my dissertation.

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CHAPTER 1 INTRODUCTION

In this dissertation, I report on a study in which I developed a hypothetical learning progression of lower elementary students' (G1-G4) systems or systemic reasoning about species interactions in an ecosystem and describe students' sources of knowledge (Barton, 2009) that may explain specific ways of reasoning. In this chapter I introduce the importance of ecology as one of the big ideas in science as well as systemic reasoning as a cross cutting concept. In the second chapter I present the literature concerning learning progressions, students' learning of ecology and systemic reasoning, and the importance of students' sources of knowledge, all of which lead to presenting the research questions of the this study. In the third chapter I present the research design including the participants, the data I collected and the methods I used for analyzing this data. In the fourth chapter, I present results about the hypothetical learning progression and students' sources of knowledge. Finally, in the fifth chapter, I discuss the implications of the findings in light of other empirical work and outline future research based on the study's findings.

The Importance of Ecology and Systems Reasoning

In his book *The Diversity of Life,* Wilson (1992) describes the various factors that have impacted biodiversity over 600 million years, but emphasizes that human factor in this modern age has the most detrimental effect on biodiversity. Biodiversity in an ecosystem is of extreme importance to our lives. Food, wood, and medicine are the result of species biodiversity which requires that we work on preserving it. However, the documented loss of biodiversity is alarming and has reached the level of mass extinction (Lauro, 2012). The 2010 Convention on Biodiversity mentions that the rate of species loss is 1000 times more than the normal rate and list several factors that contribute to this – most of which are human behavior such as habitat loss due to human change of natural ecosystem to crop land, introduction of new species, global climate change, and pollution (UNEP, 2010). Ecologists believe that studying changes on ecosystems requires a model of including human action because of the interaction between biophysical and social aspects of the ecosystem. As Robertson et al. (2012) put it:

> The importance of understanding these dynamics cannot be underestimated: Without understanding couplings between natural and human systems, workable policy solutions to some of the most recalcitrant environmental problems of today, which range from degraded water quality to biodiversity loss to climate change vulnerability will remain difficult to design and even more difficult to achieve. (p. 345)

In order for the public to understand the importance of biodiversity and the role of humans in preserving it, they need to be educated. Thus, learning about ecosystems and the various interactions is extremely important for K-12 students. Without proper understanding of species interactions in ecosystems, matter and energy recycling, and the systemic nature of the ecosystem, citizens will not understand the importance of biodiversity and may not support the preservation of ecosystems. In fact, the latest framework for the new science education standards identified ecology as the one of four main ideas in the life sciences that needs to be taught (NRC, 2012).

Understanding how ecological systems work is important for many reasons. The renowned ecologist Odum (1977) states: "We are abysmally ignorant of the ecosystems of which we are dependent parts" (p. 1289), meaning that we need to increase awareness of species interaction in ecosystems as they influence us and our environment. He argues that biology needs to have a balance between reductionist approaches (molecular) level and holistic approaches (ecology). Major ecological concepts, such as the flow of matter and energy as well as biotic and abiotic interactions, connect the microscopic and macroscopic levels.

Systems or systemic reasoning[1] about ecosystems influences understanding and decision-making about environmental issues (Hogan & Weathers, 2003; Mohan, Chen & Anderson, 2009).The NRC framework (2012) identified system reasoning as a crucial practice that applies to open systems such as ecosystems which have complex levels of organizations leading to properties of the whole system different from the individual parts. When contrasting closed and open systems, it is worth noting that no system is completely isolated from the environment; however, some systems (e.g., a watch) have minimal interaction with environment and so even when they exchange energy as heat with the environment, the matter exchange is minimal. In contrast, an open system depends on a constant dynamic "input" and "output" that determines what happens to the system. Odum (1992) emphasizes considering ecological systems as open systems that dynamically interact with the input and output of matter and energy. He gives the example of a forest that is not a "self contained" system because external factors influence the forest, just as the forest influences neighboring environments. Hence, understanding open systems requires understanding the whole system. In fact, many educators have advocated teaching systems reasoning in ecology and many other areas of science as a key socio-scientific practice for scientific literacy:

> The main goal of having students learn about systems is not to have them talk about systems in abstract terms, but to enhance their ability (and inclination) to attend to various aspects of particular systems in attempting to understand or deal with the whole. (AAAS, 1993, p. 262)

This study investigates early elementary students' systems reasoning about ecology. I consider a scheme for categorizing levels of students' ecological reasoning within a learning progression. Since this learning progression is for students who have not yet had formal

[1] Note that systems reasoning or systemic reasoning are used interchangeably because they refer to same reasoning.

instruction about the topic, it is important to understand where students acquire their ideas. Therefore, I also investigated students' sources of knowledge and related that to students' levels of reasoning. I pose the following research questions:

1. What are the patterns in 1st to 4th grade students' system reasoning about ecosystems?
    a. What are the patterns in 1st to 4th grade students' system reasoning about ecosystems with respect to relating the effect of biotic or abiotic factors on the rest of the food web? (systemic interdependency)
    b. What are the patterns in 1st to 4th grade students' system reasoning in identifying key factors in ecosystem? (systemic analysis)
    c. What are the patterns in 1st to 4th grade students' systems reasoning in constructing a complex food web? (circular connectivity)
    d. What are the patterns in 1st to 4th grade students' systems reasoning about recycling of matter? (dynamic recycling)
2. How is 1st to 4th graders' reasoning similar or different across each grade level, gender or ability?
3. How is 1st to 4th graders' reasoning across the various system categories correlated?
4. Where do 1st to 4th graders learn about ecological relationships?

CHAPTER 2: LITERATURE REVIEW

In this chapter, I review the literature that pertains to two areas: the first area deals with the research on students' reasoning about ecology, which allows us to identify what we know about students' understanding and reasoning in the this topic so far and what unanswered questions linger. The second area deals with research on learning progressions, which allows us to take a developmental approach to how reasoning develops from simple to more sophisticated levels.

Research on Students' Reasoning of Ecology

Various empirical studies have investigated students' reasoning about ecological systems, particularly the reasoning and misconceptions about species interaction in the ecosystem at the middle or high school level (e.g., Alexander, 1982; Barman et al., 1995; Gallegos et al. 1994; Hogan 2000; Web & Glott 1990). In these studies, students were interviewed or given written assessments that involved questions concerning the effects of a change of one population on another. Students tended to recognize predator-prey relationships but not other relationships. For example, students recognized that if a rabbit population decreased, the eagle population that fed on rabbits decreased, but they did not recognize that if grass decreased, the effect would eventually influence the eagle population. This reasoning of changing a factor such as population size and having students predict the effect of the change on other populations in the ecosystem generated more studies about students' causal reasoning in the ecosystem context.

Other studies investigated such cause-effect relations in more detail. Green (1997), for example, examined undergraduate students' causal reasoning about two or three organisms (e.g., M feeds on N, A eats Z which feeds on O) and asked what would happen to N if M decreased or what would happen to A if we changed the population of O. He found out that students were more likely to identify a simple direct relationship of M on N and only reasoned with two-way causality (meaning that a change in M will lead to change in N which in turn leads to change in M) when prompted to do so and did not do this spontaneously. Similarly, White (1997) found that undergraduate students' causal reasoning was better when considering a direct predator-prey relationship rather than a food chain of three populations. He referred to this as a "dissipation effect" where students thought that the influence was reduced as it moved further away from the source. For example, if there was a food chain that started with plants that transfer energy to rabbits that, in turn, transfer energy to wolves, students could recognize the effect of a changing rabbit population on wolves, but not necessarily the effect of changing plants' population on wolves. Green (1997) argued that rabbits and wolves were seen in a direct relationship (one being food for the other), but that plants and wolves were further from each other and so students were less likely to recognize the effect. In more recent work, the idea of causal reasoning was also investigated with elementary students. Grotzer and Bell (2003) found that third grade students' causal reasoning improved as a result of a curriculum that explicitly addressed the causal relationships in the ecosystem. Students were able to identify indirect relationships in food webs as well as the effect of removing one population on several others in the food web. This study showed how a specific curriculum and teaching instruction foster a change in students' understanding; specifically recognizing what the authors called a "domino effect" of changing one population on the rest of the food web populations. However, even with the slight improved understanding, the number of students who mentioned understanding of one or two indirect effects on the ecosystem as a result of changing one population was more than those revealing understanding of several effects. .

Other researchers, Griffith and Grant (1985) investigated a hierarchical model of learning about food webs. They classified nine skills in a general food web of “subordinate” and “superordinate” difficulties. They predicted that some skills (e.g., predicting the effect of directly related populations in one food chain) are easier that others (e.g., predicting the effect of changing producer population on top carnivore). When testing this model statistically, they found that certain tasks were indeed more difficult than others (i.e., fewer students were able to trace the effect of changing a certain populations). They concluded that it is important to recognize the hierarchy of different interactions in a food web model when teaching about species interdependency and design a curriculum that moves from simpler to more sophisticated tasks. However, this study revealed two drawbacks: one was that it started from abstract model rather than from students’ ideas, and the second was that it was conducted with grade 10 students, so it was unclear whether this result would hold for students at lower or upper grades.

In addition, other studies considered additional important concepts in reasoning about ecosystems. Hogan and Fisherkeller (1996) classified 5^{th} and 6^{th} graders’ reasoning of various concepts (nutrient cycling, food webs and decomposition). They constructed a “bi-dimensional coding” to determine 5^{th} and 6^{th} graders’ level of sophistication compared to scientific ideas. This coding scheme organized students ideas according to two dimensions: compatibility with scientific views and elaboration of students’ reasoning. They found that even when students responded in a scientifically compatible manner, they still could not elaborate on this response rendering the understanding rather shallow. Moreover, they also noticed that students did not recognize that (1) carbon is recycled in the ecosystem and (2) understanding of decomposition was a precursor to understanding the nutrient cycling and food web interaction.

Another study considered the consistency of students' ideas of ecology. Reiner (2001) investigated 9th grade students' ideas and ontological beliefs about food chains; she found that students' ideas were "incoherent but consistent". For example students did not relate the process of feeding and that of decomposition to matter and energy conservation processes in the same ecosystem unit; hence their ideas were "incoherent". The students; however applied the concept of food chain being an "eating order" to different assessment items that asked them about producers and consumers; thus rendering this concept "consistent". In other words, students were consistent in thinking that organisms feed on each other, but were not coherent in relating feeding and decomposition to matter and energy. Moreover, there was not much change after instruction in students' ontological beliefs in thinking of food chains: Students thought of food chains as organisms feeding on each other, and identified the organisms' size as a constraining factor to how long the food chain can be. This means that rather than having energy as the main concept of what a food chain represents and how long this food chain can be, students resorted to intuitive reasoning of food or size of animals to think of food chains.

While there have been studies about students' misconceptions, causal reasoning, and conceptual coherence in ecology, Leach et al.'s (1995; 1996a, b) research attempted to paint a picture of conceptual development of ecology over longer periods of time by taking a cross section of students at different ages (ages 5 to 16). They classified the main concepts in the field into recycling of matter, recycling of energy, and interdependency of organisms. They discovered that students' ideas about matter recycling start by reasoning from experience and teleological reasoning and moved to more scientific explanations as they get older. For example, students' teleological reasoning for the reason why animals need food was to "become strong", whereas more sophisticated students used scientific reasoning to refer to the scientific explanation of energy. Similarly with organism interdependency, younger students used more teleological explanations whereas some older students referred to food habitat and behavior to explain their answers (Leach et al., 1995; 1996 a, b). One example of teleological reasoning consisted as students referring to predator-prey relationships as enemies (e.g., so owls come out at night because their enemies are not there). This is contrasted with the scientific explanations where students recognize that predator-prey relationships are governed by energy principles.

Recently, Lehrer and Schauble (2012 a, b) have taken a developmental approach to studying students reasoning in evolution and ecology by examining students' learning about these topics through scientific modeling. They use concepts such as variation and change to describe reasoning development in evolution, and the concepts such as the relation of organisms to the place, and other elements of the environment to describe the reasoning development in ecology. The authors categorize initial reasoning that starts with mapping human characteristics to animal populations, and the reasoning becomes more sophisticated as students consider the needs of animals. Later, students are able to develop reasoning that consider factors that influence populations' survival and finally students use computer models to consider the biotic and abiotic interactions in the ecosystem. The authors construct a convincing argument of how elementary students' reasoning advances as a result of immersion in modeling practice.

In sum, the literature presents two important ideas that require further research: one is the need to build on research that has been done with lower elementary students to further investigate how elementary students about the ecosystems, on lower elementary students and another is the need for emphasis on investigating learning over time. Research with elementary students (e.g., Grotzer & Bell, 2003; Lehrer & Schauble, 2012 a, b) has investigated students' ideas as a result of specific instructional methods, without considering students' ideas before instruction. Moreover, while Leach et al.'s (1995; 1996 a, b) studies emphasized categorization by age, they did not investigate the consistency of students' ideas among the different concepts. A potential reason for shortage of detailed studies at lower elementary may be the fact that some middle, high school, and even university students exhibit simple reasoning about food webs. Thus there may be an assumption that younger students can only exhibit simplistic ecological reasoning. However, Carey (1985) reminds us that: "Human beings are theory builders; from the beginning we construct explanatory structures that help us find the deeper reality underlying surface chaos" (p. 194). Therefore, more empirical work could build on the previous empirical studies of Leach et al. (1995, 1996 a, b) as well as Lehrer and Schauble's (2012 a, b) work in order to understand how younger students reason about species interactions in various settings. Even though this study did not investigating the same students' over time, it is still taking students from various grades which allowed us to shed light on students' ideas about ecology as they progress in school.

Research on Learning Progressions

Driver and Erickson (1983) summarized the research on student learning into three categories: research that (a) empirically tests the validity of a certain theoretical learning model, (b) attempts to understand what knowledge students spontaneously draw upon in naturalistic settings, and (c) tests a framework's stability over time or contexts. The authors argue that the most effective research is that which uses a clear theoretical background which informs theory and, in turn, instruction and classroom culture. This is what learning progressions research attempts to do:

> Learning progressions are descriptions of successively more sophisticated ways of thinking about a topic that can follow one another as children learn about and investigate a topic over a broad span of time. (NRC, 2007, p. 214)

This means that learning progression research investigates students' conceptual development over time as students have more experiences and opportunities with various topics.

Although the idea of tracing students' conceptual development is not new, the idea of relating conceptual development to curriculum and instruction is new (Duncan & Hmelo-Silver, 2009). Smith et al. (2006) explained that learning progressions bridge the gap between standards and what students know through empirically documenting the various stages of learning of "big ideas." Identifying big ideas and what we expect students to learn is a starting point. This is followed by empirical research to identify students' knowledge and reasoning about the big ideas in order to categorize various stages of knowledge. It has been customary to use the terms "lower anchor" to refer to least sophisticated reasoning and "upper anchor" to refer to the most sophisticated reasoning that is age and grade level appropriate and the same time scientifically sound. The whole process feeds into curriculum development and instructional practices in order to help students reach the desired outcome. Rather rapidly, learning progressions has become a research paradigm embraced by many researchers (e.g., Mohan et al., 2009; Schwarz et al., 2009; Songer et al., 2009) to shed light on students' reasoning of content and practice.

Duschl et al. (2011) review the learning progression empirical research and notice the variations in the empirical work of learning progression. They distinguish between learning "validation" learning progressions and "evolutionary" learning progressions. In the former, the learning progression takes a top-down approach that starts from the standards and attempts to construct fixed steps to reach an upper anchor that is dictated by college science content. In the latter, the learning progression takes a bottom-up approach that starts from empirical data and attempts to constructs flexible progress variables to reach the upper anchor that are age appropriate and dictated by scientific literacy of citizens. The main difference between those two kinds of learning progression is how they view conceptual change:

> Because the learning progression uses a *'fix it'* conceptual change focus that seeks to validate the initial sequences and levels of progression, we refer LP like this as '*Validation LP's*' as opposed to '*Evolutionary LP's*' that refine and define the developmental pathway(s) through identification of mid levels or stepping stones that are then used to bolster meaning making and reasoning employing crafted instructional intervention. (p. 157)

Even though Duschl et al. (2011) prefer the evolutionary learning progression because of its advantage of improving science learning and teaching, they acknowledge both types of learning progression are important at this point because they increase our understanding of the different levels of students' reasoning. In fact, the learning progression literature exhibits considerable variation in terms grain size of sample or content. Some researchers cover broad spans of time from elementary, middle school and high school (e.g., Mohan et al., 2009; Smith et. al., 2006); whereas others cover a shorter span, such as upper elementary or middle school students (e.g., Alonzo & Steedle, 2009; Songer et al., 2009). Moreover, some studies considered a broad content such as carbon transforming processes that can be applied in situation of respiration, decomposition and photosynthesis (Mohan et al., 2009), whereas other considered a narrower content such as photosynthesis (Alonzo et al., 2009). Yet others considered the learning progression of a practice such as modeling (Schwarz et al., 2009). Even though there is still no common rule as to what content, sample size that should be followed in the learning progression, the empirical work of the learning progression has opened the floor to research students' reasoning in various contexts in an iterative process that considers content, context and students background knowledge.

For the specific case of ecology and biodiversity, Songer, Kelcey, and Gotwals (2009) describe an empirically based, integrated learning progression for ecology and scientific explanations that are used to guide the development of curricula and assessment items for elementary students. They describe how ideas in classification, ecology and biodiversity can progress over three grades – 4^{th}, 5^{th} and 6^{th}. Parallel with this content progression is the progression in inquiry skills, which is manifested with a four level progression describing increasingly sophisticated explanations, with each level also containing elements of scaffolding to guide students in their development. Moreover, Gotwals and Songer (2010) discuss the trajectories students follow in order to reason about biodiversity issues and categorize several kinds of reasoning that they call "middle knowledges" which are elicited by using assessment items based on writing scientific explanations. They found that even when students are scaffolded in formulating scientific explanations, there still existed "messy middle" knowledge, where students may reason using content in certain types of situations, but not others.

The variety in considering various content, practice or grade levels is important to push our understanding of learning progression at the onset of this research paradigm. However, even when a learning progression investigated different grain sizes, different grades, or different content, a common ground for all the studies resides in describing learning in such a way that related content or practice to students' reasoning. In addition, many scholars in this area agree on its value of supporting formative assessment and instruction (Heritage, 2008). Another important similarity in the above research was that all the studies have been conducted after students were exposed to formal instruction at some point even when they did not always consider an intervention study (Mohan et al., 2009). One assumption of this research is that students' conceptual framework is influenced by the scientific concepts that they are exposed to in classroom. Thus, as many younger students have not been "officially" introduced to science, most of the learning progression research has emphasized upper elementary or middle school students as a starting point. However, Alonzo et al. (2009) worked with younger elementary students in an attempt to construct a learning progression of plant nutrition for grades 1 to 6. They found that students vary in their levels of sophistication even when they have not officially learned about how plants make food (i.e., photosynthesis). Hence, students' scientific knowledge is informed by many experiences, and their beliefs about scientific concepts are well established before they enter schools. Thus, many students reach the classroom with experiences that help them develop their conceptual framework. In fact, Metz (2009) emphasizes the importance of background knowledge and resources that students capitalize on in their development:

> Children's thinking cannot be simply characterized by common, universal strengths and weakness. Furthermore, children's capabilities and trajectories of their development are more plastic than the original model assumed. Rather than stage alone, an interaction of maturation, experience and instructional history and current instructional opportunities (together with individual differences in aptitude, background, interests and motivation) constrain the path of children's learning and development. (p. 18)

One could then argue that learning progression research on younger students could enrich this research paradigm and could help understand how ideas are constructed early on. Moreover, understanding students' background knowledge also enriches this paradigm by relating students' reasoning to their experiences and knowledge resources. Since learning progressions identify several levels of reasoning (not just the most simple and sophisticated), it is important to identify the intermediate levels of reasoning for younger children which many times could also be persistent for students at upper grades or for those who have received formal instruction and the sources of those ideas. In addition, the question of where students acquire their ideas and reasoning from becomes important to understanding reasoning at each level. In their revised version of conceptual change theory, Strike and Posner (1992) emphasize the importance of what they call “conceptual ecology” that takes into account students’ beliefs, culture, everyday knowledge, epistemological commitments and even emotional factors. Knowledge is always constructed within a social milieu which influences the way one reasons and this social construction of knowledge is equally important to the cognitive reasoning. As the authors mention:

> At the same time, it is important to be clear that our view is not neutral about the social character of knowledge. While scientific concepts may be human constructions, they are predominately social constructions into which the young are initiated. No account of learning or of conceptual innovation that misses that fact that conceptions (and misconceptions) are parts of “forms of life” (Wittgenstein, 1953) into which human beings are initiated is likely to be reasonable. (p. 170).

This stance has implications for how one views learning progressions. In order to understand the different learning progressions, one needs to understand the conceptual ecology of students that examines why students are reasoning in a certain way and from where they acquire ideas. With very few exceptions (e.g., Mohan et al., 2009), the learning progression literature has been focused on studying students reasoning from a cognitive perspective, but I argue it is important to consider the conceptual ecology of the students if we are to understand how and why learning progression levels exist. In this study, I build on socio-cultural researchers (Moll et al. 1992; Barton & Tan, 2009) who investigated students’ backgrounds and related learning to students’ original repertoire of practice. .

Consequently, this study constructs a learning progression about ecology for students at lower elementary grade (G1-4) that documents how students reason in ecology. The rationale for this study builds on the existing literature in three ways: First, this study builds on research of lower elementary students in order to document how students reason in ecology before they have formal instruction. Second, most learning progression research studies investigated upper elementary students. However, this study investigates lower elementary students' reasoning about systemic reasoning of ecology. Third, this study includes the sources of knowledge of students in order to investigate how students construct their knowledge and not just document the various levels of learning progression. However, in order to build the learning progression, it is important to introduce the theoretical framework that I use which I discuss in the next section below.

Theoretical Framework and Research Questions

Bertalanffy (1968) was the first to develop the general systems theory that is applicable to open systems. Rather than taking a mechanistic approach, which recognizes the mechanisms of the different parts, he advocated taking a holistic approach that recognizes the relationship among the whole system as an entity. The classical laws of thermodynamics propose that a closed system evolves from a state of order to that of disorder, which is unlike the open system which evolves from a state of disorder to order and complex organization. Bertalanffy (1968) asserted that a key concept in biology is "organization," which produces a whole that is different from the sum of its parts. For example, the human body systems have characteristics which allow them to perform functions different from individual cells. Similarly, ecosystems have characteristics of energy flow, and species interaction that are at a different level from a single organism's need. Moreover, systems such as ecological systems are considered open systems; when comparing closed and open systems, Bertalanffy argued that equilibrium can only be reached in a closed system, whereas an open system can only reach a "steady state," a state of disequilibrium which nevertheless 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. He states;

> The living cell and organism is not a static pattern or machine like structure consisting of more or less permanent "building materials" in which energy yielding materials from nutrition are broken down to provide the energy requirements for life processes. It is a continuous process in which both so-called building materials as well as energy-yielding substances are broke down and regenerated. But this continuous decay and synthesis is so regulated that the cell and organism are maintained approximately constant in a so called steady state. This is one fundamental mystery of living systems; all other characteristics such as metabolism, growth, development, self regulation, reproduction, stimulus response, autonomous activity, etc., are ultimately consequences of this basic fact. (p. 158)

It follows that when dealing with open systems, one should engage in systems reasoning. This raises the question of what systems reasoning is and how it differs from other forms of reasoning. Capra (1997) emphasizes the complexity as part of the system and that the complexity is revealed as an "emergent property" which is understood by studying the pattern rather than sum of the parts:

> Systems science shows that living systems cannot be understood by analysis. The properties of the parts are not intrinsic properties but can be understood only within the context of the larger whole. Thus systems thinking is "contextual" thinking; and since explaining things in terms of their context means explaining them in terms of their environment, we can also say that all systems thinking is environmental thinking. (p. 37).

It follows from the above that one can think of the whole system by thinking of the relationships of the different parts and not by thinking of each part separately. Capra (1997) gives the example of the tree and mentions that when one thinks of the relationship of the leaves, stems and trunk one automatically thinks of the tree as a whole and not of the specific parts separately. Therefore, one has to think to identify the specific properties of the system to study. Chandler and Boutilier (1992) proposed a hypothetical reasoning model that applies to open systems, "dynamic system reasoning." They propose four properties for systems reasoning:

1. Systemic synthesis: understanding that a change in one component affects others.
2. Systemic analysis: 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: one element is a source of energy that projects to other elements but also receives energy that affects other elements of the system (as opposed to linear flow of energy from one source to a final destination).
4. Dynamic recycling: molecules do not exit from the system but instead keep circulating in it.

Chandler and Boutilier (1992) tested 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" (p.133). They interviewed 96 students (ages 8 to 18), about two systems (the hydrologic cycle and nitrogen cycle), and asked questions aligned with the four properties. They also administered classical Piagetian tasks to compare the two kinds of reasoning. Although the results showed that systems reasoning correlated with formal Piagetian reasoning (i.e., older children performing better in both kinds of reasoning), there were significant statistical differences between the two kinds of reasoning. That is, students do not necessarily have to master the Piagetian tasks in order to perform well in the dynamic system reasoning tasks; rather, students' performance on the dynamic system reasoning task was a separate "ontogenic" category that develops "parallel" to Piagetian reasoning and follows after it (p.133).

Since its emergence, the idea of systems reasoning has been empirically tested in order to determine if students exhibit complex systems reasoning. The results were mixed: some studies showed that even explicit teaching of systems reasoning did not produce significant improvement. For example, Sweeny and Sterman (2007) conducted a study with middle school students to find out if systemic reasoning is intuitive. They interviewed students about feedback-loop reasoning of predator prey relationships and other ecological systems and found that students do not readily use feedback loop reasoning about those systems and thus concluded that systemic reasoning is not intuitive. Raia (2005, 2008) delineates that reasoning in complex system requires students to think of several factors that affect the system at its different levels in order to emergent property which in turn induces what she calls a "downward" causal effect on the system. For example the V-shape property of geese while flying is an emergent property that constrains the movement of birds in this shape. She used two questions from earth sciences and one from biology about V-shape movement of bird flocks and asked students to explain or hypothesize about the reason for the shape of the birds. The results showed that college students did not have complex systems' thinking. She concluded that it is important to explicitly teach students about the emergent properties in the complex system.

On the other hand, some studies showed that explicit teaching of systems reasoning resulted in improving complex system reasoning. For example Roberts (1978) found that fifth and sixth graders significantly improved their systemic reasoning after explicit teaching about feedback loop models and students were able to identify underlying structures of the models and demonstrate understanding of the factors that allow the system to change. Similarly Plate (2010) showed that middle school students who received explicit teaching about systems were able demonstrate the influence of various factors on the system. The author used a fictitious story about fish in the ocean that he read for students then gave them cards to reconstruct the system and he found out that students who received instruction about systemic thinking were able to construct more complex connections of the system even when they did not receive content knowledge instruction. Hill and Hedden (1985) investigated third and fourth grade students' systems reasoning using assessment tasks such as introducing students to different ways of folding the paper and changing the paper folding and asking students what is happening. They found that students who were introduced to a curriculum that handled systems performed much better at those tasks than those who did not receive any explicit instruction about systems.

In all of studies above, there was little emphasis on younger students' reasoning of ecosystems. Therefore in this study, I take a developmental approach to systems reasoning in constructing a learning progression of what I will call "systems ecological reasoning." Knowing that there are many systems ideas that cut across the ecosystem concept, I first present the ecosystem model I chose.

Hogan and Weathers (2003) reviewed the literature about ecological reasoning, presented the history of ecology, and interviewed ecologists in order to identify models of ecosystems. They present three ecological models that ecologists work with. In the energy model (Odum, 1977; 1992), ecologists view the complexity of ecosystems in terms of energy flow. In the nutrient recycling model, ecologists analyze the inputs, outputs, and accumulations of nutrients in their study of ecosystems. The third model emphasizes the interaction among populations, community, biotic-abiotic factors, and human influence on the ecosystem. It is noteworthy that the three models are not independent but overlap in explaining the ecosystem. However, the way certain factors are foregrounded or backgrounded dictates how to study the ecosystem. I will work within the third model, which emphasizes the species interactions.

I justify this choice in two ways. First, while many studies worked within the causal reasoning of species interactions, this study uses the systems reasoning framework to study different aspects of students' thinking in detail. Second, the other two models (flow of energy and nutrient recycling) can be thought of as parts of a more general concept of matter and energy that have been studied before. For example, Mohan et al. (2009) examined carbon transformation in different instances (photosynthesis or respiration) and developed a learning progression of how students think of carbon along these phenomena. Therefore, in this study, I focus on the species interaction as the systems model and attempt to study students' system reasoning based on that model. I investigate first through fourth grade students' systems reasoning about ecosystems before formal instruction.

I pose the following research questions:

1. What are the patterns in 1^{st} to 4^{th} grade students' system reasoning about ecosystems?
    a. What are the patterns in 1^{st} to 4^{th} grade students' system reasoning about ecosystems with respect to relating the effect of biotic or abiotic factors on the rest of the food web? (systemic interdependency)
    b. What are the patterns in 1^{st} to 4^{th} grade students' system reasoning in identifying key factors in ecosystem? (systemic analysis)
    c. What are the patterns in 1^{st} to 4^{th} grade students' systems reasoning in constructing a complex food web? (circular connectivity)
    d. What are the patterns in 1^{st} to 4^{th} grade students' systems reasoning about recycling of matter? (dynamic recycling)

2. How are 1st to 4th graders' reasoning similar or different across each grade level, gender or ability?
3. How are 1st-4th graders' reasoning across the various system categories correlated?
4. Where do 1st to 4th graders learn about ecological relationships?

This chapter reviewed the literature that relates to students' learning of ecology, ideas about learning progressions, and discussed the systemic reasoning framework that is used in this study. Most studies about learning ecology and learning progression of ecology were conducted with upper elementary and were intervention studies, and this study builds on the literature to investigate lower elementary students before instruction in order to broaden our understanding of how students reason about ecosystems. Moreover, the learning progression literature did not include the idea of sources of knowledge of students so the last research question of this study addresses this concept. Knowing that the ecosystem is an open system, I applied the framework of systemic reasoning adopted from Chandler and Boutilier (1992) in order to construct the learning progression. Chapter 3 discusses the methodology that I used in order to investigate the research questions and analyze the obtained results.

CHAPTER 3

RESEARCH DESIGN

In this chapter, I present the setting for my study, the participants, and data sources. In addition, I present the coding scheme and analytic techniques I developed and used. I also discuss how I checked for reliability in coding to and how I accommodated for the cultural differences between me and the participants.

This study uses a mixed methods approach to construct a hypothetical learning progression of lower elementary students' reasoning about ecosystems. It also compares students' ideas across various categorical properties of systems reasoning, and examines students' sources of knowledge and how various informal experiences influence their reasoning about ecosystems. Specifically, the research questions are:

1. What are the patterns in 1^{st} to 4^{th} grade students' system reasoning about ecosystems?

    e. What are the patterns in 1^{st} to 4^{th} grade students' system reasoning about ecosystems with respect to relating the effect of biotic or abiotic factors on the rest of the food web? (systemic interdependency)

    f. What are the patterns in 1^{st} to 4^{th} grade students' system reasoning in identifying key factors in ecosystem? (systemic analysis)

    g. What are the patterns in 1^{st} to 4^{th} grade students' systems reasoning in constructing a complex food web? (circular connectivity)

    h. What are the patterns in 1^{st} to 4^{th} grade students' systems reasoning about recycling of matter? (dynamic recycling)

2. How is 1^{st} to 4^{th} graders' reasoning similar or different across each grade level, gender or ability?
3. How is 1^{st} to 4^{th} graders' reasoning across the various system categories correlated?
4. Where do 1^{st} to 4^{th} graders learn about ecological relationships?

Setting

This study took place in a Midwestern suburban school in which 71.22% of the students are white, 10.76% are Hispanic, 7.27% are African American, 5.23% are Asian, and 5% are American Indian, American Hawaiian or a mixture of two races. The school also had 30.72% economically disadvantaged students (data available at https//www.mischooldata.org). When I asked the teachers about the socioeconomic status of the families in the district, all mentioned that school is mainly middle and low-middle class. As one teacher puts it:

> Compared to Lansing, Huron Valley or Detroit, this school is definitely considered more wealthy, but compared to Okemos, Birmingham, or West Bloomfield, it's not even close. This area is just *okay*; it's still farming, working class, manufacture, we've got some of the Michigan State parents but at least half of the parents of the kids I teach are blue collar working class parents. (Interview with second grade teacher)

I was in contact with teachers in this school for almost a year before starting data collection. I met one teacher during educational events and then slowly began to participate in cultural activities and build close relations with the teachers, the principal, the students and some parents. This relationship built trust, which was an important foundation for my research.

Participants

Students

Each class (grades1-4) included approximately 24 students. After gathering permission from parents, I interviewed 10 to 12 students from each of the 1st through 4th grades. The total sample was total of 44 students, with a total of 20 males and 22 females. Teachers also identified the achievement of students.[2] I gave each student a code to protect students' identities, so for example, S1G4M refers to Student 1 in grade 4 who is a male (see Table 1 for the details of the student sample):

Table 1: Student Sample (N=44)

	High	Middle	Low	Total
Grade 1	1M, 2F	2M, 4F	1M, 2F	12 (4M, 8 F)
Grade 2	4M, 1F	1M, 4F	1M, 1F	12 (6M, 6 F)
Grade 3	2M	2M, 4F	1M,1F	10 (5M, 5F)
Grade 4	2M, 1F	3M, 3F	1F	10 (5M, 5F)
Total	13	23	8	N=44(20M. 22F)

Teachers

The four female teachers were experienced elementary teachers, each having taught lower elementary school for more than 10 years. Although this study is primarily about students, I have attempted to understand the students' achievement from the teachers' points of view. Therefore, throughout data collection, I checked with the teachers on how specific students may have come up with their ideas. For example, when I found that a student mentioned that she learned a topic from the teacher, I asked the teacher about it. Moreover, knowing that the

[2] Note that categorizing students by high, middle or low was mainly dependent on the teacher's judgments of students reading and math achievement and not necessarily their science knowledge. Later in the results section I show that there were cases that the teacher's judgments did not match what the students' answers were.

teachers knew their students very well, I consulted with them about specific answers that the students gave and whether it would be a good idea to talk further to those students' parents. In addition to having conversations with the teachers regarding the students, I also had formal interviews with the teachers that I explain below.

Parents

Even though this study focuses on the 44 students, I found that many students referred to learning opportunities with their parents. Therefore, I realized that parents would be an important source of insight concerning students' sources of knowledge. I started analyzing students' data to select interesting cases to pursue and I used "purposive sampling" (Noor, 2008) to select specific parents. I consulted with teachers about the students and parents to find out who can make an interesting case. I also strove to have a balanced sample of student with high and modest levels of reasoning. I ended up selecting eight family members of students who I interviewed: six mothers of the students, one father of a student, and for one case (S36G1M), I interviewed the whole family (mother, father, sister and the student).

Data Sources

Curriculum

Knowing that a major source of students' ideas comes from experiences in school, I made copies of the science curriculum that they used in order to examine if students were exposed to ecological concepts in those early grades. All teachers used the Battle Creek Science Curriculum[3] and three teachers mentioned that they teach one to two periods of science per

[3] The Battle Creek Science curriculum is provided by the Battle Creek Area math and science center that provides materials, workshops and activities for the improvement of science and math teaching in Michigan. Many districts including the school I conducted the study at use the

week except for the third grade teacher who mentioned that she integrates science with literacy and does not necessarily devote time to science alone but prefers to integrate it with other subjects:

> I integrate it so it's not on …it's not science on its own. We're supposed to teach 175 min a week of science, but I integrate it with language art, reading, and writing. There's a lot of comparing and contrasting and observations in science and I integrate that with language and arts as well. (Interview with 3rd grade teacher)

However, all four teachers mentioned the need and the desire to teach more science. One fourth grade teacher mentioned:

> It's unfortunately cut back into twice a week and 40 min each time much less than we used to. If you were to ask our district director, she would say that kids learn very little science nowadays. It's very sad; I wish I could teach more. (Interview with 4th grade teacher)

In the curriculum three disciplines cut across G1-4 elementary science: life sciences, physical sciences and earth science. I examined all units that might influence how students would reason about ecosystems or life sciences more generally. For example, when the topic was about life cycles, the unit required first graders to observe the life cycle of butterflies (the teacher showed me the samples of various stages of butterfly that she would use in that unit). Then there was a worksheet where students can draw the stages and the name of each stage. Except for the third grade teacher who integrates science, the other teachers mentioned spending somewhere between 6 to 8 weeks on each unit. Table 2 provides a brief summary of the life science units for each grade level, and the big ideas of each unit:

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science curricula provided by this center. More information about this center can be found at https://www.bcamsc.org/

Table 2: Summary of Life Science Units for G1-4.

	Grade 1	Grade 2	Grade 3	Grade 4
Title of life science units	An animal's life	A plants' life	Organisms have character	Organisms and their environment
General theme and ideas	Life cycle of animals. The teacher mentioned helping students identify living and non-living things and towards the end of the year she takes them to MSU garden and teaching them about butterfly life cycles	The plant's life and needs for growth. The teacher mentioned having them experiment what plants need to grow and manipulating variables such as water, sunlight in order to identify what plants need to grow	Classification of animals. The teacher mentioned helping them classify but she said that she usually integrated that with language and arts and did not teach them the topic separately	Animals and their habitats. The teacher mentioned that this unit is about ecosystems and having them learn about energy and matter transfer in the ecosystem in addition to organism interdependency

Note that 4th grade covers ecology. I asked the teachers about what they do in the unit. The fourth grade teacher mentioned that during the last academic year (2010-2011), they did not cover that unit and that she expects that she will not cover it again for the year of this study (2011-2012). The reasons were lack of time towards the end of the year and the fact that they still be working on other science units. Therefore, when I interviewed the sample of students, none of the students, including 4th graders, had formal instruction about ecosystems. However, they did have some experience with other aspects of life science that might influence their understandings and reasoning abilities in ecosystems.

Student interviews

The main data sources in this study were students' responses to questions about several scenarios concerning ecosystems. Southerland et al. (2000) discussed the importance of interviews and the wealth of information they provide about student understanding:

> To build thick descriptions of students' conceptual frameworks, researchers have turned to more descriptive tools, such as the structured interview, in which we ask students to explain their understanding in their own words and/or apply that knowledge in selected task. (p. 72)

In addition to finding out about students' "conceptual frameworks," interviews are preferred to written assessments for students at a very young age. Stromen (1995) discovered that interviews can elicit more student ideas than drawings, and when he compared 1^{st} graders' ideas about forests in drawings and interviews, he found that interviews produced richer data. Similarly, Grotzer and Bell (2003) used only interviews to study 3rd grade students' causal reasoning about ecology. Knowing that my sample constituted for early elementary students and my goal was to understand how students reason about the ecosystem, semi-structured interviews were used.

Southerland et al. (2000) classified interviews into "interviews about instances," "sorting interviews," "problem solving," and "prediction interviews." Knowing that my goal was to understand students' systemic reasoning, I had several questions in which I asked them to predict what would happen to the system under certain circumstances. This made my interviews lean towards these "prediction" interviews that are very useful in understanding the reasoning of students. Southerland et al. (2000) state,

> Prediction interviews require students to anticipate an outcome of a situation and explain or justify that prediction. The strength of this kind of interview is that it focuses on the ways students apply their personal meanings of the concept. Unlike interviews about instances, which require students to explain a concept, prediction interviews emphasize the application of that knowledge. And because they require application, prediction interviews are very useful in teasing out what has been learned by rote with minimal understanding from what is meaningful knowledge. (pp. 76-77)

Each interview (see Appendices I & II) consisted of several parts or scenarios and took place in a quiet room and lasted 35 to 45 minutes. I had conducted a pilot study in order to test these questions in May 2011. In this pilot study, I interviewed three students from each grade (1-4) and pilot tested the questions in order to find out whether the questions made sense to young children and whether students could answer them. As a result, I modified many questions and included others that showed to be useful in eliciting students' thinking.

The final interview consisted of different scenarios which all were designed to understand students' systems reasoning of species interaction and sources of knowledge that they build their ideas from. Table 3[4] summarizes how clusters of interview questions address the research question related to systemic reasoning and sources of knowledge:

Table 3: Addressing the Various Research Questions Thorough Interview Questions.

System Property/ Sources of knowledge	Subset questions of Research Question	Interview questions
Systemic Interdependency	What are the patterns in 1st to 4th grade students' system reasoning about ecosystems with respect to relating the effect of biotic or abiotic factors on the rest of the food web?	Scenario I (effect of changing specific populations on others food web): 6, 7, 8, 9,10, 17
Systemic Analysis	What are the patterns in the 1st to 4th graders' system reasoning in identifying key factors in the food web?	Scenario I (Detection importance of producers and sunlight energy): 3,4
Circular connectivity	What are the patterns in the 1st to 4th graders' systems reasoning in constructing a complex food web?	Scenario II, (constructing an interconnected food web) 3, 4, 5
Dynamic recycling	What are the patterns in the 1st to 4th graders' systems reasoning about recycling of matter?	Scenario I: (matter recycling through decomposition):13, 14, 15, 16
Sources of knowledge	Where do 1st to 4th graders learn about systems reasoning in ecology?	Scenario I: 21 22, 23, 24, 25, Scenario II, 7.

[4] Note that that when I refer to Scenario I question, I am referring to Appendix I-B where the picture is with the arrows, because they are the more specific questions. Moreover, the interview question numbers refer to the number of the question in the interview scenarios.

The first scenario consists of questions that gather data about students' systems reasoning and where they had been exposed to this topic before. Therefore, I presented students with the picture of an ecosystem without the arrows and asked them general questions that started a conversation about the picture, such as where they have seen it in real life and what relations existed before showing them the arrows. This is designed to reveal their intuitive ideas without any prompting. After that, I showed them the same picture with the arrows and I asked them specific questions about the relationships of populations, and what would happen to the ecosystem if some of populations in the picture disappeared or died. I also asked them where they learned about species interactions before. The questions attempted to gather information about students' systemic interdependency (how one elements affects others in an ecosystem), systemic analysis (essential element of ecosystem) and dynamic recycling (recycling of matter in an ecosystem). The whole scenario with all the interview questions and figures is found in Appendix I (A & B), but I illustrate in Figure 1 the picture that I showed the students and in Table 4 two questions about the picture for each of the three categories of systemic reasoning.

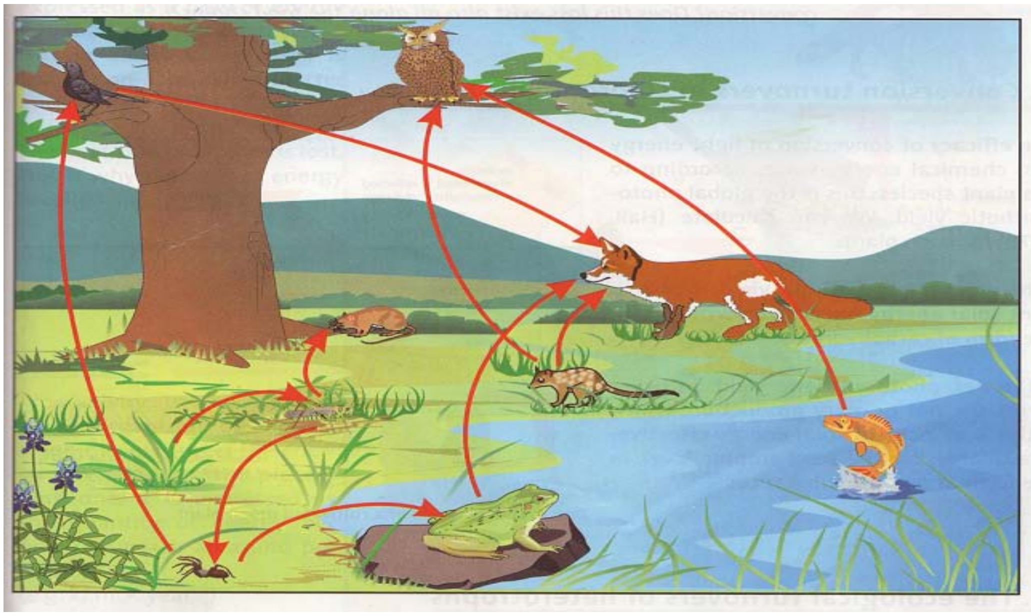


Figure 1: Picture Used in Systemic Reasoning Question. *For interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this dissertation.*

Table 4: Summary of Questions Representing Three Category of Systemic Reasoning.

Systemic interdependency	Systemic analysis	Dynamic recycling
1- What would happen if all insects died? 2- What would happen if all black birds died?	1- What is the most important element that allows this system to be working properly? 2- Do you think something is missing in this system?	1- If the fox died, what would happen to its body over time? 2- If the fish died, what would happen to its body over time?

The second scenario consisted of students constructing a food web allowed me to probe students' circular connectivity of the systems reasoning. The picture of the question has been used by Leach et al. (1995) as illustrated in Figure 2 below:

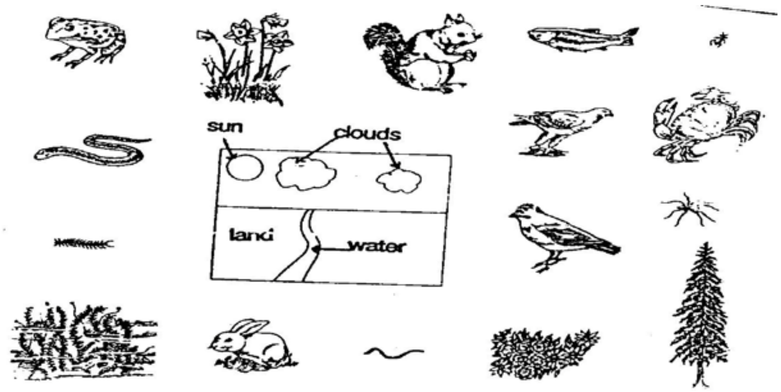


Figure 2: Scenario Question for Probing the Circular Connectivity Category.

The original form of this question involved choosing six of those organisms that could live together for a long period of time without needing anything, and the second question was to choose the population which is highest in number. When piloting the scenario, I found that students were often confused restricting themselves to picking six organisms only. Therefore, I decided to use the organisms but modify the question in order to help me elicit the students' "circular connectivity" about the system. I cut out each organism in the picture and put in an envelope then I presented the envelope to students. Then I asked them to make up an environment that can work properly and for that purpose I asked them to choose as many animals or plants as they want that can live in place with sun, clouds ,water, and earth. The students then had to choose the populations and this part of the interview was similar to a think aloud because often they were justifying their choice as they were performing the activity. After they finished choosing, I asked them follow up questions about the environment such as why they left out some organisms and chose other which helped them elaborate on what they were talking about. Appendix II shows all the questions for the circular connectivity questions.

In both scenarios, I probed students several times about where they learned about the topic and about their relevant experiences. This allowed me to gather information about the students' sources of knowledge. In addition to the formal interview questions, when I found that students were providing interesting information about the science content, I asked them about where they learned about this specific information.

Teacher interviews

In addition to interviewing students, I also interviewed each teacher for 25 to 30 minutes about several topics, such as the science curriculum they teach, the amount of science they teach, the science homework they give, and from where certain students get ideas. This interview was semi-structured and I used the questions in Appendix III as guidelines.

Parents' interviews

Yin (2011) discusses the importance of case studies in educational research and classifies case studies into three categories: descriptive, explanatory and exploratory. Knowing that my study is descriptive and explanatory in the sense it attempts to describe the learning and explain where students acquire their ideas about this topic, I have used mini case studies to help me shed light on students' ideas and sources of knowledge. To do that, I conducted semi-structured interviews with family members of eight students (two from each grade level) to learn more about students' sources of knowledge. The interviews had questions concerning general activities parents do with their children, the learning style of their children and the way they see themselves influencing their children's education, specifically science education. After the general questions, I then quoted certain sections from the student's interview and asked if they knew how their child got this information. This part was different with each parent. There were three parents for whom I had interviewed two of their children from different grades and for those parents I also asked about the differences between their two children. An example of one parent's interview where I interviewed both of her daughters (4th grade and 1st grade students) is shown in Appendix IV.

Analytic Techniques

To analyze the data, I first coded the interview questions in an iterative process that allowed me to construct the learning progression, and then I used quantitative and qualitative methods to answer the various research questions. Table 5 summarizes the data sources and analytic techniques for each research question before I discuss those in detail:

Table 5: Summary of Data Sources and Analytic Techniques for Each Research Question.

Research Question	Data sources	Analytic techniques
What are the learning progression levels in 1st to 4th grade students' system reasoning about ecosystems?	Interview questions of the four categories of system reasoning in scenario I and II in the student interviews.	*Qualitative technique*: Iterative coding and qualitative inter-rater reliability check in order to construct the learning progression of the four categories of systemic reasoning. *Quantitative technique:* Cronbach alpha to check for reliability within and across systemic reasoning categories.

Table 5 (cont'd)

How is 1^{st}-4^{th} graders' reasoning across and within the various system categories correlated?	Interview questions of the four categories of system reasoning in scenario I and II in the student interviews.	*Quantitative technique:* Rank correlation method to determine if there is correlation between grade and learning progression levels.
How are 1^{st} - 4^{th} graders' reasoning similar or different across each grade with respect to the two questions above?	Interview questions of the four categories of system reasoning in scenario I and II in the student interviews.	*Qualitative technique:* I used qualitative constant comparative method to look for students consistency *Quantitative technique:* Rank correlation method to find out if there is a correlation across various systemic reasoning categories and within the categories.
Where do 1^{st} - 4^{th} graders learn about ecological relationships?	Questions about sources of knowledge in the student interview in addition to interviews with eight parents and teacher interviews.	*Qualitative Technique:* I used constant comparative method and triangulation of data sources from students' interviews, parents' interviews and teachers' interviews

Iterative Coding

After finishing the interviews, I transcribed all the interviews verbatim. Then I organized each interview into sections that correspond to each category of systemic reasoning. I also had a section where students talked about where they know about the topic. This made the data easier to locate in order to code each section. An example of the interview transcript for S23G2M is included in Appendix V. The four systemic elements identified by Chandler and Boutilier (1992) were systemic interdependency, systemic analysis, circular connectivity and dynamic recycling. Those elements were translated into interview questions that required students to think of population changes (systemic interdependency), importance of plants and sunlight (systemic analysis), food web construction (circular connectivity), and recycling of matter (dynamic recycling). The first rubric I worked with was derived from the literature and from a small pilot study that I had conducted. I used the rubric as a coding scheme, and I specified a lower and upper “anchor,” as has been customary in the learning progression research (Mohan et al, 2009; Mohan & Plummer 2012). Appendix VI shows this initial rubric whereby the lower anchor stipulated anthropomorphic or aesthetic reasoning (e.g., “if the worms disappear the nature will become not beautiful”) and the upper anchor was derived from scientific explanation for each concept (e.g., “if the worms disappear, the food chain would not work, it would get ruined, because chameleon cannot eat grass, then chameleon dies, then whatever eats the chameleon dies finally all would die). I first coded a small sample of the interviews using the initial rubric and then changed the rubric accordingly. Gotwals and Alonzo (2012) mention the importance of incorporating the top-down and bottom-up approaches in learning progression research:

> As part of the top down design approach to learning progressions, scientists and science educators select the big ideas from the core knowledge needed for understanding socio-scientific issues and achieving scientific literacy. However, this logical decomposition of big ideas may not necessarily reveal the paths students take as they learn scientific content. Therefore the bottom up design approach to learning progressions promotes the organization of content based on students’ thinking as they develop more sophisticated understanding. (p. 4)

As such, my initial rubric (top-down approach) was complemented with the bottom up approach and was iteratively revised as a result of emerging findings and with several discussions with my advisor to refine this scheme. During the discussion sessions, my advisor and I went over the various levels with different examples for each level and discussed whether the levels need revisions or further sub-categorization or merging of categories. After every session, I revised the rubric and recoded the data accordingly. This method is common in learning progression research (Jin & Anderson, 2012), which stipulates that constructing a final learning progression takes many rounds of investigations to refine the codes, and it is aligned with the constant comparative method that Strauss & Corbin (1998) advocate for in qualitative research. I illustrate this method by one example from the lowest anchor. Although I had originally identified the lowest anchor to be anthropomorphic, I found during coding that many students reasoning was neither anthropomorphic nor simple causal reasoning. It was a different way of reasoning that took into account practical implications of any changes and not necessarily systemic ones. I discussed this with my advisor and we agreed that this level fell in between anthropomorphic and simple causal reasoning, and therefore I identified that as level 1.5 and called it concrete or practical reasoning. I illustrate this by the following example from systemic analysis questions:

> I: Which is the most important population in this picture?
> S1G4M: Maybe the spider because it eats moth and moths eat our shirts.

The above answer shows the student is reasoning practically and although he recognizes what the spider feeds on, he relates that to the practical interest of the preventing moths from eating the shirts. Someone may argue that this reasoning could be related to anthropomorphic reasoning, but there were no human characteristics or aesthetic values, it was a reasoning that was related the practical benefit or interest of not having moths eat the shirt. This reasoning was not related to the ecosystem but it was not exactly related to anthropomorphic reasoning and this why I labeled it as level 1.5.

In addition to this emerging level, I also found qualitative subcategories within each level. A more elaborate discussion of the learning progression is presented in the results sections where I present the final learning progression constructs, which is the fourth iteration of the learning progression from the starting rubric. Note that each time I revised the rubric; I went back and recoded the data using the revised rubric.

Reliability

In order to check for reliability, I have used quantitative and qualitative methods. In the quantitative method, I used Cronbach's alpha to check for internal consistency of the questions. In the qualitative method, my colleague and I coded the 30% of the data and discussed them.

To check for internal consistency of the questions, I used Cronbach's alpha coefficient in which a score of 0.700 is considered high and indicates good consistency of the questions for a certain construct. The internal consistency for the entire interview was $\alpha=0.821$ which means that the interview had high reliability in measuring students knowledge about systemic reasoning of the ecosystems. After that the interview was broken down into questions that belonged to each representative element of systemic synthesis. I used Cronbach's alpha to test for internal consistency for each cluster of questions. The result of this revealed that the question that required students to construct their own environment and justify their choice was the only one that could represent this circular connectivity category. Other questions that might have belonged to this category were questions that required students to pick an animal and talk about its needs for living. However, in those questions, students mentioned general ideas like food or shelter without connecting to the ecosystem. For this reason, the question concerning the construction of the environment allowed me to gather more information about the circular connectivity element of systemic reasoning. The two questions about asking about the most important element of the system was and what was missing of the system resulted in low Cronbach alpha of $\alpha=0.150$ which means I considered those questions separately for comparisons. The consistency for the six questions for systemic interdependency (what would happen to the ecosystem if one population disappeared? And what would happen if poison was sprayed[5]) was α= 0.725 and the consistency for the four dynamic recycling questions (What happens to the body of organisms when they die) was α=0.702. This means that there was high consistency for those set of questions targeting the systemic interdependency and dynamic recycling.

With regard to qualitative method for checking for reliability, I first coded two students from each grade (n = 8) by myself after revising the rubric as a result of discussions with my advisor. Following that, I asked a colleague who is an assistant professor in science education in a different university to code 2 interviews and we re-discussed the rubric after which I revised the rubric again. After that we both recoded 4 interviews and I revised the rubric again and discussed it with my advisor. After having the final rubric, my colleague and I coded 30% of the data (n =12 students, three students from each grade). We discussed the coding and we had an agreement of over 85% in coding of the interview responses. The differences were resolved through discussions. I illustrate the differences in opinion and how we resolved the differences in the following excerpt:

> I: If you were to create your own environment having water sun clouds and soil, choose some of those organisms (Referring to Figure 2) that can live there in such a way that the environment is working well for a while?
> S42G1M: I would choose squirrel, fish, frog, trees, bushes, worms and bunnies, and I would have flowers and bugs, the hawk and the bird.
> I: Why did you choose those?
> S: I chose the flower because that plant eaters like bunnies and birds can eat the plants. I chose the fish just in case we have water so we have something to put in it, I chose worms so that fish can eat, and I chose the frog because can take care of the bad bugs, the bad ones such as the spider. I chose the squirrel so that there's

[5] Note that I first considered the question about the poison with dynamic recycling, but the answers of the students showed the levels were more related to systemic synthesis because they were thinking of direct of more indirect populations at the macroscopic level without really tracing matter. Moreover, when I changed this question from dynamic recycling to systemic synthesis, the Cronbach's alpha for both the dynamic recycling and systemic synthesis increased.

a lot more trees than there really is. And I chose the hawk to make sure there's no other hawks.
I: what do you mean no other hawk?
S42G1M: actually two birds
I: What do you mean by two birds?
S42G1M: I mean that I would like to have the small bird and the hawk as well, I would like to have two have birds in his nature.

My colleague coded the excerpt above as level 3 in circular connectivity because the student was able to relate the populations to the habitat and to what they feed on. I coded the excerpt as level 3 and level 1 because I argued that the student mentioning that "taking care of bad bugs" means that he is still reasoning anthropomorphically due to a personal dislike of the bugs. My colleague argued that the words "bad bug" could be taken in context and that indeed the frogs eat the insects, but I argued that even if this is true, the choice of frog was dependent on personal liking and not on what he naturally the environment should have. My colleague was convinced and we settled to code this as 3a and 1a. Similar differences in coding were resolved through this kind of discussion.

Using rank correlation to examine consistency

To check for the correlation of students' ideas among the various systems thinking categories, I used rank correlation method (Cohen et al., 2003). There were 13 questions that were relevant for the analysis: One question represented circular connectivity category and required students to choose the populations that can live together in an environment that function well. Two questions represented the systemic analysis category and they required students to choose of the most important element of the system and of what may be missing in the system; six questions represented systemic interdependency and required students to talk what would happen if one population was removed or poison was introduced to the ecosystem; and five questions represented the dynamic recycling category and required students to talk about the what would happen to the body of some organisms when they died. The average was calculated for the set of questions representing systemic interdependency and dynamic recycling and was used in correlations with other categories. In addition, I used the rank correlation method to check for students' consistency within each category of systemic reasoning, particularly in the categories of systemic interdependency and dynamic recycling.

After finding correlations, I also used the constant comparative method to identify examples for students who were consistent in their thinking within and across levels and those who were not. To do this, I looked at examples to see if a student has the same learning progression level across all the answers to the questions or not. A representation of this will be presented in more detail in the results chapter.

Using qualitative triangulation to examine sources of knowledge

In addition to the learning progression levels, I also attempted to find out where students obtained their ideas. For this, I identified the different sources mentioned by all 44 students. Then I zoomed in at the eight cases and triangulated information from students, teachers, and parents (Yin, 2011). I illustrate this activity in Table 6 below:

Table 6: Sample of Triangulating Data to Find Out About Students' Sources of Knowledge.

Student S9G4F	Teacher	Parent	My Comments
I: have you read books or movies? S: I watch Animal Planet a lot and I've read a lot of books S: what books I: I like the book "warriors" book series it's about pets in the forest that eat rabbits squirrels birds and sometimes they eat fish	She is always interested in animals so I connected her with some research with MSU and she researched about dogs	She researched "general" information about Golden Retriever dogs in books at our school library. Then she researched the internet for pictures. After that she collected the information, she created a poster with pictures and various facts about Golden Retrievers.	The teacher evaluated her as a high achiever but during her interview I found that she exhibited various abilities with different questions so she was high in the circular connectivity category and middle in systemic synthesis and systemic analysis.

Table 6 (cont'd)

		She is always happy to read by herself hat is a science fiction or fantasy but the characters are cats, and their warriors because the groups are divided into clans and how they fight each other and how they survive and how they compete. I have done many activities with her but it was never part of direct instruction or planned activity	Her mother mentioned that there is not direct instruction at home and there did not appear to be a direct relation between her informal experiences and her answers in the different interview

After constructing a similar table for each of the 8 cases, I examined the emerging ideas for each student that described their sources of knowledge and how these sources were or were not related to their interview responses.

Accommodating for Differences between the Researcher and the Participants

Knowing that I come from a culture different from the students, it was important for me to make sure that I can understand the students' "world." This was especially important since I was also investigating their "sources of knowledge," which –is culturally specific I used various strategies to engage in the young students' culture. These included:

1- Watching several movies and TV shows that helped me understand what the kids watch: I watched movies like *Lion King*, episodes of *Peep and the Big Wide World*, *Magic School Bus*, and *Wild Kratts*. During this time, I tried to understand the cartoon characters and the information that those movies convey. For example I specifically watched an episode of the *Magic School Bus* that was about a food chain in a marine ecosystem. Even though the characters were not real humans or animals, many of the students I interviewed referred to this TV show and so I was able to relate to what they are talking about once interviewed them.

2- Visiting Impression 5 Museum: many students referred to Impression 5 during the interview, so I visited the museum in Lansing and interviewed one of the instructors about what they do with the students concerning the food web and food chain. The instructor explained that they have classes that align with their philosophy of "play and create" whereby they prepare activities for students to explore. Concerning the food chain topic, they model long food chains using Russian dolls called "Matrioshka" which is big doll which has several dolls inside and each one inside the other represents what the animal eats. Moreover, there was a section concerning the ecosystem with animal discs and arrows and the children can sit and create their own food chains and webs. The visit to this museum helped me understand what students were referring to when they mentioned Impression 5 and I could have a conversation of what they did there because I knew what was in the museum.

3- Talking to the parents: Even though the parents were participants in the study, I had a chance to ask them several questions that I felt needed clarification. For example, while discussing with one parent that her child watched *Wild Cats,* the mother explained to me about this Disney movie was about, she was also explaining to me about the history of some shows such as *Peep and the Big Wide World* and *Curious George* which is very similar to the *Peep.* Those kinds of conversations with the parents helped me understand what American children are exposed to such as movies, TV shows, books and other resources.

4- Data sharing sessions with my advisor: While I was working on the data and even after the data were collected, I met regularly with my advisor and we discussed the data and what the students are saying. Knowing that my advisor is a native who has young children of her own, we had discussions about what the students were saying and about the various media or books that are popular.

Having put effort into engaging not only in research but in the culture of the children, I believe that by the time I was analyzing data, I was reflecting on the various experiences I had, and was trying to make connections with the various resources that the children were referring too. I do not claim to have exhausted learning about all the resources, but I believe that my efforts allowed me to make sense of what the students were referring to in most of the cases.

This chapter consisted of describing the research design of my study. I started the chapter by describing the setting, the participants and the various data sources that I used in my research. I then described how I coded the data in an iterative process, attended to reliability, and used various qualitative and quantitative tools to analyze the data. I also described how I attended to my background as an individual from a different cultural setting from my participants. In the next chapter I present the results of my data analysis techniques to the various research questions that I posed.

CHAPTER 4 RESULTS

In this chapter, I present the findings related to each of the four research questions I proposed. I start by presenting the final learning progression levels, illustrating each level with examples, and then I present the frequencies of responses in each level. Next I present the correlations and qualitative analysis that answer the questions of students' consistency across the various systemic reasoning. I, then, present the results of analyzing the data for students' sources of knowledge. I end with detailed description of eight student cases where I interviewed parents and looked more closely at the students' sources of knowledge.

Results of Research Question 1: What are patterns in 1st to 4th grade students' systems reasoning about ecosystems?

To answer this question, I first present a short summary of the four elements of systemic reasoning which are the following:

1- Systemic interdependency[6] (SI): This category of systemic reasoning addresses understanding that each element in the system influences all others. The set of questions that allowed me to evaluate students reasoning of this category were related to asking students what may happen if one population was removed from the system.

2- Systemic Analysis (SA): This category of systemic reasoning addresses understanding that there are certain elements of the system that are essential for the system to keep working. In case of the ecosystem, the sunlight and the plants as producers are the main elements, without which the whole system will collapse. The

[6] Note that the original name by Chandler and Boutilier (1992) for this category was systemic synthesis, but the idea of "synthesis" may be confused semantically with creating something rather than analyzing the effect of the changing one population of the ecosystem. For this reason I substituted the word synthesis for "interdependency".

interview question asking students about the most important element of the system and the question concerning what is missing in the picture are the two questions that allowed me to evaluate students' reasoning of this category.

3- Circular Connectivity (CC): This category of systemic reasoning addresses understanding of the criteria of building a system from the various elements and the criteria students used to build this system. The question that allowed me to evaluate students' understanding of this category was the one when they were give separate pictures and they had to build their environment and say why they were choosing the populations they picked.

4- Dynamic Recycling (DR): This category of systemic reasoning addresses the understanding of matter recycling in the ecosystem, specifically understanding that once organisms are decomposed, matter is recycled. The set of questions that address this category required students to reason about what would happen to animal bodies or plants once they die.

Presentation of the Learning Progression with Illustrations

After several iterations of the learning progression rubric, the final learning progression is presented in Table 7. Levels 2 and 3 in systemic interdependency have sub-levels and level 2 in circular connectivity also has sub-levels. Examples of each level and sub-level are presented after Table 7.

Table 7: Final Learning Progression for Systemic Reasoning of Ecology.

		Systemic Interdependency (e.g., What would happen if all insects died in the ecosystem?)	**Systemic Analysis (e.g., What is the most important element in the ecosystem that allows it to function properly?)**	**Circular Connectivity (e.g., Choose the populations that can make an environment that works properly for a while)**	**Dynamic Recycling (e.g., What would happen to the body of the fox once it dies?)**
Anthropo-morphic or Aesthetic Reasoning (Relating reasoning about populations to human feelings or to beauty of nature)	**Level 1**	Identifying intentional and human characteristic or aesthetic reasons as effects to the change of population without any reference to external mechanism	Identifying an irrelevant element in the ecosystem as the most important due to the feeling of power / identifying the missing element due to personal liking	Relating their choice of populations human relations or personal liking of those populations	Relating what happens to a dead animal to spiritual or human feelings
Concrete or Practical Reasoning (Reasoning based on everyday experiences and observations)	**Level 1.5**	Identifying concrete or practical effects to population change / Relating the poison to the death of the animal the consumes it only	Identifying an important element because they see a lot of it in nature / Identifying elements that are missing because they are part of the nature they see everyday	Relating their choice of populations to being part the nature they see in their everyday life	Relating what happens to a dead animal to what they see in real life, such as disappearing, rotting without further elaboration

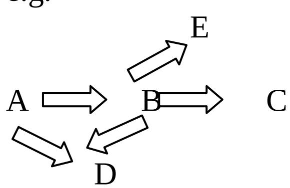
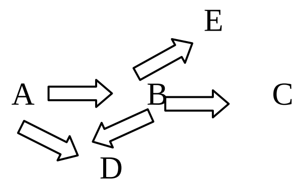
Table 7 (cont'd)

Simple Causal Reasoning (Beginning to identify an external mechanism that is related to phenomena)	**Level 2**	2a- Identifying a direct effect on ONE population that feeds on the removed population/ Relating the effect of the poison to the loss of food source of other animals OR death of the animals the eat the poisoned animal OR Identifying the direct effect on the ONE population that they themselves feed on 2b Identifying ONE sided mutualistic relationship between producers and primary consumers	Identifying a reason that is logically sound (e.g., plants giving oxygen) but is not related to energy for the importance of plants or another population	2a- Relating their choice to the habitat that the populations live in 2b- Relating their choice to a ONE way eating relationship like squirrel eats nuts A $\Longrightarrow$ B	Relating what happens to a dead animal to ONE external factor such as soil or predation by another organism

Table 7(cont'd)

Semi-complex Causal: Reasoning (Reasoning that takes into account more than one external factor affecting phenomena	**Level 3**	3a- Identifying the effect of a population removal to more than one population that feed on it OR Identifying the effect of a population removal to more than one population that it feeds on/ Relating the effect of the poison to the death of other animals that eat the poisoned animal AND loss of food source for other animals	Identifying two reasons to justify their choice of the importance of plants of another populations OR identifying two populations with a logical reason for each	Relating their choice to the habitat they live in AND the organisms they feed on	Relating what happens to a dead animal to more than one factor such as worms and fungus or soil and air
		3b- Identifying the effect of population removal to the population that feeds on it AND the population that it feeds on OR Identifying of a mutualistic relation that benefits both populations.			

Table 7(cont'd)

Complex Causal reasoning (Reasoning that considers a network of relations which recognizes the complexity in an ecosystem	**Level 4**	Identifying the web-like relationship in the ecosystem and that one change in one population will influence the all other populations in the ecosystem e.g.  Relating the effect of the poison to being transferred in the whole food web from one population to another	Identifying the critical importance of sunlight and plants because they are the primary producers of energy in the ecosystem	Relating their choice to the network of feeding relationships of populations of the organisms that constitute a food web in the ecosystem 	Relating what happens to a dead animal to the breakdown of matter that can be used by other organisms or can be recycled in the ecosystem

Having presented the general levels in Figure 8, I now present a description of each level with examples to illustrate reasoning at each level. I have chosen to give examples of different questions, specifically when there were a set of questions that address a given category (e.g., systemic interdependency), in order to present how each level was revealed with different questions during the interview.

Level 1: Anthropomorphic reasoning.

Level 1 represents anthropomorphic reasoning, where students refer to organisms based on human characteristics or personal liking. At this level of reasoning, there was no reference to any external mechanism or cause. Therefore, this was the lower anchor of the learning progression and it was demonstrated along all four categories of the system. Table 8 shows examples of anthropomorphic reasoning.

Table 8: Level 1-Anthropomorphic Reasoning[7].

Systemic Interdependency sample question	**Systemic analysis sample question**	**Circular connectivity sample question**	**Dynamic recycling sample question**
What would happen if all foxes died?	Which population is the most important in keeping the environment working properly?	If you were to create your own environment having water, sun, clouds and soil, choose some of those organisms that can live there in such a way that the environment is working well for a while?	When the fish dies, what would happen to its body over time?

[7] The italics explain why the answer is anthropomorphic. The same is true for Tables 9, 10, 11, 12, where italicized sentences explain why the answer is considered at that specific level.

Table 8 (cont'd)

S14G3M Answer:	S43G1F Answer:	S11G3F Answer:	S21G2F Answer:
the foxes have families too and whoever cares about them they would be sad I: Will other animals? S: If the possum tells his family about it, that would be very sad *(This is anthropomorphic reasoning because it stems from transferring human feeling to animals)*	The fox because it is very strong *(The human characteristic of strength was the main reasoning why the fox is important in the ecosystem)*	Frog, squirrels, fish, bird, bunnies Because I really love frogs and my dad loves fish and the squirrels are so cute and birds I like to watch them fly and bunnies are so cute *(Personal liking is the reason of the choice)*	All the other fishes would gather around and will dig a hole and call their friends and they would make friends carry it and bury it and make a grave *(Human habits were transferred to animals)*

Table 8 (cont'd)

Level 1.5: Concrete or practical reasoning based on everyday experiences.

At this level of reasoning, the students still do not utilize an external mechanism that consider underlying causes of the event, but at the same time do not relate the reasoning to personal liking of human characteristics. Their reasoning stems from their everyday experiences or observations. They assume a pattern for events to keep occurring similar to what they are used to and so they cannot use any further reason for explaining the effect. Even though this reasoning does not include personal feelings as in anthropomorphic reasoning, it also does not consider any external mechanism that governs the dynamic process of ecosystem change. At this level the only external cause is either the status quo or a cause that is related to practical interests. Moreover, for this level, there were two kinds of answers concerning the dynamic recycling category. As seen in Table 9, the two examples presented were ones that expressed the idea that nothing will happen to the body or one that was describing the external changes that they are used to seeing but without relating to any reason except the idea or rotting which is the macroscopic phenomenon that they observed. Table 9 illustrates examples of this level:

Table 9: Level 1.5-Concrete or Practical Reasoning.

Systemic Interdependency sample question What would happen if all insects died?	**Systemic analysis sample question** Which one is the most important in keeping the environment working properly?	**Circular connectivity sample question** If you were to create your own environment having water, sun, clouds and soil, choose some of those organisms that can live there in such a way that the environment is working well for a while?	**Dynamic recycling sample question** What would happen to the body of the fox when it dies?
S37G1F Answer: S: New ones will come I: how? S: they just get born again and it keeps repeating over and over I: and if they did not have babies? S: we wouldn't see any more insects because they're dead I: anything else may happen? S: no *(The only effect was that we don't see the insects which s is a reasoning considering concrete observations)*	S1G4M Answer: Maybe the spider because it eats moth and moths eat shirt. Maybe all of them if someone is extinct its gone you can't see them again *(In this answer, the student is thinking the importance of animals to humans so he's considering the practical importance of the spider and also thinking that nature has many animals so all maybe important. Both of those reasoning are involve practical or concrete reasoning.*	S 33G1F Answer: *Student picked all the pictures* I: why did you pick them all? S: because this is like in nature and it has many animals so the more animals the better *(This answer reveals that the student considers nature as she experiences her everyday and her choices depend on her concrete experiences with nature without any external mechanistic explanation)*	S35G2F Answer: It would stay there I: How about after one month? S: it would just be lying on the ground I: would anything change after one year S: no *(This is the reasoning that depends on the concrete observations, if they've seen an animal dead on the ground there's the assumption it will stay there).* OR S9G4F S: It would probably just be rotten. I: why does it become rotten

Table 9 (cont'd)

			S: It becomes rotten because its dead for a long time and flies would be buzzing all over it. I: why would it rot S: Because if no animal ate it and if it's not buried it rot I:what happens if its buried S: it probably disappears, or goes in the ground *(In this example, the student recognizes the rotting but does not identify a reason other than the fact that it is not buried or eaten)*

Level 2: Simple causal reasoning.

At this level, students begin to use external mechanisms the influence the change in the ecosystem. However, their thinking is still at a simple level, meaning that they can identify one external factor that influences ecosystem or one factor that is influenced by a certain change. In this level, students' reasoning about the effect of the change was limited to one direct population, or, for decomposition, was limited to one external factor. Students do not identify when a certain change happens more than one factor is affected. Moreover, at this level, there were sub-levels at the systemic interdependency and the circular connectivity categories of systemic reasoning. Those different sub-categories represent qualitatively different ways of reasoning for each system reasoning category. For example, in systemic interdependency, there were some students who recognized the mutualistic relationship between birds and plants, which was different from feeding relationships and could be considered at a different sub-level from answers that strictly considered feeding relationships. The reason why the sub-categories are part of level 2 is that they all show that students are considering one external reason in their answers and do not show signs of thinking of several factors that influence the ecosystem or several effects from on change on the ecosystem. Table 10 shows examples of each of each category and the sub-categories as well.

Table 10: Level 2-Simple Causal Reasoning.

Systemic Interdependency sample question What would happen if all black birds died?	**Systemic analysis sample question** Which one is the most important in keeping the environment working properly?	**Circular connectivity sample question** If you were to create your own environment having water sun clouds and soil, choose some of those organisms that can live there in such a way that the environment is working well for a while?	**Dynamic recycling sample question** When the fish dies, what would happen to it over time?
S16G3F: the fox will probably eat more possum *(2a, which is recognizing the effect on the direct population)* S24G2M no flowers because they make more flowers each time they eat the nectar *(2b which is recognizing the effect due to the mutualistic relationship between birds and flowers)*	S5G4M: Plants because they give food for animals *(Identifying food as the reason of importance of plants)*	S6G4M: I chose these that birds sometimes walk on the ground and sometimes in the air. Squirrels are sometimes on the ground and sometimes they're up in the trees, and rabbits are around the trees. *(2a because it is considering only the habitat)*	S17G3M: S:It would be bone I: where would the skin go? S: something that would eat meat will eat it I: what if nothing ate it? S: it would disappear and get rotten I: any idea how it would rot?

Table 10 (cont'd)

		S20G3F: I would choose squirrels, rabbits, fish and frogs. I: why those S: Squirrels will eat nuts in the land, rabbits will eat grass, fish will tinier fish in the water, frogs will eat flies in the clouds. *(2b, because the reasoning is considering simple feeding relationship between two animals.*	S: sometimes the sun can shine at it for two weeks and it can get rotten *(Identifying one external reason such as the sun as the agent of decomposition)*

Note that for dynamic recycling four students out of 44 mentioned that there was a reason for rotting, but they did not know what it was. For those students, I considered their answers at level 2 because they do recognize an external reason. Consider the following:

I: what will happen to the body of the fox when it dies?
S34G2M: It will get rotten
I: how?
S34G2M: it will be really be old and super hard to eat
I: what will happen to it after one year?
S34G2M: it will turn into soil, the bones kind of disappear and turn into soil and the skin gets eaten by worms and it disappear
I: how will it disappears
S34G2M: I don't know how it disappears but I know that bones disappear in the soil, I really don't know the reason I'm still trying to learn that.

Level 3: Semi-complex causal reasoning.

Responses at this level take into account more than one external factor affecting phenomena. This level shows that students are beginning to consider the complex interactions in the ecosystem by thinking of various effects or causes. This is the level where students' responses illustrate an emerging sense of complexity of ecosystems. This means that students can think of the effect of change on more than one direct population or can think of more than one external reason for decomposition. However, at this level, students do not consider more than the effect on direct populations; in other words, students do not transfer the influence of change to further populations in the food web. Table 11 illustrates level 3 examples.

Table 11: Level 3-Causal Reasoning that Takes into Account Two External Factors.

Systemic Interdependency sample question What would happen if all insects died?	**Systemic analysis sample question** Which one is the most important in keeping the environment working properly	**Circular connectivity sample question** If you were to create your own environment having water sun clouds and soil, choose some of those organisms that can live there in such a way that the environment is working well for a while?	**Dynamic recycling sample question** When the fox dies, what would happen to it over time?
S22G2M: Frogs, beavers and black birds would have no food and they would die *(level 3a because he is considering more than one population that is affects by the insects)* S1G4M: Those that eat insects would starve to death and those eaten by insects they would be overpopulated *(level 3b, because he is thinking up and down the food chain)*	S16G3F: The bugs because the bug goes to the bird and then that bug would go to the other bugs. The bugs because its feeding like 3 animals and goes to many animals *(3a because it is identifying the importance of insects due to the different links it has in the food chain)* S3G4F: Water, tree and grass, because lots of animals need water because they need to drink, they need grass because some of them eat the grass and some animals need the trees because they live in the trees. *(this is level 3b, because she is thinking of more than one reason for the importance of plants and more than element that is important in the ecosystem)*	S39G3M: Snake, the spider and the ant, a bird, flowers and trees, some fish, and crabs, I choose those because some animals need to eat the other ones, snake needs to eat the ant and spiders and the crab needs to eat fish, the birds need to eat spiders and ants and the some animals eat flowers and trees make a little home *(this is level 3 because the student is thinking of feeding relations and the habitat that organisms live in)*	S7G4F: the owl would feed on its flesh and then after longs periods will be a skeleton. I: if nothing fed on it? S: it would rot I: how would it rot? S: starts to stink and the meat would rot I: why would it rot? S: after a while it starts to wore down like apples I: is there's a reason for that? S: air and water and nature starts to wore them down and after quite a few years it would go down in the dirt because more dirt gets on top and gets buried down *(level 3 because it is recognizing more than one element for the decomposition process)*

One may argue that level 3a of systemic interdependency is similar to 2a because both consider the influence of direct predator-prey relationships. However there were students who considered the effect on only one population (level 2a) and some that considered the relationships on several populations (level 3a). Griffiths and Grant (1985) would consider those as one level because they require the same skill, but Griffiths and Grant's study was done with 10th grade students and this study was conducted with lower elementary students. For this age group, the distinction between effect on one direct population and the effect on many direct populations is important because it helps us tease apart fine divisions of lower levels for primary grades.

Level 4: Complex causal reasoning.

At this level, students' responses recognized a network of relations in the ecosystem that revealed a sense of a more advanced complexity than at level 3 in the system. This is the level where students considered the interdependency of organisms and identified how most parts of the system may be affected when a specific change happens in one of its elements. Students considered changes in the system as a whole and not as separate entities. Table 12 illustrates examples of this level from sample questions of different categories of system reasoning:

Table 12: Level 4-Causal Reasoning that Considers a Network of Relations.

Systemic Interdependency sample question	**Systemic analysis sample question**	**Circular connectivity sample question**	**Dynamic recycling**
What would happen if all plants died?	e.g., Which one is the most important in keeping the environment working properly	e.g., If you were to create your own environment having water sun clouds and soil, choose some of those organisms that can live there in such a way that the environment is working well?	e.g., What would happen to the fox when it dies?

Table 12 (cont'd)

S7G4F: If plants died, all animals would die, first it'll be the bugs, then the ones that eat the bugs, then the ones that eat small animals and then the big animals and then and we would die too because we have no food *(level 4 because the student is thinking if the chain of reactions that influence all the system)*	S23G2M: the most important part is the plants because if there are not plants then insects cannot eat and if no insects then other animals cannot eat and then all would die *(level 4 because the student is thinking of series of effects that affect every population in the system)*	S45G4M: flower, spiders, snakes need spiders so we can put snakes, birds, frogs, fish, insects we can put them all together I: why did you choose those? S: Because they can eat each other and get their needs from each other I: what do you mean? S: I mean birds can eat from the flowers, snakes can eat birds and spiders and frogs can eat insects and spiders can eat insects *(level 4 because the student is thinking of the several food chains and the web-like model of the ecosystem)*	*No answers were found at level 4*

As shown in Table 12, there were representatives of level 4 in three of the four elements of systemic reasoning. There were no level 4 responses in the category of dynamic recycling – where students were asked to predict what would happen to the body of the organisms when they die. An important caveat here is the level of sophistication of level 4. Grotzer and Bell (2003) label a sophisticated view the recognition of what they called the "domino-effect" factor, meaning the students recognize that any change in one population influences all other populations. While this is important, Robertson et al. (2012) emphasize the importance of understanding system interaction -- and that we don't want students to think that any change in population level results in the collapse of the system: "The nature of interconnectedness of systems is overstated, e.g., removal of one species leads to system collapse" (p. 349). Therefore, I had a conversation with an ecologist about some of the answers at level 4 to check a content expert's opinion. For example, we discussed S7G4F's answer of systemic interdependency. She said:

> It's exactly the kind of response that could lead you in either direction, right? On the one hand, this response could be interpreted as "everything linked to everything else", but on the other - I'm inclined to think it's relatively sophisticated 4th grader. The reason I'm more inclined to believe the latter is because she articulates the nature of the connections. I 'think' (and have no evidence to support this, other than anecdotal) that when students truly don't understand, and employ the "everything connected to everything" strategy as a response, you're far less likely to see them explain "why" everything would collapse - they're likely to say "it just would" with no indictment of mechanism. In this response, the student is clearly showing her knowledge of trophic structure for this community. Thus, her reasoning is clear, but it is narrow b/c it is focused only on food, and not other interactions that shape ecosystem structure. (Personal communication with T. Long, June 12, 2012)

Level 4 answers were those that recognized the interdependency of organisms, but at the same time provided reasoning that could justify the interdependency.

General frequency at each level

Response frequencies at each level is represented in Figure 3. When students reasoned at different levels, I chose the higher level as a representative for that question because it meant that the student can reason at such level. I illustrate this by the following example for systemic interdependency category:

> I:What would happen if all black birds died?
> S32G2F: Then there will be more spiders because eat spiders, and this will hurt us because spiders can bite people, I hate spiders.

The above example can be coded at two different levels: level 2 because the student recognizes that spiders will increases in number because there is no predator, and level 1 because she is adding to that the effect on humans as a result of personal dislike to spiders. However, because she can recognize the effect on one direct population then I coded the answer as a level 2 answer.

The interview had many questions some of which managed to tap into students' reasoning more than others. The following 13 items best represented the four categories of systemic reasoning:

1- Pic CC: This question requires students to make up their environment and this belongs to the Circular Connectivity (CC) category of systemic reasoning.
2- Most imp SA: This question requires students to talk about what is the most important population that can keep the ecosystem functioning properly. Those questions belong to Systemic Analysis (SA) category.
3- Missing SA: This question asks student if there is something missing the presented ecosystem and belongs to the systemic analysis (SA) category of systemic reasoning.
4- Insects, birds, fox, fish, plants and poison SI: This set of questions ask students to predict what would happen if each one of those populations died in the ecosystem and belong to the systemic Interdependency (SI) category of systemic reasoning; the question about the poison requires students to predict what would happen if a poison was sprayed and killed all insects.
5- Fox, grass, mouse and fish DR (This set of questions require students to predict what would happen to the body of each of those organisms when they die over time. These questions belong to the Dynamic recycling (DR) category of systemic reasoning).

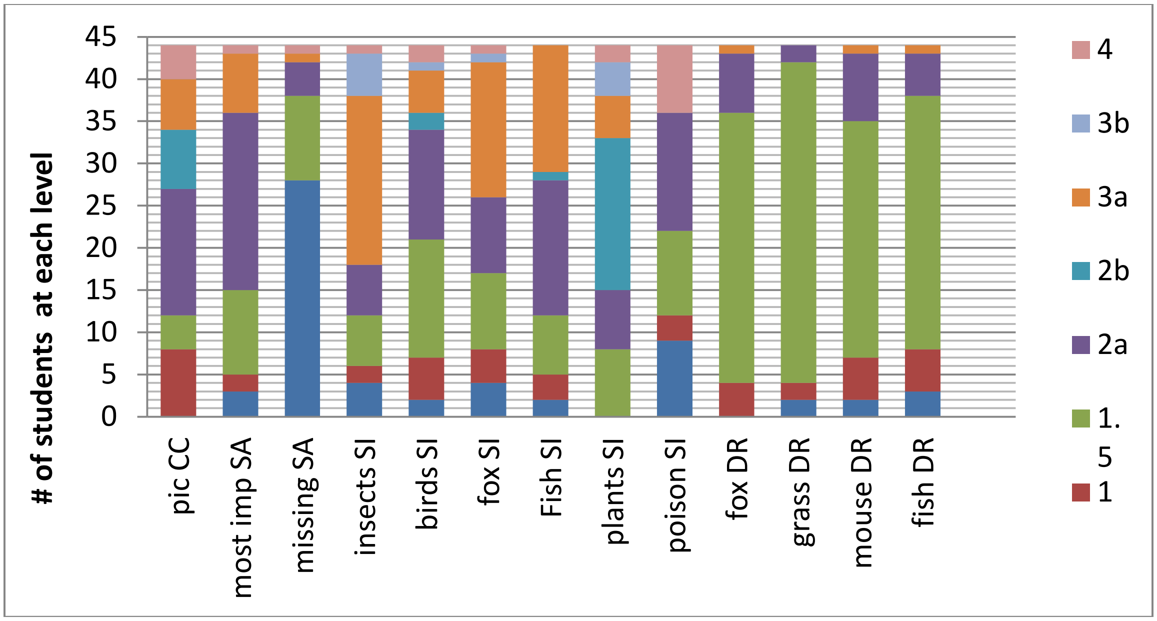


Figure 3: Frequencies of Various Levels and Sub-levels of Various Interview Questions.

As shown in Figure 3, the highest frequencies are those of low levels (levels 1 and 2) and the lowest frequency of level 4 was in the dynamic recycling questions that do not have any answers at this level. Level 3 constituted higher frequency in the Systemic Interdependency category than in others.

Circular Connectivity

The question which required students to make up the system, and belonged to the circular connectivity had the highest frequency of 2a, which means that students were more likely to think of habitat rather than other factors such as feeding relationships when constructing their environment. When looking closely at what students chose to make up their environment, thirty four students chose trees because of the importance of food and shelter (e.g., S4G4F mentioned: “We need a lot trees for animals to live and eat like birds, squirrels and rabbits.”), 33 students chose squirrels, and 31 students chose rabbits. The rest of the populations were chosen by less than 30 students.

Systemic Analysis

For the systemic analysis questions, there was a clear variation between the distribution of levels for the two questions: the question that required students to think of the most important part of the system resulted in responses with highest frequency being at level 2, whereas, the question where it required them to think if there was anything missing in the picture resulted in highest frequency being at level zero meaning they did not think anything was missing or did not know.

A more detailed inspection of the questions that required students to identify the most important population in the system showed that 25 out 44 students mentioned plants as the most important. Some reasons for that were the facts that plants gave food, oxygen, or shelter for animals. For example, S5G4M said: “Plants are the most important because they give us oxygen and they are food for animals.” Three out of 44 students talked about the importance of the sun in helping plants make their food; for example S35G1F said, “I think the most important is the sun because it makes plants grow and plants give food.” The rest of the answers were distributed between various populations due to several reasons such as strength (anthropomorphic); for example, S43G1F said, “The most important is the fox because it is very strong” or requirement to drink or keeping insect population down. For example, S31G2M said: “ The most important are frogs because they eat bugs.”

In the question that required students to identify the missing element, 28 students did not think that anything was missing. The rest of the answers were distributed among the sun because it gives warmth (five students), the clouds that are part of nature (two students), more food and shelter (five students), rocks or water for the frogs (three students). Only one student mentioned the importance of the sun as the primary source of energy without which the system collapses.

Frequency of Systemic Interdependency.

In the Systemic Interdependency category, the question which required students to talk about what would happen if all insects died resulted in the highest frequency of level 3, and the question with level 2 being the next highest in frequency and there were no level 4 answers for the question concerning the fish population dying. In order to visually perceive the data better, I present part of the information from Figure 3 in Figure 4 below which shows the frequency of distribution at all levels for the set of questions addressing systemic interdependency:

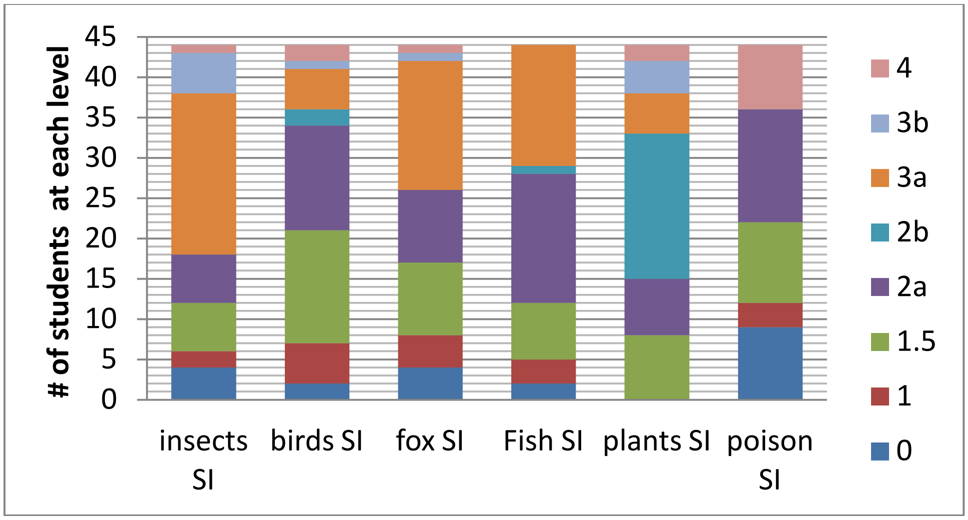


Figure 4: Frequency of Distribution of Levels of Systemic Interdependency Questions.

Frequency of Dynamic Recycling

In the Dynamic Recycling category (with three questions about recycling of matter when organisms die) the highest frequency of responses was level 1.5 and there were no level 4 responses for any of the three questions. In order to visually perceive the data better, I present part of the information from Figure 3 in Figure 5 below which shows the frequency of distribution at all levels for the set of questions addressing dynamic recycling.

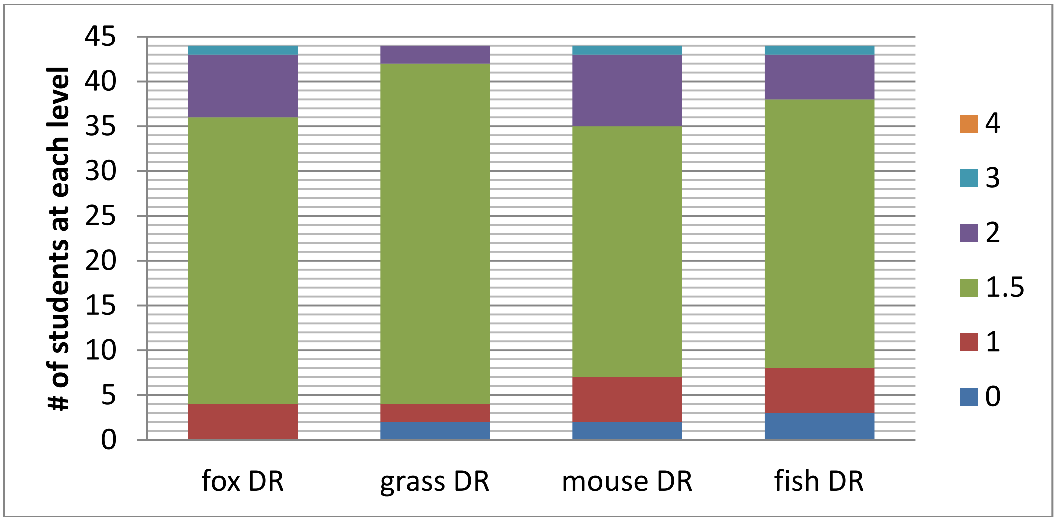


Figure 5: Frequency of Distribution of Levels of Dynamic Recycling Questions.

Results for mixed-levels reasoning

The results presented above provide one level for each student for each response. However, there were many cases where students revealed several levels in the course of the conversation (e.g., during the interview questions the students could reveal responses at levels 3 and 1 or levels 2 and 1 or other combinations). I call this reasoning "mixed-level reasoning." Table 13 shows the frequency of answers with mixed-level reasoning

Table 13: Frequency of Occurrences for Students with Mixed-levels.

Picture CC	Most important element in ecosystem SA	Missing SA	Insects SI	Birds SI	Fox SI	Fish SI	Plants SI	Fox DR	Fish DR
20/44	7/44	3/44	8/44	8/44	10/44	5/44	1/44	9/44	5/44

Whenever students exhibited more than one level, one of the levels in their response was level 1 or level 1.5. This means that students included reasoning at the anthropomorphic or concrete level reasoning in addition to reasoning at higher levels. The question that required students to choose populations to make up a viable environment (circular connectivity category) had the highest frequency of mixed-level reasoning. Later, I discuss some conjectures as to why this might be the case. An illustration of mixed-level reasoning is shown in Table 14 with representative questions from each category of systemic reasoning:

Table 14: Illustration of Students Showing "Mixed-level Reasoning" in Systemic Reasoning[8].

If you were to create your own environment having water sun clouds and soil, choose some of those organisms that can live there in such a way that the environment is working well (CC)	What is the most important element in the ecosystem (SA)	What would happen if all foxes died? (SI)	What would happen the body of the fox when it dies (DR)
S10G4M: I choose birds, trees, squirrels and bunnies. I choose them because they all work together, they don't hurt each other, they usually don't bother each other, some of them help each other ***(level 1 because he is transferring human characteristics to animals and plants)***. The trees help the squirrels and birds because they live in them. The flowers make food for the animals for the birds and bunnies ***(level 3 because he is considering habitat and food to make up this environment)***.	S24G2M: The trees and the flowers because they can give us oxygen ***(level 2 because he is considering a reason of the importance of plants)*** I:anything else S: and the frog because if there were bugs they can eat them and keep us safe ***(level 1 and 1.5 because he is relating the reason to human need to being safe but at the same recognizing that frogs eat insects)***	S27G2F: chickens will be safe and the farmers wouldn't have to take care of the foxes anymore and the fish would be happy to survive but owls would still eat them ***(level 1 and level 3 because she is relating human emotions to the animals but at the same time recognizing the how foxes eat many other animals)*** I: is this good S: no, because the foxes make sure there's not too many chicken ***(level 2 because she understands that the top carnivore keeps other populations down)***	S15G3F: If the fox died, it would probably go to heaven ***(level 1 because she is transferring what she learned about human to animals)*** I: what would happen to its body S: it would be eaten by birds and possum I: And what if they don't eat it S: it will go under the ground ***(level 1.5 because she recognizes what she is used to experiences or reading about that the fox will eaten or goes underground)***

[8] The sentences in bolded italics explain why that part of the students' answer was at that specific level.

Results for scientific technical terminology.

Students used two scientific terms in their reasoning, "food chain" and "disintegrate" despite the fact that I did not mention these terms in the interview. Four students used "food chain" while talking about the influence of population change in the ecosystem and five students used the word "disintegrate" when talking about decay of dead organisms. Knowing that the students did not learn the terminology formally in school, having some the students use those words prompts one to probe whether students are reasoning scientifically because they are using scientific terms or not. Moreover one would be curious where students are acquiring those words if they have not learned formally in school. Therefore, I present in this section the reasoning of students when using those terms and in the later section of sources of knowledge where students have learned those words from.

Two students from fourth grade, one student from third grade, and one student from second grade mentioned the word "food chain." Below is an illustration of how a fourth grade student used this word:

> I: Have you learned about this topic before?
> S3G4F: I learned how big fish eats small fish and that fish keeps on eating, sort of a ***food chain*** and how the bigger fish will eat it.
> I: what is a food chain?
> S3G4F: let's imagine a small fish and a bigger fish eats that and bigger fish eats that and then a shark comes and eats the big fish; that is a ***food chain***
> I: where have you learned about that?
> S3G4F: I had this one video it had all these whales and stuff and how they eat krill and how they open their mouth and how they suck the krill in that's all I can remember right now

One student from fourth grade, two students from third grade, and one student from second grade used the term "disintegrate." The following excerpt illustrates how a third grade student used the word disintegrate:

> I: What will happen when the fox dies?

S12G3M: It would ***disintegrate*** because the sun shines on it. After one year, the bones will be all broken and underground.
I: Why will the bones be broken?
S12G3M: It will be broken because it goes into the ground.

Summary of Results for Research Question 1

There were three main results for the first research question. The first concerned the development of the learning progression levels which starts with the lower anchor of anthropomorphic reasoning and ends with the upper anchor of complex causal reasoning. The second result concerned looking at the frequency of levels for answers across the various categories of systemic reasoning and the levels 1.5 and 2 were the most frequent in the overall picture. The third concerned presence mixed-level reasoning for some students and the use of technical scientific terms.

Results of Research Question 2: How are 1st-4th graders' reasoning similar or different across each grade level, gender or ability?

In order to answer this question, I used the rank correlation between grade, ability and gender with the students' responses representing Circular Connectivity, Systemic analysis, and the average of the set of questions representing Systemic Independency and Dynamic Recycling. . The results are shown in Table 15.

Table 15: Correlation of Gender, Grade and Ability with Systemic Reasoning (N=44).

	Gender	Ability	Grade	Pic CC	MostimpSA	MissSA	SI Average	DA Average
Gender	1	-.294	-.115	-.020	-.048	.117	.094	-.032
Ability		1	-.006	.046	.036	.140	.182	-.033
Grade			1	.071	.222	.095	***.374(*)***	.278

* Correlation is significant at the $p \leq 0.05$ (2-tailed).

As shown in Table 15, there was no correlation between grade level, gender and ability (as indicated by teacher) with any of the variables except a low correlation between grade level and Systemic Interdependency average. In order to understand what may have caused this slight correlation ($r=0.374$; $p<0.05$), I examined the correlation of the grade level with each question in the Systemic Interdependency category and the results are show in Table 16:

Table 16: Correlation between Grade Level for Systemic Interdependency Questions (N=44).

	Grade	insectsSI	birdsSI	foxSI	fishSI	plantsSI	poisonDR
Grade	1	.87	.61	.185	.289	***.480(**)***	***.474(**)***

** Correlation is significant at $p \leq 0.01$ level (2-tailed).

As shown in Table 16, there was a modest positive correlation between grade level and the question which required students to talk about what would happen if all plants died ($r=0.480$; $p<0.001$), and the question concerning the poison ($r=0.474$; $p<0.01$). This means that students in higher grades tended to answer at higher levels for those two questions. To illustrate this, I present the frequency of answers for those questions in each of Figures 6 and 7:

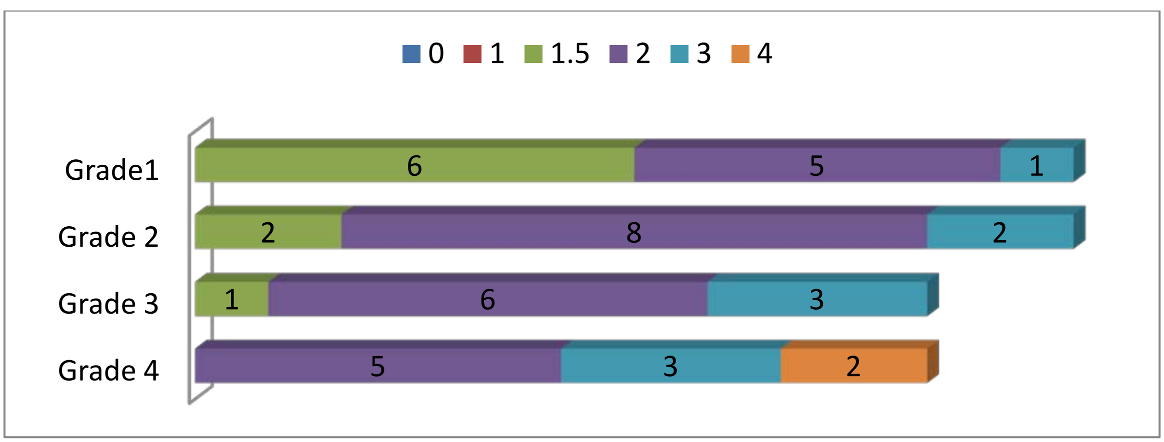


Figure 6. Frequency of Responses at Each Grade Level for the Plant Question

As shown in Figure 6, there were more answers at levels 1.5 in grade 1 and none in grade 4. Moreover, there were two answers at level 4 in grade 4 showing that there is slight difference towards higher levels at grade 4 which explains the weak correlation. The two students (S7G4F & S9G4F) who showed this high level of reasoning for the plants are the same students who will be discussed later as cases.

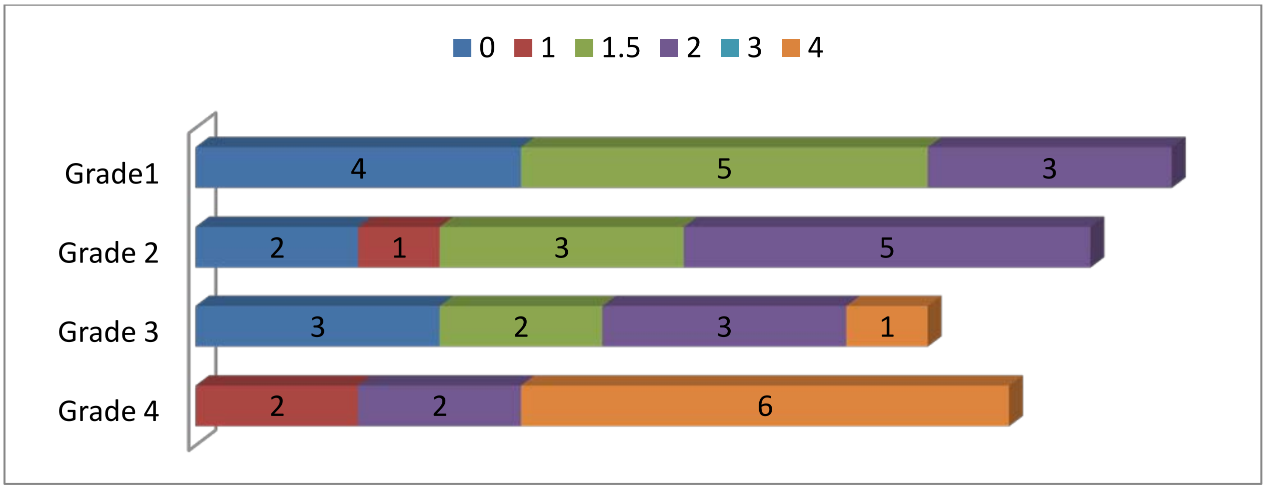


Figure 7 The Frequency of Responses at Each Grade Level for the Poison Question .

As shown in Figure 7, no fourth grade students demonstrated level zero reasoning and six fourth grade students reasoned at level 4 about the poison. No first and second grade students reasoned at level 4, but there were four students at level zero in first grade and two students at level zero in second grade. An example of a fourth grade student reasoning at a level 4 student is:

> I: If poison was sprayed that killed insects, would other creatures be affected?
> S3G4F: Yea if any animals ate them, like if the cricket dies of poison and so if something like the possum ate the cricket it will die, and then if the fox will eat it and it will be affected and if the fox dies and nothing else eats the fox it will just die as it did.

Summary of Results for Research Question 2.

The results for the second research questions showed that was no correlation between gender and ability and any of the interview questions. There was a slight positive correlation between grade level and the two questions of systemic interdependency, the question concerning the influence of plants and the question concerning the influence of poison on the ecosystem. The implications of those results will be discussed in the next chapter.

Results of Research Question 3: How is 1st-4th graders' reasoning across and within the various system categories correlated?

In order to answer this question, I looked at the correlations across the systemic reasoning categories using rank correlations. The results are shown in Table 17.

Table 17: Correlations across Systemic Reasoning Categories (N=44).

	PicCC	MostimpSA	MissSA	SI Average	DR Average
Picture	1	.283	.198	***.331(*)***	.123
MostimpSA		1	.086	.287	.010
MissSA			1	***.416(**)***	***.329(*)***
SI Average				1	***.435(**)***

* Correlation is significant at $p \leq 0.05$ level (2-tailed).
** Correlation is significant at $p \leq 0.01$ level (2-tailed).

Table 17 reveals that there was modest positive correlation between Systemic Interdependency and circular connectivity (r=0.331; p<0.05); the question of systemic analysis concerning what is missing in the picture (r=0.416; p<0.01); and the average of dynamic recycling (r=0.435; p<0.01). Moreover, the question concerning what was missing the picture (a systemic analysis question) had a modest positive correlation with the average of dynamic recycling (r=0.329; p<0.01).

In addition to testing for correlation across categories of systemic reasoning, I zoomed in at each category of systemic synthesis and dynamic recycling, and examined the correlations within each category. Table 18 presents the correlation analysis with students' responses to items within Systemic Interdependency.

Table 18: Correlation within Systemic Interdependency Category (N=44).

	InsectsSI	BirdsSI	FoxSI	FishSI	PlantsSI	PoisonSI
InsectsSI	1	***.433(**)***	.292	***.500(**)***	***.303(*)***	***.476(**)***
BirdsSI		1	***.541(**)***	***.417(**)***	***.458(**)***	***.302(*)***
FoxSI			1	**.211**	***.415(**)***	.182
FishSI				1	***.554(**)***	***.409(**)***
PlantsSI					1	***.493(**)***

** Correlation is significant at $p \leq 0.01$ level (2-tailed).
* Correlation is significant at $p \leq 0.05$ level (2-tailed).

As shown in Table 18, there was a modest correlation among most of the questions except for the question concerning the fox in relation to the questions concerning the insects as well as the poison. Moreover, the highest correlation was between the question concerning the fish and that concerning the plants (r=0.500; p<0.01).

Table 19 presents the correlation analysis with students' responses to items within Dynamic Recycling.

Table 19: Correlation within Dynamic Recycling Category (N=44).

	FoxDR	GrassDR	Mouse DR	FishDR
FoxDR	1	.189	***.758(**)***	***.300(*)***
GrassDR		1	***.344(*)***	.297
MouseDR			1	***.400(**)***

** Correlation is significant at $p \leq 0.01$ level (2-tailed).
* Correlation is significant at $p \leq 0.05$ level (2-tailed).

As shown in Table 19, there was no correlation between the question concerning the grass and either that of the fox or that of the fish. However, there was high correlation between the question concerning the fox and that concerning the mouse (r=0.758; p<0.01).

Students' consistency of responses across various categories of systemic reasoning

In order to look more closely at students' consistency in answering the interview questions within and across systemic reasoning categories, I constructed a table that illustrates the consistency in students' responses to the 13 most representative questions of the interview. Similar to Jin (2010), I used the most frequent level for each student as the baseline (labeled as a "0"). If a student had a response that was at a different level than the most frequent level (the baseline), the difference is indicated by a positive or negative number indicating how much above or below the students' response was from the baseline. For example, if the most frequent level is 2, then any answer at level 2 will be counted as the baseline "0" and any answer that is at level 3 will be coded as "1" because I subtract 3-2 which gives "1." If the answer is at level 1, then the code will 1-2 which is "-1." Table 20 shows a sample of four students (one from each grade level) for the 13 items used. Appendix VII has the detailed data for all 44 students.

Table 20: Sample of Four Students' Consistency of Answers[9].

Student/ most frequent level	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13
S1G4M (2)	0	0	**-2**	**1**	0	**-2**	0	0	**2**	**-0.5**	**-0.5**	**-0.5**	**1**
S11G3F (1.5)	**-0.5**	**0.5**	**-1.5**	**-1.5**	0	0	0	**0.5**	**-1.5**	0	0	0	0
S21G2F (1.5)	**0.5**	**0.5**	**-1.5**	**1.5**	**0.5**	0	0	**0.5**	0	0	0	**-0.5**	**-0.5**

[9] The bold letters indicate the difference between the level for that response and the baseline or most frequent level.

Table 20 (cont'd)

S36G1M (3)	**1**	0	**-1.5**	0	0	0	0	0	0	**-1.5**	**-1**	**-1**	**-1**

In order to examine the consistency in students' responses, I calculated the percentages of baseline responses. 49.65% of students' responses were consistent, meaning that almost half of the students' responses were consistent with their baseline response. In examining the consistency of response to the six systemic interdependency questions, I found that 58.85% had consistent answers. The consistency of responses for the four dynamic recycling questions was 82.95%.

As indicated by the results above, some students were consistent while others were not. Table 21 shows an illustration of students' consistency of levels across systemic reasoning categories.

Table 21: Example of One Student's Consistent Answers S12G3M.

Systemic Interdependency What will happen if all insects died?	Systemic Analysis What is the most important element of the system	Circular Connectivity Choose the populations that make up your environment that can function properly	Dynamic Recycling What would happen to the fox when it dies
Then the frogs will die because they have nothing to eat	Trees and plants because they help you breathe	S: I would choose the trees because trees make oxygen and if there was no trees we would all be dead by now, I picked birds because birds need homes like we do and squirrels do too. I picked bushes so that other animals can go there and make a home. I: why didn't you choose the rest? S: because some of these don't have to here, centipedes are under the ground	It will disintegrate because the sun shines on it

Table 21 (cont'd)

Level 2 because he is thinking of one population directly related to the insects	Level 2 because he is considering one reason for the importance of plants	Level 2 because he is considering the habitat as the main reason for choosing the populations	Level 2 because the he is thinking of one factor for disintegration

Even though half of the students showed consistent answers, the other half were inconsistent, Table 22 illustrates an inconsistent case.

Table 22: Example of One Student's Inconsistent Answers S14G3M.

Systemic Interdependency What will happen if all insects died?	**Systemic Analysis** What is the most important element of the system	**Circular Connectivity** Choose the populations that make up your environment that can function properly	**Dynamic Recycling** What would happen to the fox when it dies
Many animals won't have any food and they will die too, like the bird, the possum, the frogs and the owls and lots of animals	Plants because without plants the fox will have nowhere to hide	I chose the frog because it could eat the beetles and the bunny can eat plants and the fish eats different fish, the crab eats worms and fish. I chose flowers and trees because they are homes for animals I: why didn't you choose squirrels and birds S: because the spiders would eat the worms and so birds won't have worms to eat, so there wouldn't be enough worms for the birds	His family would bury him and they will be sad
Level 3 because he is considering several populations that feed on the insects	Level 2 because he's considering plants as shelter	Level 3 because he is considering the habitat and the feeding relations as reasons to construct the environment	Level 1 because he is considering anthropomorphic reasoning

Summary of Results for Research Question 3.

The correlation results across various categories of systemic reasoning were very modest. In examining the highest frequency for all 13 items, the results indicate that the consistency of the level of students' responses was about 50%. This means that, in general, a given student would have approximately 50% of his or her answers at a certain level and the rest of the answers at different levels. This percentage was the same for systemic interdependency category. However, in the dynamic recycling the consistency rises to 82.98% meaning that the students' answers were more consistent at a certain level within this category. This is supported by the correlation within the dynamic recycling category where the only strong correlation was observed ($r=0.758$, $p\leq 0.01$) between the question concerning the fox and that concerning the mouse. The students' responses, therefore, are more consistent within the dynamic recycling category and less consistent across systemic reasoning categories.

Results of Research Question 4: Where do 1st- 4th graders learn about ecological relationships?

During the interview, I asked students about where they have learned about the topics that we discussed, and the experiences they had with nature and animals. Moreover, whenever a student answered in an interesting way, I asked how he or she learned that information. If some students were reluctant, I tried to prompt them to think of books, movies, TV shows or trips in order to find out as much as I could about their experiences. Having asked them several times about the sources of their knowledge, I was able to able to gather information about their various sources of knowledge. I first present the general picture of the various sources of knowledge that contributed to students' responses, and then illustrate examines for each resource. Later, I present eight cases that include information about the students, and information from when I interviewed the parents to learn more about the students' sources of knowledge, the students' learning styles, and the parent's influence on the students' education.

Students' sources of knowledge

When I asked students how they know about a given topic during the interview, I got various answers and many students mentioned more than one resource of their information. Table 23 shows the various resources and the frequency of occurrence of each resource.

Table 23: Frequency of Occurrence for Each Resource.

Resource	Don't know	Books	Media: movies and TV shows	Personal experience (e.g., camps, nature walks)	Museums (e.g., Impression 5)	Teachers or school	Parents	Others, like travel or website
Number of times	2	21	25	23	3	8	15	2

As shown in Table 23, most of the students mentioned resources that contributed to their knowledge of the topics we discussed. Only two students said they did not know where they learned about the topic. If the student mentioned several resources I counted each resource. As seen from Table 23, the resource mentioned with highest frequency was the media, followed by personal experiences and books.

Concerning the media, the highest frequency of answers mentioned TV shows such as *Magic School Bus* (8 students mentioned that), and *Animal Planet* (8 students), followed by *Wild Kratts* (4students mentioned it). There were other movies that were mentioned by a couple of students such as *Lion King*, *My Cat from Hell, and Alvin and the Chipmunk* at PBS Kids and *National Geographic* channels. I illustrate this category by the two examples; the first was from a third grade student when I asked in general how she knows about the topic:

I: How do you all of this information about the topic?
S18G3F: I watch *National Geographic Kids* and *Animal Planet*.
I: what did you see there?

S18G3F: I watch the life of sea turtle. I watched something sad but nice, it's about sea turtle when they hatch they have to go a long way to the ocean and seagulls diving try to eat them and crabs grabbing them.

Another example was from a second grade student when I asked a specific question about what would happen when fish died, and she replied:

S21G2F: The owl would have nothing to eat; the owl would eat possum but maybe not many possums that come around. If there's a bear here, it would starve because bear's favorite food is fish
I: how do you know bear's favorite food is fish?
S21G2F: on *National Geographic* I saw that and they always go on waterfalls and find fish and I'm surprised they don't slip, maybe those steady claws.

In addition to the media, students mentioned books as a major resource of their knowledge. In many cases, students mentioned various resources during the conversation, for example one second grade student said:

I: Where do you have all this information from?
S22G2M: I have lots of bird books and animal books and tree book, they are called "All about Insects" and "All about mammals of the earth" and "Animals of the world" one book my grandma gave to me and one we found in the house somewhere and the big animal book we bought from Meijer
I: any movies you watch?
S22G2M: *America s Videos* and *Wolverine Shows* and *Wild Kratts* they teach you about animals
I: any cartoons
S22G2M: *Wild Kratts* is actually a cartoon, it's about all animals like monkeys and about food chain.
I: What is a food chain?
S22G2M: It is when animals eat other animals
I: is there a food chain here
S22G2M: cricket is at the bottom of the food chain
I: where did you learn that?
S22G2M: *Wild Kratts*, go to PBS Kids and you can find *Wild Kratts* and watch it if you like

As seen from the excerpt above, S22G2M related learning the topic the various books he has and to the TV show *Wild Kratts.* He explicitly related information about the food chain that he learned from that show. It is also worth noting from the excerpt that he understood the concept of the food chain even though it was not clear the extent of complexity that he thought about it.

As for the other resources, students mentioned that their personal experiences (e.g., nature walks in the woods, their backyards, or going camping or hunting with one of their parents and relatives) were ways by which they know about the topic. S4G4F illustrates this by saying:

> I like animals and I like to go exploring, one time we went into the forest and we saw a snake so we were careful. I went with my uncle and I've seen a rabbit and I picked it because it was nice and kept her until she died.

Moreover, students reported visiting the Impression 5 museum that helped them learn how plants get their food or how they learned about that in class how water and sunlight help plants grow. S27G2F illustrates this by saying:

> I: How do you know about this topic?
> S27G2F: We went to Impression 5 with all my class and in class she showed us how to make a biosphere and she told us that plants make oxygen
> I: Where else did you did you learn
> S27G2F: I went to Potter Park Zoo last year and I went with the class, it was fun I like the combination of having fun and learning about animals, one time I saw somebody feeding the otter fish.

Other students mentioned learning about how plants grow about the animals they had in class, for example a third grade students said:

> I: where did you learn about this?
> S11G3F: we had a crayfish and crickets and a frog. We have it in our classroom
> I: what do you do with them?
> S11G3F: we don't do anything, our teacher feeds them
> I: do you watch any shows?
> S11G3F: I watched Animal Planet once

Summary of Results for Students' Knowledge Resources

Students mentioned various resources for their knowledge with the most mentioned resource being the media (e.g., movies and TV shows). Most of the students mentioned a combination of resources such as the media, books, museums, school parents and websites such "birds.com." In some instances, students could identify where they have learned about feeding relationships of some animals but in many other instances, it was not always possible to directly pinpoint the source of information that influenced their answers during the interview. For this reason, I interviewed eight parents to ask them about their children's sources of knowledge and to learn more about the students and about the opportunities that parents expose their children to and I present the results of those cases in the next section.

Learning More about Students Sources of Knowledge from Eight Cases

In order to learn more about the students' sources of knowledge and experiences, I selected eight students and interviewed their parents. The selection process depended on my judgment of the student and the teacher's judgment of the student and their parents. For some cases, the teachers told me that the parents may not respond and so it would be better to choose a different case and I did that. After careful selection, I ended up with two cases from each grade level. It is worth noting here that not only is it hard to find a causal relation between students' informal experiences and their performance during, but also it may be not very convincing to do so. The reason lies in the fact that all experiences, learning styles, or parents' influences are too complex to tease apart during one interview. However, what might be possible is to shed light on some of the experiences, opportunities or resources that are important for each student and to learn about the parents' ways of influencing their children's science education.

Knowing that each case is different in the level of understanding the ecosystem and in the richness of information that they provided during interviews, I am presenting each case separately with information from students and parents' interviews that shed light on the students' experiences and in some cases relating specific experiences to some answers that the students gave.

Case 1: Student S7G4F: Jane the Dinosaur Lover.

Table 24: Jane's Profile

Pseudonym	Jane
Age	9 years
Grade	4th grade
Hobbies	Drawing, bird watching, swimming and Karate
Reason for parent interview selection	Her understanding of the sun as the major element without which the whole system collapses

Jane was one the students who showed understanding of the ecosystem as a whole. During the interview, she took her time to think and talked extensively about how all elements of the ecosystem are related. Most of the answers to the interview questions were coded as levels 3 and 4. She immediately recognized the food chain when I asked her about scenario 1 which showed the environment with several animal populations and she said:

> It's a food chain, it's a big food chain, the arrows are pointing to what they eat so like the spider would go to the mouth of the crow. A lot of them are pointing to the fox because is one of the only meat eaters. So it's a big food chain, there's the spider and the frog would the spider and the fox would the frog and the owl would be the fish.

Her answers concerning the question of what she thinks might be missing in the picture of the ecosystem made me curious to probe her understanding further:

> Jane: I just saw there's no sun in this picture, they need the sun or else the plants won't live and the animals that eat plants won't live, and then all the animals would die and then all meat eaters would die and all would die
> I: so its complex, right?
> Jane: yea I used to read about dinosaurs so when dinosaurs got extinct that's where I learned all that from, it could be the same with animals here.
> I: what did you learn about dinosaurs?
> Jane: I learned how dinosaurs from books and movies, so I know they became extinct so they believe that there was a volcano or meteorite wiped them all out or both of them at the same time.
> I: did it affect the environment?

> Jane: it affected it very much, after it hit, there was enough smoke to cover up the sun for long time and if no sun no light and all of it just died away and when the sun came it started over.

Jane was the only student among the 44 students to think of the importance of the sun to whole system and to reason that the sun influences all other populations in the ecosystem, so if there is no sun, the whole ecosystem will be affected in a “domino-like” manner. In a similar way, Jane also realized the importance of the plants so when asked what would happen if all plants died she said:

> If plants died, each animal would die, first it’ll be the bugs, then the ones that eat the bugs, then the ones that eat small animals.

When I investigated how she has the knowledge about ecosystem she said:

> Jane: I just look at it, I have a good time when we are on summer and spring vacation in our cottage, we always see snakes and birds and how all the animals, frogs, tadpoles, how they live and the lake and the rocks.
> I: you mean it’s all from your observations?
> Jane: I also read some books, fact books about animals I’m interested about those things.
> I: who chooses those books?
> Jane: sometimes I get them and usually my grandpa gets them to me.
> I: do you watch any movies?
> Jane: I watch *Animal Planet*, it shows the life style and how babies are born
> I: what is something you have learned from *Animal Planet*?
> Jane: it can be about anything really, it can be about the ocean, animals and mountains, it can just be about plants and rocks.
> I: Any other movies or shows you have seen?
> Jane: I have seen many cartoon movies like the *Lion King*?
> I: what have you learned from the *Lion King* movie?
> Jane: kind of how the life style of animals are what they eat and what happens to them when they die, they go in the grass after they die and they become food for other animals.
> I: so other animals come and eat them?
> Jane: yea that and also they go inside the grass and earth.

Those excerpt show that Jane has capitalized on several resources to learn about animals in the ecosystem. When I asked her mother, who is a teacher, about where Jane had learned about the ecosystem she reinforced that *Animal Planet* is her main source of information about animals and the ecosystem, but she also confirmed that Jane has multiple sources of her information said:

> Jane's Mother: She's done two science camps through Impression 5, she won a poster through Impression 5 when she was in Kindergarten, she made a picture of a river of a little ecosystem of a river, she won and got to meet the mayor. She has also been two science camps through Impression 5, one about the human body systems and one about dinosaurs.
> I: what are her other experiences?
> Jane's mother: she reads facts books about dinosaurs and had a dinosaur fact game like a quiz game. Also through our memberships of zoos and museums, we go to several and when we go to Pittsburgh we go to children's museum. We also went to the Cincinnati museum and we also went to zoo this spring break too, She has also been to the Field museum in Chicago when was as 5 and saw SUE[10] when she was five years old. She also has a dinosaur fact quiz game and she always read about animals in national geographic magazines which were in our backyard.

Through both my interview with Jane and her mother, it became clear that Jane's reasoning about ecosystems are influenced by these various resources. I also asked Jane's mother about Jane's learning style and she said:

> Jane's mother: "she makes connections to other things, she says that works there so maybe we can apply it here too. For her she has a strong science understanding but struggles with other parts but this is kind of natural.
> I: what does she struggle with?
> Jane's mother: she has been a low reader and a struggling reader, and she's always received extra help. Not to the point of special education, but still struggles with reading. She can read and get the whole picture but she doesn't always pay attention to the details and sometimes substitutes words. Just recently she started reading more independently, but before it was a more of a conversation about what we saw what she was watching or we would read the books to her. She always asked questions and conversations about it.

This information about Jane's struggling with reading is paralleled by Jane's teacher classification of her as a middle achiever. Similarly, when I spoke with the teacher about Jane's case, she said: "She struggles a little with reading, but I know that Jane is a deep thinker."

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[10] SUE is the largest *Tyrannosaurus rex* 67 million year old dinosaur skeleton preserved in Chicago Field Museum.

To sum up, Jane has showed interest in science and in learning about animals and ecosystems. Her parents encouraged that interest and created several opportunities for her to be engaged in learning about the ecosystem and it was obvious that Jane was thinking at the systemic level and analyzing the various elements of the ecosystem that all influence each other. Moreover, her mother mentioned that she would always have a conversation about they read especially that Jane was struggling with reading so the discussion was her way to learn about the topics she read or her parents read to her.

Case 2: Student S9G4F Profile: Olinda the Dog Lover.

Table 25: Olinda's Profile

Pseudonym	Olinda
Age	9 years
Grade	4th grade
Hobbies	Reading, Sports, Dancing
Reason for parent interview selection	Her high level responses in most of the interview questions

Olinda showed sophisticated answers (mostly level 3) in questions, particularly when she was asked to select populations to make up her environment and when she was asked about the influence of removing specific populations. For example, her response to what would happen if black birds disappeared was:

> Olinda: there will be more insects in the world and the crocodiles have to have birds coming and cleaning their teeth and the crocodiles will have diseases if birds did not clean their teeth and it could spread to other animals.
> I: how did you know about that?
> Olinda: I've watched *Animal Planet* a lot
> I: anything else will happen?
> Olinda: lots of things would stay like berries and what they eat.

In her answer, Olinda was one of the few who considered mutualistic relationships and reasoning about other populations that the birds eat. In addition, Olinda showed that she could think of plants as food and shelter in an intertwined way. Therefore, when she was asked what would happen if all plants died, she said:

> Olinda: lots of animals will not have homes lots of them would die because they don't have food or plants and many animals eat plants and hide in them and if the cricket or birds kept eating all spiders (because there wouldn't any shelter for them to stay hidden), then there wouldn't be any spiders in the world and there would be more insects.

Even though her answer concentrated mainly on the populations that eat the plants, she also reasoned about plants as providing shelter from predators. Thus, her idea of shelter was interconnected with feeding relationship, which is different from how most students thought of plants as providing food and shelter in separate ways.

When asking her mother about Olinda's experiences, her mother emphasized that although they have been to museums or to zoos and aquariums, she believes that Olinda has a natural interest in animals and when it comes to this topic she just "absorbs" it. Olinda was considered a high achiever by the teacher and when I asked the teacher about Olinda she said: "She is an excellent student and she loves animals. So I hooked her in research about dogs at MSU with researchers so she is doing more on her own about this topic." I asked her mother about that, the mother said,

> They researched "general" information about Golden Retriever dogs in books at our school library. Then they searched the internet for pictures. After they collected their information, Olinda created a poster with pictures and various facts about Golden Retrievers. There was no paper or written work, other than the small amount on the poster.

However, despite those experiences, Olinda's mother reiterated that all the activities are more or less happening in an informal setting and that she thinks that Olinda is just good at school and likes to learn and that's why she believes that her daughter can do well in the interview:

> I don't feel I've done anything directly to reflect her performance in this other than trying to give my kids life experience. She learns well in any type of environment, she can sit down and read and learn on her own, she's an excellent reader and writer. She's a good student, but she also enjoys working in groups and doing research in a group.

Olinda's interests, knowledge and experiences showed during some of her answers to the interview questions. She was incorporating some of what she learned from *Animal Planet* in her reasoning about the ecosystem. However, besides *Animal Planet*, it was clear where she's acquiring all her ideas from especially that the mother thinks that "she likes the animals and likes to learn more but not necessarily going deep into it".

Case 3: S19G3M: Ron the Book Worm.

Table 26: Ron's Profile

Pseudonym	Ron
Age	8 years
Grade	3th grade
Hobbies	Reading, traveling, marble runs in museums
Reason for parent interview selection	His teacher recommended I talk to the mother

Ron was one of the students whom the teacher categorized as a high achiever and she recommended interviewing this mother. The teacher said: "She does a lot with her kids and I would recommend you interview his mother." When analyzing his interview, Ron had few answers at levels 3 but most of his answers were levels 2 and 1.5. Some of his answers were determined at one level such as when asked about the effect of insects dying on the ecosystem, he said:

> Ron: some of the animals would die, the frog might be extinct, the bird and maybe the fish.
> I: why?
> Ron: because they eat insect so if there are no insect they have nothing to eat and will die.

The above answer shows that Ron is thinking of several populations that feed on insect and but when asked about what would happen if all black birds disappeared, his answer was:

> Ron: Birds, farmers wouldn't be able to put up scarecrows,
> I: anything else?
> Ron: we would get a lot of spiders
> I: why?
> Ron: because birds eat spiders so if there are no birds the spiders will stay alive and become more and more

Even though Ron identified the importance of the birds in feeding on spiders, his reasoning was a mixture of simple-causal reasoning and concrete-practical reasoning. He said that birds eat spiders which could be identified the simple causal reasoning but at the same time, he was thinking of the practical reasoning of the lack of need for scarecrows. It is worth noting that many of his answers revealed this mixed-level reasoning.

When trying to learn more about Ron, I asked him how he knew about this specific topic and he said that he reads books. He was not specific about book names and nor was his mother who confirmed his love for reading and said:

> Ron's Mother: Ron is a bookworm and rather ingests it slowly; he'll sit down and observe and thinking about it mentally
> I: do you discuss what he learns?
> Ron's mother: Not really, Ron just reads to read and does not share with me.

I also learned that the mother, who previously worked for the federal government agency of the US geological survey, had made a special effort to expose her children to many opportunities for learning science. She said:

> When I learned I was pregnant with my first son, I decided I was going to expose my child to as much as I could especially that this is university town so I wanted to take advantage of that. I also realize that the United States is lagging behind so far scientists and engineers so my focus is to expose them to as much scientific elements as I can.

And with this being her policy, Ron's mother informed me of the different opportunities that she exposed her children to:

> We have a membership to Impression 5 so we use it whenever we go, we were in Toronto few years ago and we went to Ontario science center. Just this last spring break we went to Columbus, Ohio and we went to COSI science center. We also went to Indiana this Spring in 2012 and also to Grand Rapids children's museum. Also, here in school in kindergarten and in 1st grade, they visit nature centers, in kindergarten they go to nature walk and there's a little discussion indoors and some animals to see in the nature center.

As for the TV shows that her children watch, she mentioned *Magic School Bus* and *Peep and Big Wide world* as shows that Ron watches regularly and recently they started watching animal planet but less regularly.

After looking closely at the interviews both with Ron and his mother, it was clear that Ron was exposed to a lot of informal experiences, but it was not clear how his experiences or readings transferred to the interview answers.

Case 4: S13G3M: Cory the Horse Lover.

Table 27: Cory's Profile

Pseudonym	Cory
Age	8 years
Grade	3th grade
Hobbies	Reading, Horse watching , soccer
Reason for parent interview selection	The teacher recommended her as one of the candidates to talk to her parents

Cory's teacher identified him as a high achiever, but he was one of the students who did not elaborate much during the interview, so I was intrigued to learn more about him. His answers during the interview were mainly level 1.5 with few answers at level 2. His understanding of the food web was better when he was asked to make up the environment rather than when he was asked to predict the effect of losing a specific population. When asked to make up his environment he said:

> Ron: I choose the frog because it can stay on water. A bird likes to eat worms so I chose those two birds, worms clean animals, I did not chose the crab because the crab fights with other crabs, once my teacher got crayfish and it died because it fought with another one
> I: how do you know worms clean other animals?
> S: My dad told me
> I: do you how they might clean animals?
> S: no

When reasoning about the environment, Cory was able to consider the simple feeding relationship of the birds which is level 2, but when I asked in a different scenario what would happen if birds died he said: “We wouldn’t have birds anymore so we can’t see them and that’s a bad thing”.

Cory mentioned that he gets his information from reading, specifically about horses, so I asked his mother about this and she told me:

> He has a huge passion for horses; we’ve got one really thick hard cover books and it is full of information it’s called animal book or something and has books about horses that has the terminology and not just fiction.

Other experiences with animals that his mother mentioned were some nature fun walks in the woods and going to zoos a lot. When I asked about the media, she mentioned he sometimes watches *Animal Planet* but not regularly. He has also seen a movie about horses called “Flicka.” From the interview with Cory and his mother, it was hard to determine how he drew upon his experiences to answer the interview questions. His experience with horses was not necessarily supporting his reasoning about the ecosystem as a whole – especially because the interview scenarios did not have horses as animals so it was difficult to transfer his knowledge of horses to the interview answers.

Case 5: S30G2F: Macy the Zoo Lover.

Table 28: Macy's Profile

Pseudonym	Macy
Age	7 years
Grade	2nd grade
Hobbies	Reading, Gymnastics, Biking
Reason for parent interview selection	The teacher recommended speaking with her parents

Macy was identified as an average achiever by the teacher and her answers during the interview were mainly at levels 1 and 2 with more answers at level 1.5; for example when asked to make up her own environment, she said:

> Macy: I would choose the squirrel, the bird, the rabbit, the flowers and fish.
> I: why those?
> Macy: Because they are all animals and some live on the ground like rabbit and squirrel, squirrel in tree and bunny in a hole in the ground and bird lives in a nest in the tree, and I chose the fish because it lives underwater and I have fish also, also the flowers I chose them to look beautiful where the animals live to look beautiful.

The above example shows that Macy is thinking of the habitat of organisms and the aesthetic aspect of the environment without thinking of the feeding relationships. Similar low levels were shown when asked to predict what would happen if black birds died when she said, "They can't get babies anymore and no black birds exist anymore and they wouldn't have any more chirping."

When asked about how she learns, she mentioned personal experiences such as going to Detroit zoo, and her mother confirmed that by saying:

> We go Impression 5 and we went to the science museum in Detroit last year in addition to Detroit zoo which she loves, but I think she's more into getting her hands dirty and knowing the nitty-gritty about how are they born and how they are when they are young, she's very intrigued.

When asked about the media, her mother said that Macy mainly watches Disney movies such *Lion King* and *Black Beauty* and does not watch many of the TV shows. One aspect that Macy did not mention but her mother mentioned was that she likes to read and she is currently reading about fairies, but she also reads about horses on some websites. Despite those informal experiences and her interest in horses, this did not support Macy's higher levels of thinking concerning the ecosystem.

Case 6 S35G2M: George the Insect Lover.

Table 29: George's Profile

Pseudonym	George
Age	7 years
Grade	2nd grade
Hobbies	Soccer, playing video games
Reason for parent interview selection	His high level of thinking about the system for his age

George's teacher identified him as a middle achiever. She said: "Maybe his father is a physicist and he teaches him many things, but if I if I look at what I like to call 'school behavior' sitting down, getting your work done, checking your work and making sure that your work is accurate, he's not so good at that."

Despite that, George exhibited high levels (mainly level 3 and 4) during the interview. Several instances during the interview he revealed how he's thinking of every element of the ecosystem influencing the rest. One of the prominent examples was when I asked what would happen if all insects died and he answered:

> George: The plants will die because the bugs help the plants.
> I: how do they help them?
> George: some of the flowers have nectar and bees take the nectar so some flowers will die
> I: Anything else will happen?

> George: After that, the frogs will probably die, and if frogs will die, the owl and some birds will die because they don't find anything to eat, and plants and flowers are the same thing the possums will die because berries will be gone and if the beavers didn't have berries or stuff, he will die and the fox could only get the fish and it won't be enough because there would only be fish so he would die, and the fish will be the only left.
> George: how do you know all that?
> George: My dad, nature camp and teacher.

The above answer shows that George is thinking of mutualistic relationship of insects and plants, in addition to complex effects on the ecosystem if insects were removed. This effect was transmitted to most of the populations of the food chain as he explained, and he systematically explained his reasoning of how one population after another will be affected.

During other instances of the interview, George told me that had a collection of insects that he collects with his father. When I asked him to pick an animal and talk about what it needs to live he said:

> Probably the bugs, because me and my dad have the biggest collection of bugs we've ever had, we put little pins in them and its cool. We put them in the picture frame and there's a glass, and sometimes we put bugs and pins. I have cool moths, one I found on the ground it was dead and one my dad got by the gas station. Also when my dad went to Chicago, he caught two pinching beetles and got them.
> I: how do you know the names?
> S: I have a book that tells us what their names are, I got it for my birthday.

The father who is a physicist confirmed this and said:

> We spend a lot of time in summer collecting insects, and that's one of the activities he and I share. We have a field guide and we look it up and we read about them where they live what they eat and what category they are in: is it an outlet moth or a mantis fly, we find some really unusual insects.

George showed high level thinking in other questions as well and I asked the father about how he may have answered at this level knowing the George has not formally learned about this in school. His father said:

> I care about conservation, so I give him seeds of ideas of how populations interact in the ecosystem. But we also put him in camps so he's going from camp to camp to camp. He goes to nature camps and science camps, so I'm pretty sure he's been taught things like that from various camps. I cannot pinpoint the exact source of his knowledge, but he goes to many camps, we have a membership at Impression 5, and he has quite a few books on sea creatures and classification books on reptiles and amphibians that we use in our summer nature walks or camping. Also my wife has a degree in elementary education so she's collected tons and tons of science books.

I asked him if George likes to read books the father said that: "George is not an avid reader, he does read by himself but mainly we read for him". When asking him about the shows he watches the father mentioned that George is into *Pokémon* and *Avatar Cartoons* but not necessarily into any movies or shows that show life styles or relationships among animals.

This information about George showed that he was very involved in science outside school, specifically from camps and from discourse between him and his father. His answers revealed high level thinking about the ecosystem for his age, and this was revealed in most of his answers. However, the most prominent relationship between his interview and his experiences was his answer about insects where he thought of insects as part of the ecosystem.

Case 7 S36G1M: Evan: The Environment Lover.

Table 30: Evan's Profile

Pseudonym	Evan
Age	6 years
Grade	1st grade
Hobbies	Reading, Music, Soccer, swimming and Legos
Reason for parent interview selection	His high level answers to some questions and his diversion to other science topics where he showed knowledge of science content

Evan was identified by the teacher as a high achiever and she told me that he has an interesting background. The interview with Evan was very interesting because he revealed high level reasoning in most of the interview questions. However, he would often change the subject to tell me some other scientific information that has nothing to do with ecosystem but was quite interesting and scientifically sound information. This made me intrigued to learn about his ideas and his learning style. I asked his mother for an interview and I was able to interview the whole family including Evan. The interview was more of a conversation with the family about what they do at home and what they learn.

Evan's high level of reasoning was revealed when he was asked to select populations to make his environment:

> Evan: I'll pick flowers because they grow on land, and I choose a tree and that grows on land, I'll choose snakes and worms and I'll say they live on land, I'll pick the centipedes, I'll pick the spider and the robins and the bushes, the crab, the seaweed and that goes in the water (*You know that seaweed used to be a plant in the air then it got covered with water and became a water plant)*
> I: how do you know that?
> Evan: I looked it up in internet
> I: what else would you choose?
> Evan: squirrel and all the rest
> I: why did you choose them ALL?
> Evan: because I like nature, animals eat other animals and some animals eat bugs and if the bugs weren't there for the birds then birds have no food and if no nuts, then the squirrel can't eat that's why I chose the tree and squirrel and the frog can't live without the water because they have to live in soggy places and I want to choose the birds because if they didn't eat anything they couldn't feed babies and die. They need worms to survive. They all need each other to survive
> I: how do they survive?
> Evan: some survive and some don't, trees usually survives during storms but some don't, but all those need to feed off each other to survive

Even if the above answer was long and sometimes digressing from the main question (e.g., talking about seaweed), one could tell that Evan was thinking how all animals need each other in the ecosystem. During another section of the interview, he also told me about how one can tell the age of the tree from the circles on it. I was intrigued by his general knowledge of science and his answers about the ecosystem. So, while having a conversation with all the family, both of his parents emphasized the importance of science and how they would like to push their kids to learn science:

> Evan's mother:, I came from a background where I struggled with math and science, and I don't want my kids to struggle, I'm an English and social studies teacher and this comes easy and I'm pushing my kids away from that, they do enjoy reading but math and science come first, he (referring to Evan's father) also made his career of that.
> Evan's Father: I also think that public schools do a good job teaching language than they do science and math, so we make sure that we're very very attentive to those subjects so we make sure they get additional help if they needed, additional work if needed. We make that even when they don't have science homework; they are always having something to think about.

And so when I asked the father about an example of such opportunities that he does with Evan, the father said:

> Evan's Father: something that I didn't realize I was doing until we started discussing talking to you at home, but I've always done this with the kids, I drop them off at school every morning and we're always having something we're talking about, lately Ethan and I have been talking about glaciers and he can tell you a lot about that, we went looking at the glacier marine.
> I: have you discussed specifically the ecosystem with him?
> Father: We do nature walks and camping a lot, so we try to do it organically and when there are opportunities we stop and talk about it, I'm an environmental scientist so it's easy for us to find something and stop and talk about it while walking. We've done hikes and force lands, and discussed trees and ecosystems, we do life cycles and we might walk on the beach and talk about interactions of birds and aquatic life.

In addition to his father putting an effort to teach him whenever the chance arises, I asked about TV shows he mentions and his parents mentioned three times during the conversation that the main show he watches is *Magic School Bus*. Moreover Evan's idea of what happens to the fish when it dies was the following: "Fish, bones disintegrates, I know it rots, the water will get bad and fish will disintegrate, "so when I asked the parents how does he know the word disintegrates the father immediately answered that this is definitely from *Magic School Bus* and that he as a father likes the show because "I think the *Magic School Bus* is a very good primer to start the conversation about something else, it's a great place to start, it seems that it's been a very effective for both of our kids".

Although Evan emphasized getting his information from camps, walks or even researching on internet, his parents told me that Evan is an "avid reader" and reads and learns on his own, and whenever they go to choose books the father mentioned, "We always make sure that when he chooses books that at least one book is educational."

With Evan's case, it was clear that the father uses every opportunity to teach his son scientific information about various science topics, and this was revealed during the interview with Evan who expressed high level reasoning about the ecosystem, but who also wanted to talk about other scientific topics such as finding the age of the tree from the circles or glaciers.

Case 8: S34G1F: Annie: The Grasshopper Lover.

Table 31: Annie's Profile

Pseudonym	Annie
Age	6 years
Grade	1st grade
Hobbies	Reading, Song writing, gymnastics, ballet
Reason for parent interview selection	The teacher recommended her as one of the candidates to talk to her parents

Annie was identified by her teacher as a high achiever. During the interview, Annie exhibited sophisticated thinking when asked what would happen if all insects died and she said:

> Annie: Some of these animals wouldn't have food so nature die because they wouldn't have food to survive.
> I: why would the whole nature die?
> Annie: if these were gone and all the animals around don't have food so they would die.

However for most other interview sections her answers were mainly at levels 1.5 and 2. For example when asked to choose populations to make up a viable environment she said:

“Frogs, seaweed, flowers, tree, birds, and squirrel, water and land and that’s it. I chose those because these are the things we see most in nature.” This answer is based on concrete practical experiences that she observes without thinking of other external reasons to how the ecosystem functions.

When I asked Annie about how she learns about nature, her main answer was from nature walks and observations in nature, and her mother mentioned that they have taken her to zoos and the Field museum in Chicago and also hands-on experiences such as:

> Annie’s Mother: Annie’s uncle is an entomologist and for Christmas, he gave her Lubber grasshoppers. We have been able to watch them molt, mate and lay eggs. We have talked about what eats the grasshoppers and she has experimented with the types of food they eat or don't eat.

Since both of her parents are high school math teachers, they emphasize math and give her problems to solve in informal setting. They also emphasize reading and so push her to read daily. When asking about movies or TV shows Annie watches, the mother said that she only watches cartoon movies and they not necessarily about animals. From the above interview, Annie had several informal experiences, mainly observational or hands on experiences with animals, but those experiences did not directly result in her thinking of the ecosystem.

Summary of the eight cases

To summarize these cases, I present in Table 32 the most frequent learning progression level during the interview, brief description of the major source of information, and brief statement that may or more not link the students’ interviews with their “sources of knowledge”.

Table 32: Relating Students Learning Progression Level to their Sources of Knowledge.

Student/ Grade	**Student Achievement**		**Major source of knowledge as identified by the student and the parent**	**Comments on relating the source of information to the students' learning progression average**
	Teacher evaluation	**Most frequent Learning progression level**		
Jane (G4)	Middle	4	Watching Animal planet and reading fact books about dinosaurs.	The connection between what she read about dinosaurs and transferring this knowledge to the interview was clear in several instances during the interview
Olinda (G4)	High	3	Watching Animal Planet and reading books especially about dogs	The connection between Animal Planet was at one instance during the interview but not necessarily in all questions
Ron (G3)	High	2	Watching Magic School Bus and reading books in general	There was no clear relation between his "sources of knowledge" and the interview answers
Cory (G3)	High	1.5	Reading about horses	There was no clear relation between his readings that interview answers
Macy (G2)	Middle	1.5	Going to zoos and personal observations	There was no clear relation between her experiences and the interview answers
George (G2)	Middle	3	Nature and science camps, learning with his father about insects during camping	There was a relation about what he learned with his father and from camps in many answers
Evan (G1)	High	3	Magic school bus and learning with his father about various science topics	There was a relation between his knowledge from media and the interview answers
Annie (G1)	High	1.5	Mainly concrete observations of the nature	There was no relation between her experiences and interview answers

As seen from Table 32, two patterns appear: (1) teachers' evaluation of the students' ability level did not always match the students' most frequent level of reasoning during the interview and (2) it was not always possible to match the students' answers with where they acquired their knowledge.

With regard to first result, only Olinda in grade 4 and Evan in grade one were judged as high achievers by the teacher and their answers were at high level during the interview. However, Jane (G4) who had the highest frequency of level 4 answers was judged as a middle achiever and George (G2) who also had high level answers was judged as a middle achiever by the teacher. Moreover, students who were judged as high achievers by the teachers (Ron, Cory, Annie) did not have a high frequency of high level answers during the interview. Macy (G2),judged by the teacher as a middle achiever, had answers that were mainly at a low level.

Concerning the second observation, only with the students who performed at a high level was it possible to trace some of their answers to the source of knowledge. With Jane (G4), the main source was her extensive reading about the dinosaurs and *Animal Planet*. With Olinda (G4), it was *Animal Planet.* With George (G2) it was the camps and learning about insects and nature from his dad, and similarly with Evan (G1) it was learning science with his dad and *Magic School Bus*. Despite those links that were revealed during the interviews with students and their parents in some specific questions, one cannot say that it's possible to identify the links to every answer especially that no student was coded at the same level for all the questions.

Summary of the chapter

To summarize this chapter, I present the main findings of each research questions in Table 33 below.

Table 33: Summary of the Findings for Each Research Question

Research Question	Main Findings
What are the learning progression levels in 1st to 4th grade students' system reasoning about ecosystems?	• After an iterative process of coding and recoding, the learning progression consisted of four levels, the lowest being the anthropomorphic level and the highest the level of causal reasoning that considered the network of feeding relationships. Levels 2, and 3 were intermediate levels of causal reasoning. Level 2 was simple causal reasoning that begins to identify an external mechanism in the phenomenon, and level 3 is semi-complex causal reasoning that identifies more than external factor on the phenomenon.

Table 33 (cont'd)

	• Level 1.5 was categorized in between level 1 and level 2 because it considered concrete or practical reasoning. • The highest frequency of students' answers fell in the lower levels of 1.5 and 2 with very few answers at level 4 and no answers at level 4 in the dynamic recycling category. • Only four students used the scientific term "food chain" when talking about the scenarios, and five students used the scientific term "disintegrate" describing what happens to dead bodies. •
How are 1st - 4th graders' reasoning similar or different across each grade with respect to the two questions above?	• There was a modest correlation between grade-level and two questions of systemic interdependency: One question was concerning the plants and another was concerning the poison. • There was no correlation between gender or ability as identified by the teacher and any of the interview questions
How is 1st - 4th graders' reasoning across and within the various system categories correlated?	• There was a modest correlation between systemic analysis and systemic interdependency. There was an also modest correlation within the systemic interdependency questions, but there was a strong correlation between the question concerning the fox and that concerning the mouse in the dynamic recycling category. • When examining the consistency of students' answers, approximately 50% of each student's answers were at the same level across systemic reasoning categories. However 82.98% of each student's answers were consistent within the dynamic recycling category.
Where do 1st-4th graders learn about systems reasoning in ecology?	• Students identified various resources for their knowledge, the most frequent of which was the media followed by personal experiences, books, museums, school, parents, travel and websites. The most mentioned media sources were *Animal Planet* followed by *Magic School Bus* and *Wild Kratts*. • A close look at eight students whose parents participated in the interviews showed that it was not always possible to relate the resources of knowledge to the students' performance in the interview. Despite that, it was possible to identify, with three students, the importance of science discourse that takes place at home between the students and parents.

Having presented the results of this study in this chapter, I now turn to discussing those results in the next chapter. The discussion will be centered around three main points; the first addresses the identified learning progression and compares it with other empirical work about learning progression and students' reasoning in ecology, the second addresses the idea of students' consistency and some conjectures concerning the correlation results, and the third addresses the idea of sources of knowledge and parents role in students' education.

CHAPTER 5 DISCUSSION

In this chapter I discuss the results that were presented in the previous chapter. After comparing this work with other empirical studies on ecology and learning progressions, I discuss the implications of this work for the definition of learning progressions in general, for the evaluation of the proposed hypothetical learning progression in this study, and for the importance of the sources of knowledge as a tool to inform learning progressions.

Comparing the Results to other Empirical Work

Overall the learning progression in this study consisted of levels 1, 1.5, 2, 3, and 4. The lower anchor (level 1) represented anthropomorphic reasoning in which students transferred human characteristics to non-human organisms. In this level, students did not reason using any external cause but were concentrated on human feelings and analogizing animals and plants to humans. These comparisons appeared subjective for each student depending on what they liked. Following the anthropomorphic reasoning, the concrete or practical reasoning (level 1.5) emerges where students consider factors with which they have concrete or practical experiences. The next level is Level 2, simple causal reasoning, where students reason using a simple cause-effect relationship between populations directly related to each other. This reasoning differs from concrete reasoning in that it moves away from practical and everyday reasoning and mentions some scientifically sound ideas even though they are simple. Level 3 becomes more complex in that students consider multiple factors related to the change in a given ecosystem, even though those factors still only consider effects on populations that are directly related. At this level, the students are partially considering several factors in the ecosystem but have not reached a stage where they consider the change in part of the ecosystem influencing the whole ecosystem. Finally at level 4, causal reasoning, students are able to consider a network of relations in the ecosystem and this allows students to consider the ecosystem as a whole and not as separate parts.

Taking one question from each category of systemic reasoning and looking at the frequency of responses, one can find that there was different distribution of levels. Table 34 provides a summary of the frequencies of one representative question from each category as an example.

Table 34: Frequencies for Each Category of Systemic Reasoning[11]

	Systemic interdependency What would happen if all insects died?	Systemic analysis What is the most important element in the system?	Circular connectivity Choose the populations that and make up your environment that can function properly	Dynamic recycling What would happen to the body of the fox when it dies?
Level 0	4	3		
Level 1	2	2	8	4
Level 1.5	6	10	4	**32**
Level 2	6	**21**	**22**	7
Level 3	**25**	7	6	1
Level 4	1	1	4	*0*
Total	44	44	44	44

Across all categories, level 4 had the lowest frequency. It is also noticeable that the level with the highest frequency was different for different questions. The systemic interdependency question concerning the insects resulted in approximately 57% of students giving answers at level 3. Some parents mentioned that they teach their children about insects, so it is possible that students were more exposed to insects in their everyday life and they knew that many populations feed on insects. As a result, they could talk about the various populations that feed on insects and reason about what would be affected by the absence of insects, which placed those

[11] Bolded numbers refer to the highest frequency.

students at level 3. However, this knowledge may not lead to their having an ability to recognize the web-like effect of how the change of the insect population could indirectly influence other populations.

The highest frequency for systemic analysis question was level 2, recognizing only one important factor that is food or oxygen as the most important factor in the environment. Similarly, the highest frequency for the circular connectivity question was level 2 where students recognized the importance of shelter (15 out 22 accounts) as a condition to make up the environment. This kind of reasoning (level 2) is what Leach et al. (1996) call "descriptive reasoning" which considers a factor with which students are most likely familiar – meaning that students were likely familiar with the importance of oxygen and shelter to animals and plants. However, even though this reasoning is logical and important (plants in fact give oxygen, and animals seek shelter), it is not a reason that takes into consideration all other elements of the system or at least more than one element.

When comparing the question of insects with others, one could see that insect question yielded more answers at level 3 while the question of the most important element and constructing environment yielded more answers at level 2. Students' acquired knowledge about each of those factors may play an important role in their reasoning. Students may know from several resources (parents, stories, and media) that many animals feed on insects, and that prompts them to think about it when asked the question. The concentration on the importance plants of giving oxygen when asked about the most important element in the ecosystem may be the result of being exposed to this topic in the curriculum that discusses the importance of plants. The second grade teacher mentioned that this topic is part of what they teach them in science. Moreover, the concentration on shelter as a condition to construct an environment concurs with

Lehrer and Schauble's (2012 a, b) conception that elementary students' conception of ecology in general starts with anthropomorphic reasoning and develops to consider shelter as an important factor and later students think of species interdependency and how populations interact with each other and with the environment. Later in the discussion, I relate those inconsistencies to various sources of knowledge of the students.

The question concerning dynamic recycling, which is represented in Table 10 by the question about the fox, resulted in the highest frequency of level 1.5 with no students reasoning at level 4. Almost one third of students demonstrated concrete or practical reasoning, which is consistent with findings by Mohan et al. (2009), who found that most elementary and middle school students' ideas of carbon transforming processes were at lower levels. Mohan et al (2009) characterized the lower anchor for their learning progression on carbon cycling as "force-dynamic reasoning," which is similar to level 1.5 in this study and what I call concrete or practical reasoning. Mohan et al. characterize the force dynamic reasoning as one where students discuss macroscopic properties, "changes are explained by the visible changes of the object" (p. 685). Similar accounts were observed in this study when students were asked about the body of the fox dying, and students mentioning the "rotting" process without going further into any details of the process. This is related to what Leach et al. (1996) call "familiarity" of what students see in nature.

However, whereas 10% of high school students revealed level 4 answers in Mohan et al. (2009) work, no student in this study could identify the breakdown and recycling of matter when asked about the fate of the fox's body after it dies. Similarly, Eilam (2012) showed that even after inquiry instruction about the ecosystem, 10^{th} graders did not significantly improve their reasoning about recycling of matter. This raises the challenge of appropriately identifying an upper anchor that is scientifically sound and that is at the same time empirically validated. Mohan and Plummer (2012) address this challenge and mention:

> At the start of the defining process, it may be easy for learning progression researchers to visualize the upper anchor, using guidance from standards, prior research, and years of experience. Yet when researchers search for evidence of this level in the classrooms, they rarely are able to obtain sufficient data. (p. 144)

In addition to the difficulty of the concept of matter recycling (i.e., having no level 4 answers at the dynamic recycling category), the results may suggest that this category is qualitatively different from the rest. With the three categories of systemic interdependency, systemic analysis and circular connectivity, there is causal reasoning that that requires analysis of synthesis of the ecosystem at large. However, with the dynamic recycling category, the key point is to understand that matter is broken down by decomposers and is recycled in the ecosystem, meaning that the reasoning requires more in-depth understanding of microscopic processes that result in the macroscopic phenomenon.

When comparing this learning progression to other work on ecosystem, there seems to be nuances in the learning progression levels – especially the differentiation of the lower anchor. This is because the learning progression in this study takes a “zoomed-in” approach (Gotwals, 2012) where it focuses on younger children’s reasoning. Griffith and Grant (1985) categorized the food web model into “subordinate” and “super-ordinate” skills. Even though they did not use the learning progression language, their study identified increasingly more sophisticated reasoning at low and high levels. They found that there were five hierarchical levels in how students reasoned about food webs, the lowest consists of students considering the direct predator-prey effect and the highest consists of students considering the effect of changing one population in one food chain on another population in a different food chain when there are several routes for the effect to be transferred. In comparison, the learning progression levels in this study differentiated younger students' thinking even further. For example, Level 2 in my learning progression consists of reasoning about direct predator-prey relationship and level 3 consists of reasoning about direct predator and several prey populations. This distinction was useful for my sample because very few students considered two-way causal relationships or the effect of changing one population in one food chain on another population in a different food chain. Moreover, the direct predator-prey relationship, which was the first level in Griffith and Grant study (1985), was at level 2 in my study where two lower levels (anthropomorphic and concrete practical reasoning) were identified. One reason that can account for the difference is that Griffith and Grant (1985) used a top-down approach that stemmed from the food web model whereas this learning progression is more dependent on the bottom-up approached that honored students' ideas. Gotwals and Alonzo (2012) emphasize the importance of a bottom-up approach in illuminating students' ways of reasoning and teasing apart the middle levels that are usually hardest to identify in the learning progression. The bottom-up approach allowed the distinction of various middle levels for lower elementary students in this study; something that Griffith and Grant's work did not consider.

Despite this difference with Griffith and Grant's (1985) work, similar kinds of reasoning to this study were found by Leech et al. (1996) and Lennon and DeBoer (2008), who found that even older students are more likely to consider effects on direct populations than those of indirect populations. Green (1997), who performed a study on adults and gave participants cues to consider more sophisticated relationships than simple linear predator prey relations, found that participants were not always able to consider indirect relationships. One explanation for the persistence of simple models could be what White (2000) calls the "influence resistance" (p.605) model. He theorizes that students think of the change in one population as an influence and so other populations will have a resistance to this change, and after this resistance, the net result which is increasing or decreasing of population size will result. When the influence starts at one point, the longer the food chain, the less the effect on the final population because of what he called the “dissipation effect” (p. 605) which is similar to water ripples that decrease with distance. However, even when the “influence resistance” model could explain the situations when students did not think in a more sophisticated way about the food web, it could not explain how some students were able to reason in a more sophisticated way.

Despite the similarities of the this work with other empirical work, the presence of mixed-level reasoning was a major finding which has implications for the definition of learning progressions, in general, and which is I discuss in the next section below.

Implications of the Results for the Definition of Learning Progressions

Zooming in and out

Even with the booming empirical work on learning progression, how to define a leaning progression is a debatable issue. Specifically the content of the learning progression and the context are used in various ways. Alonzo (2012) distinguishes between broad learning progressions and narrow learning progressions. In the former, the learning progression spans several age groups (elementary, middle and high school) and considers big ideas such as carbon transforming processes. However, in the latter, the learning progression is more focused and can consider a specific topic such as floating and sinking and a specific grade level. Mohan and Plummer (2012) emphasize the goal of the learning progression in determining the grain size: broader learning progressions serve to refine the standards and large-scale assessment, while narrower learning progressions serve to support curriculum and instruction and formative assessment in the classroom. Gotwals (2012) points to the importance of "zooming in" and "zooming out" of the learning progression. Zooming in allows one to see the trees while zooming out allows one to see the forest. Even though the sample was from different grade levels, I consider the learning progression in this study a narrower learning progression that has implications for curriculum and instruction and sheds light on the specific content of students' systemic reasoning of the ecosystem. Therefore, I consider this learning progression one that is zoomed-in at specific age group with a specific focus. With this zooming in, the idea of mixed-level reasoning was clearly revealed, which has implications for the defining of learning progressions.

Even though learning progression researchers do not claim that students' learning pathways are linear, there is, however, the assumption that students could be identified within one level for a specific concept. However, several researchers have alerted against considering students in one level. For example, Lehrer and Schauble (2009) believe that students exhibit variation in their reasoning and so identifying students to strictly one level is not very common. Alonzo and Steedle (2009) found that students' ideas about force and motion do not always belong to the same level for assessment questions that targeted the same concept in different contexts. If this is true, the idea of defining learning progression as having clear-cut levels may be problematic. Gotwals and Songer (2010) found that the same students can demonstrate different levels of reasoning depending on specific questions. For example questions that required students to reason about algae resulted in lower levels than those requiring students to reason about big fish and small fish. They called this inconsistency the "messy middle" where the same student can reason at one level in one question and at another level in another question addressing systemic interdependency. However, they did not reveal mixed-level reasoning where a student at level 3 or 4 was also showing reasoning at lower levels in the same assessment or think aloud account. Unlike Gotwals and Songer (2010), this study reveals all levels of the learning progression can be messy.

Explanations of mixed level reasoning

When looking at the results of this study, some students exhibited reasoning at levels 2, 3 or 4 also showed reasoning at lower levels of 1.5 and 1 in a specific conversation. The highest frequency of mixed-level reasoning occurred in the circular connectivity question that required students to construct their environment choosing some populations; in this question, 22 out of 44 students revealed mixed-level reasoning. This question was very open-ended, requiring students to build a system rather than analyzing an existing system. Therefore, students could consider several factors for constructing their environment including their personal liking or relating their choice to human characteristics which resulted in anthropomorphic reasoning. Even if one considers that this specific question required a different skill from others, the mixed-level reasoning was also existent among other categories of systemic reasoning. For example many students mentioned that if a predator population died the prey would not be eaten but it will also be happy; thus including simple causal reasoning and anthropomorphic reasoning at the same time. Moreover, some students mentioned that if the fox died, its body would rot and its family would be sad which means that more than one kind of reasoning is revealed in such an answer.

One explanation for mixed-level-reasoning is to think generally of children's reasoning at this age. Piaget (1966) distinguishes between the world of the child, which is full of intentions and subjectivity and results in what he calls "transductive" reasoning, and that of the scientist which depends on "physical determinism" and calls for "deductive" reasoning.

He then classifies the stages the child passes through in order to reach a reasoning of "objective" causality. The child first starts with subjective reasoning (e.g., a pebble is heavy because he thinks so), to reciprocity (ability to see different points of views like the pebble is light for him but heavy for water), and then to relativism (relating the concept to others such as relating the density of one object to that of the other). With each of those, the child moves from egocentrism where he couldn't differentiate the objects in the world from himself to a more objective reality where concepts exist on their own. However, even when the child grows, there remains a tendency to go back to "animism" or what is called anthropomorphic reasoning in this study because "the child's thought is in no way organized" (p. 292). Moreover, even in an adult stage there is still some "adherence" to subjectivity, or as Piaget states:

> From our present point of view, therefore, there is never complete objectivity: at every stage there remains in the conception of nature what we might call "adherences", fragments of internal experiences which still cling to the external world. (p. 244)

When looking at students' answers in this study, it is possible that the students who exhibited mixed-level reasoning were maintaining an "adherence to subjectivity" that is explained by a domain-general developmental stage for students. However, it is also possible that students who are exhibiting anthropomorphic reasoning are not necessarily at lower levels. Zohar and Ginossar (1998) advocate breaking the taboo of students' adherence to anthropomorphic explanations and found that high school students resort to anthropomorphic explanations because it was easier to communicate or understand. Recently, Alonzo (2010) recognized that having mixed-level reasoning may be one way for students to make sense of their everyday discourse as they learn the scientific discourse and make progress in their scientific reasoning.

As such, the results of having students reason at mixed-levels reflects back on how to include this reasoning in the learning progression. Rather than thinking of a learning progression as having pure levels, one could then expand the concept of levels to think of hypothetical learning progressions that takes into account mixed-level reasoning. The importance of including the mixed-level reasoning is shedding light on the non-linear way of students' reasoning. Most learning progression research agrees that studying learning progressions requires longitudinal studies of same student sample. Because these longitudinal studies have not been completed, the idea of mixed-level-reasoning could be one missing link in the status quo studies. This allows us to understand how students, especially early elementary students, are reasoning about the scientific topics. In fact, Jin and Anderson (2012) mention the challenge of having distinct levels and their revised learning progression identifies students who include force dynamic reasoning and school science words in their accounts of carbon transforming processes thus referring to the messiness or mixed-level reasoning.

Thinking of how to include mixed-level learning continues the discussion of how best to define learning progressions, however, it is also important to consider the framework used for the learning progression in this study and discuss whether the results supported this framework or not.

Evaluation of the Validity of this Hypothetical Learning Progression

The framework used for this learning progression is adopted from Chandler and Boutilier (1992) who identify four categories of systemic reasoning: systemic interdependency, systemic analysis, circular connectivity and dynamic recycling. The results of this study, specifically the correlation among various systemic reasoning categories has implications for this framework. In the previous discussion about defining a learning progression, it was clear that many students were inconsistent in their reasoning about various interview questions. The correlations between items in systemic reasoning were modest; and about 50% of students showed consistency across levels. . This provides evidence that the categories of the systemic reasoning framework are distinct and that they are independent aspects of students' systemic reasoning. Each one of these categories was targeting a different element of system and the results showed that students' answers were indeed different in each category. However, in addition to zooming-out at the results across the categories, it is worthwhile to zoom-in within each category, specifically within the systemic interdependency and dynamic recycling where there was a set of questions addressing this category.

For systemic interdependency, there were weak to modest correlations between most of the questions. There was no correlation between the question concerning the influence of loss of the fox population and that concerning the influence of the loss of fish or the insects' populations. An important point to consider is how the population participated in the food web. This means that the more the population is part in several food chains in the ecosystem, the more likely there is a correlation between this population and other populations in the system. For example, the birds are related to foxes, fishes, insects and plants. The answers concerning the birds showed a moderate correlation with all other agents, and this was similar for the plants, where the answers concerning the plants were correlated with all other populations. However, the fox is part in as many food chains as the birds or plants so there was no correlation between the fox and fish or between the fox and the insects. When considering the consistency of answers within this category 59% of responses had consistent levels which did not give conclusive evidence that students' ideas were consistent of not.

In the category of dynamic recycling, the strongest correlation was between the question concerning the fox and that concerning the mouse. This is not surprising knowing that the fox and the mouse were both terrestrial animals and students likely expected that the same thing will happen to both bodies once they were dead. There was a modest correlation between the question concerning the mouse and that concerning the grass, as well as between the question concerning the fish and that concerning the grass. However, there was no correlation between the question concerning the grass and that concerning the fox. In many answers concerning the grass, the students said that the grass dries up, changes color and is blown away by the wind. Therefore, they were not regarding the grass similar to other living organisms where it can also decay. This might be related to the everyday experiences of students when they that see that grass dries up and not necessarily “rot” as they see with other animals. Moreover the consistency of students’ answers within the category of dynamic recycling was the highest (82.95%). Jin (2010) also found that students accounts of carbon transforming across various types of interview questions was around 80%, which suggests that students think of carbon transferring in similar ways across different contexts.

There is no clear evidence for the consistency in student thinking about systemic interdependency but there is more supportive evidence for consistency within dynamic recycling. This could either mean that the questions within systemic interdependency were addressing a different concept or could mean that students were inconsistent about the answers. The latter is more likely because Gotwals and Songer (2010) found similar inconsistency for questions addressing systemic interdependency and called those the “messy middles”. A possible reason for consistency in student reasoning about dynamic recycling (but not in systemic interdependency) is the similarity of the questions concerning dynamic recycling in that the process of rotting could be thought of as the same for students. However for systemic interdependency the students' answers depended on how much they knew about each population or the sources of knowledge that students capitalize on and how that influences the learning progression research, which is discussed in the next section..

Implications of the Sources of Knowledge for Learning progression Research

The idea of capitalizing on students' background knowledge and primary discourse has been used by many socio-cultural researchers in the field, especially for those who worked within urban settings or ethnic minorities. For example, Moll et al. (1992) emphasize the importance of "historically accumulated and culturally developed bodies of knowledge" (p. 133). Other researchers emphasized students' primary discourse, traditions, and everyday knowledge that allows them to bridge the gap between students' lives and school science. For example, Calabrese Barton and Tan (2009) identified the various " funds of knowledge" and the discourses that students bring with them to the classroom in a low income urban school. Their study shows how teachers, with explicit attention to discourse, can adapt instructional approaches to legitimize the family, community, peer culture and popular culture sources which are the knowledge sources from which various discourses emerge, as meaningful and appropriate tools in science learning. In this study, I define the sources of knowledge as the collection of ideas and experiences that students acquired from various resources like parents, relatives, media, peers, books, school or others.

The learning progression literature has mainly adopted a cognitive perspective to identify various levels of reasoning. However, some researchers acknowledge the importance of a socio-cultural approach to learning progressions if the learning progression is to be successful in designing effective instruction. The learning progression in this study was mainly descriptive, but for the learning progression to have more explanatory power, the reasons why students think in a certain way and the where students acquire their ideas could help move forward with appropriate instructional material. Alonzo (2010) mentions adopting a discourse approach to the learning progression could help address the challenges of students' inconsistencies and the students' use of everyday language. In this study, I have adopted the idea of sources of knowledge as a tool to shed light on where students acquire their ideas and reasoning. I discuss how the sources of knowledge can be used to explain several parts of the results as well as how the sources of knowledge can inform a curriculum that honors students' ideas.

The results of this study indicate that there were many inconsistencies among students' answers, little use of the scientific terms, and a modest correlation between grade level and some questions of systemic interdependency. The sources of knowledge can help understand those results because understanding where students acquire their information is important to understand ways of the reasoning.

Inconsistencies and students' sources of knowledge

As mentioned in previous sections, the results of this study showed that there were inconsistencies of students' answers about the levels. It is possible that students have learned that some populations can influence the population than others and so once asked about what they already have more information about, they could reveal higher level answers than with other populations. For example George and his father mentioned that they have a hobby of collecting insects and learning about their life cycles and how they can be classified by using specialized books. Other students mentioned how much they learn about birds from the website www.birds.com; therefore, the various knowledge students acquired could explain the inconsistencies. In addition to the inconsistencies, the results showed mixed-level reasoning, and as discussed above, some students could utilize a higher level in addition to anthropomorphic reasoning. Knowing that half of the students mentioned the media as a resource of information, it is possible the students' anthropomorphic reasoning lingers because of how the media attributes human characteristics to animals in cartoon movies. For example, Jane and her mother mentioned that Jane loves The Lion King and she has watched it several times on TV and even in a play. Therefore, students' information resources and how much they know about certain population could influence how they answer the questions. Fisch et al. (2011) found that students who use various media platforms could transfer their learning more to other situations specifically problem solving skills. This emphasizes the influence of the media on students' knowledge about the topic.

Scientific terms and students' sources of knowledge

With regard to the use of scientific term, only a handful of students mentioned those terms (four students mentioned "food chain" and five students mentioned "disintegrate"). However, there was a difference between those using the term "food chain" and those using the term "disintegrate". In the former, students revealed partial understanding of the meaning of the term "food chain", but in the latter students did not reveal any understanding of the term "disintegrate". Students who mentioned the food chain did not use the word energy to explain transfer of energy in the ecosystem; however, they used the language of "eating" and were able to explain that some that some animals eat each other. However when students used the word "disintegrate" in the context of explaining what happens to the dead body they were not able to go beyond saying breaking down or reiterating the word "disintegrate". This means that they could not trace matter in the system. For both terms, students mentioned that they learned them from the media. Understanding each term scientifically requires understanding the flow of energy in the case of using the word “food chain” and recycling of matter in the case of using the word “disintegrate.” Gunckel et al. (2012), and Jin and Anderson (2012) classify such accounts as “naming” as opposed to “explaining.” In naming, students are able to use scientific terms and sometimes definitions without actually deep reasoning of what is going on. Alonzo (2010) emphasizes the importance of understanding students’ definitions of scientific terms and comparing their discourse to scientific discourse. One way to understand those terms is to understand where they have learned them from. When I investigated where students have learned about those terms some students and the parents mentioned the media as the source of information. In an informal analysis to one the Magic School Bus episodes about marine ecosystem, I noticed that the episode provided simple definitions that emphasized macroscopic relationships rather than energy or matter transfer. Not surprisingly, students used what they saw in the media as *their* explanations of those words and not necessarily how scientific discourse would explain it. What is important here is to recognize that the media is important for students and to think of ways of capitalizing on this resource to help students move up in the learning progression. One way of doing this is to use some of the popular shows in the classroom to start conversations and supplement inquiry activities to construct scientific models of the ecosystem.

Correlations of grade level and students’ sources of knowledge

With regard to the results concerning the correlation between grade-level and learning progression level, the only significant correlation was that between grade level and systemic interdependency, however the correlation was very modest. When looking at the specific questions which resulted in this correlation, the two questions, one predicting the effect loss plants on the ecosystem, and the other about predicting the effect of adding poison that kills insects on the rest of ecosystem were the ones that resulted in the correlation. Even though the correlation was modest, it is possible to relate this correlation to students' sources of knowledge and how much they are exposed to the importance of plants and pollution in the environment as they grow older. Plants are a typical part of any ecological system and the older students grow, the more they learn about plants. The second grade teacher mentioned that she teaches students about plants and she said:

> I teach the plant unit in the spring. They bought us some geraniums, so I do the experiment one with water with sun, one without sun, change variables and then if any one survives they can take it home for them. I teach them about the needs of plants and the importance of plants for us and for the environment (2nd Grade Teacher)

It is therefore understandable that students of older grades capitalized on what they have learned especially that many students mentioned that they acquire their information from the teacher. This means that students were transferring what they have acquired in one situation to the interview questions about the ecosystem.

Concerning the question of the poison, it is possible that older students have learned more about the pollution and the question concerning the poison led them to think in this direction. For example, when students were asked if they were to imagine doing something bad to the environment a typical answer from 3rd and 4th grade students included the idea of pollution; S3G4F said:

> I would put a lot of pollution and oil in river, because fish can't breathe because oil came inside of them and animals can't drink the water. Probably I would put poisonous things around like poisonous grass and they would get poisoned and die.

Moreover, many of the parents mentioned how they want their children to be aware of the conserving the environment and preventing pollution. For example George's father mentioned "I care about conservation so I give him seeds of ideas of how populations interact in the ecosystem and how it is important to keep a clean environment because wastes can disturb the balance in the environment." Moreover Jane's mother mentioned, "Every year we go to the open house of water treating center, so they talk about how landfills are made or how they recycle the water, and how to clean water and why it's important." The importance of plants and the idea of pollution are ideas that students could be exposed to more as they grow especially from the curriculum and from their parents who emphasize the importance keeping a clean environment and preserving plants.

Having mentioned the importance of sources of knowledge in explaining the results, it is also important to consider students' sources in curriculum and instruction, which is what I discuss in the next section.

Students' sources of knowledge as a way to structure curriculum and instructional materials

The results from students' accounts of their sources of knowledge revealed that the media, books they read at home, museums, parents, and personal experiences are among the ways they acquire their information. This means that capitalizing on those resources in curriculum and instruction may be one way to help students progress in the learning progression. Interviews with some students and their parents revealed that media, books and personal experiences with some students resulted in students thinking at a high level in the learning progression. Many students and parents reported the *Magic School Bus* as a major source of their knowledge. Therefore, one could think of such episodes as primers to start a unit on ecosystems and follow it up with more advanced scientific concepts. Rancone (2002) reports on a case where students who were taught about the solar system using the *Magic School Bus* series retained the information more that those that used traditional school material.

Fisch et al. (2011) support this because their research on fourth grade students' learning found that students who used various media were able to perform retain more information and perform better in solving mathematical problems. Therefore it is possible to think of some episodes of TV shows such *The Magic School Bus* as triggers for learning, and then compliment other concepts that students are required to learn. This is not to say that the media will be a substitute to learning. Metz (1995) states that even if Piaget made the claim that young children require concrete tools to learn, this does not mean that the product of the learning is concrete. In other words using concrete base of learning could allow students to learn abstract concepts such as cardinal numbers. This means that concrete tools for learning need to be supplemented with model based reasoning. Even Joanna Cole, who is the author of the Magic School Bus, acknowledges the importance of backing up the media with science concepts (Roncone , 2002) and she states:

> If you don't follow it up with real science education, then the kid is at a complete disadvantage. So I think that most of the science that you see in books and TV, they're wonderful, but they can't be everything. And very much aware of that when I'm doing my books. (p.13).

Thinking of a curriculum that includes media would be consistent with the bottom-up approach of the learning progression that honors students' ideas and interests. Complementing that with big ideas and important scientific concepts could allow students to move student to higher levels in the learning progression.

Parental Involvement

Another important factor that was revealed in the results was the kind of parents' involvement. It is known that parents have a major influence on their children's education. Wang and Wildman (1995) found that parents' encouragement of their children's study resulted in higher science achievement in seventh grade students. Similarly McNeal (1999) found that parents' involvement in their children's lives resulted in higher science achievement in eighth and tenth grade students for various socio-economic classes. A major part of the involvement was related to the opportunities that parents provide their children with in order to learn science such as reading books and having discussions. However, those studies were related to parents' support of formal school learning. In this study, I explored parents' role in helping students' learn informally and how that translated into ideas about systemic ecological reasoning. From the results of the case study, all parents provided their children with opportunities such as taking them to the museums, zoos, or buying books for them. However, only few parents (Evan's father, Jane's mother, George's father) supplemented the experiences with discourse that promoted learning science and all three students revealed high level reasoning. This suggests that the informal experiences without specific focus of learning the science concepts were not sufficient to for students to think at higher level of the learning progression. For example, Evan's father explicitly stated that he creates opportunities for his children to teach them about science because he believes that science is undermined in school at the expense of mathematics and literacy. One thing to note about Evan's father is that he's an environmental scientist, which may influence how he handles the science. A similar situation was with George's father who is a physicist and he emphasizes that he cares about "conservation" and prepares several science projects that he develops with George.

Even though it is not possible to ask every parent to be a science teacher at home whereby they can create intentional learning opportunities for their children to learn science, it is possible to think how parent-school interaction could foster students' learning. For example if one parent is an environmental scientist and the class is discussing ecology, it is possible to invite this parent to share an interest science discovery or information that this parent finds interesting to know. Strieb (2010) explains the importance of the parent-teacher interaction and discusses ways of effective communication with parents from her long teaching career as a kindergarten and first grade teacher. She mentions that newsletters are not only important in communicating to parents what their children are doing, but also important in suggesting to parents how they could contribute to what their children at home or in school. This strategy can open up the floor for parent’s involvement and contribution to the children’s learning.

Summary of the discussion

In this chapter I discussed how results from this study have implications for the discussion concerning defining learning progressions in the field, on the framework of the learning progression used in this study, and on the importance of the sources of knowledge to explain the results and be included as part of learning progression research. Perhaps the main implications of those results on the learning progression research is the presence of inconsistencies and mixed-level reasoning in addition to the importance of students’ sources of knowledge in constructing knowledge. If one considers this learning progression a “zoomed-in” view of the students’ reasoning, then it important to think of ways to include inconsistencies as part of the learning progression. Moreover, knowing the importance of what students bring with them to school, it is important to capitalize on what students already value and know in order to design curriculum and instructional approaches. This does not mean that one should avoid teaching students model based reasoning or scientific models that make sense of the world, it just means having students’ resources as a starting point may be beneficial in helping them develop scientific model based reasoning.

Limitations of the Study

Even though this study revealed a lot of information about students' reasoning and sources of knowledge regarding systemic reasoning of the ecosystem, there were some limitations that I address below.

The first limitation concerns the sample size and sample nature. Even though this study is mainly qualitative in nature, a sample more than 10 or 12 students per grade would be required in order to generalize from the results. Similarly the case studies included only eight parents, so more cases would be beneficial to learn more about a larger range of students, their sources of knowledge, and the influence of parents on their children's science education. Moreover, the nature of the sample was suburban students, so a more diverse group would be required in order to validate the learning progression.

The second limitation concerns the research instrument. While interviews are very appropriate to work with young students, this interview constituted of pictures only that represented the ecosystem. A revised version of the interview could probably be a computer-simulated system which would be interactive or showing students' different types of ecosystems such as marine ecosystem and terrestrial ecosystem. Moreover, the word "relationship" was understood differently by students. When asked whether there was any "relationship" among populations, only 15 students identified animals feeding on each as a relationship, while 16 students considered a relationship to mean interaction between biotic and abiotic factors and six students thought of a relationship as a beneficial relationship to both parties so if there is harm there is no relationship. Alonzo (2010) found a similar result with the word of "force" and "motion" and advocated taking a discourse view to learning progression. Therefore, the language difference between adults and children could also have been a limitation of the study.

Future Research

Building on the results and the limitations of this study, I envision the following research agenda that can help address some the questions that were left unanswered:

A tradition of the learning progression research is the design-based research (Cobb et al, 2003; Collins et al., 2004) that stipulates refining the design in an iterative process. Therefore taking the results of this study as another starting point, I could take a larger and more diverse sample to try and validate the learning progression. Expanding the sample to include more students and more diverse populations such as students in urban setting or English language learner would give more valid results for the learning progression especially when dealing with inconsistent answers or mixed-level reasoning. Moreover taking into account some limitations of the instrument, I could think of improving the interview to include more dynamic system and then have a conversation about it. Quellmalz and Pelligrino (2009) point out to the importance of software such as SimScientists to assess students understanding of the ecosystem. Organizing interview questions around such a dynamic system can help overcome some limitations of a static picture as a model of the ecosystem

Another important implication of this study is the importance of student's sources of knowledge in shaping their reasoning. I envision future research concerning learning progression to include in addition the cognitive identification of the levels, the socio-cultural identification of the students' sources of knowledge and relating that to the learning progression levels. Therefore I envision future research to include more parent samples and more explicit questions about the specific answers pertaining to specific levels of learning progression. This way we could learn more about the way students reason and could directly relate certain ways of reasoning to specific sources of knowledge.

Following on the point above, the explicit influence of the media on students' learning progression is an interesting question to pursue. Most people would not debate the influence of the media on students and young children, but what is debated is the whether the influence is positive or not. Neil Postman (1982) theorizes that the idea of childhood requires a distinction between the personality of the child and that of the adult. Interests, games and life of a child in the 1950s was separated from the parents, something that was more the case from the 1970's on. He considers communication between the child and the parent as a process, "whereby information became uncontrollable, whereby home and school lost their commanding place as regulators of child development" (p. 90). Gerbner (1987) reiterates the importance of the media in shaping the public image specifically that about science. He states:

> Yet a single episode on a popular prime-time program, or even a soap opera reaches more people than all other educational efforts put together. More important television reaches those who receive no other information about science. (p. 115)

Gerbner (1987) also found that television perpetuates negative images about sciences. However, not everyone shares the belief that media has negative influence on the public. The "framework for evaluating impacts of informal science projects" mentions the positive effect of the media in understanding science concepts and influencing attitudes towards science and changing behavior to reduce carbon footprint. One study showed that adult participants showed more understanding of global warming when they were exposed to a two hour television series about global warming and this understanding was manifested by their drawings, multiple choice answers, and individual interviews (Friedman, 2008). Moreover, a major importance of the media is the issue of trust. Anderson et.al (2012) found that the media plays an important factor in the public trust of science and scientists and promoting positive attitudes towards scientists and science institution. Those different views about the media raise the questions of how it could influence students' learning progression about systems reasoning in ecology. Thus, one of my future research agenda is to investigate this relationship in depth.

Finally, the learning progression in this study was what is called the "status quo" learning progression because explicit instruction of the topic did not take place. As important as this learning progression is in terms of finding out what are the different levels of students and their sources knowledge, the ultimate aim of learning progression is to relate it to curriculum and instruction. Therefore, an integral part of this work will be to investigate the learning progression of students when exposed to a curriculum that capitalizes on students' sources on knowledge and moves them to think of scientific models of the system. Building on the results of the study, I plan to investigate the effect of a media infused curriculum. I envision a curriculum where TV shows and software models are used in tandem to support students learning of ecosystem. The research on how the learning progression is influenced by instruction is essential not only to improve the learning progression research but also to improve the current instruction that is supposed to go hand in hand with the learning progression.

APPENDICES

APPENDIX I: QUESTIONS FOR THREE CATEGORIES OF SYSTEMIC REASONIG

Scenario I: Exploring the diagram below.

Appendix I-A

In this scenario, I will first show a picture without the arrows and try to see how they answer certain general questions, after that I show the same pictures with arrows and have more specific questions about the relationships

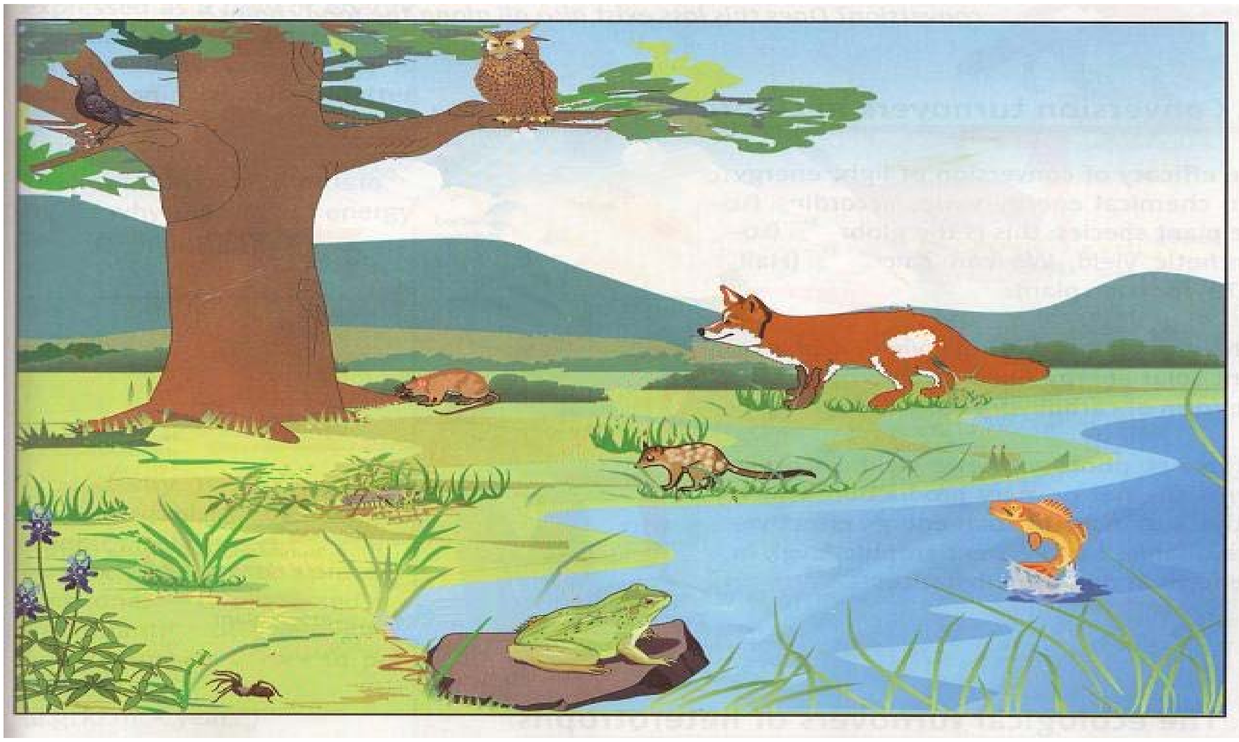

Figure 8: First Scenario for Students (Adopted from Dagher et al., 1999)

1- Look that picture, and tell me where you think you can find such an environment in nature?
2- Have you visited such a place in nature? With whom? What did you do there?
3- Do you think there are any relations among the organisms above? Do they interact with each other? How?
4- Pick one animal and tell me what you think it needs in such an environment to survive?
5- What other things does the animal you picked (e.g. frog, fish, or wolf) need to survive?
6- How does the animal you picked (e.g. frog or fish or wolf) depend on other living things to survive?
7- Do you think plants are important in this environment, why?

Appendix I-B

After those general questions I will show them the same picture with the arrows and try to ask them more detailed questions

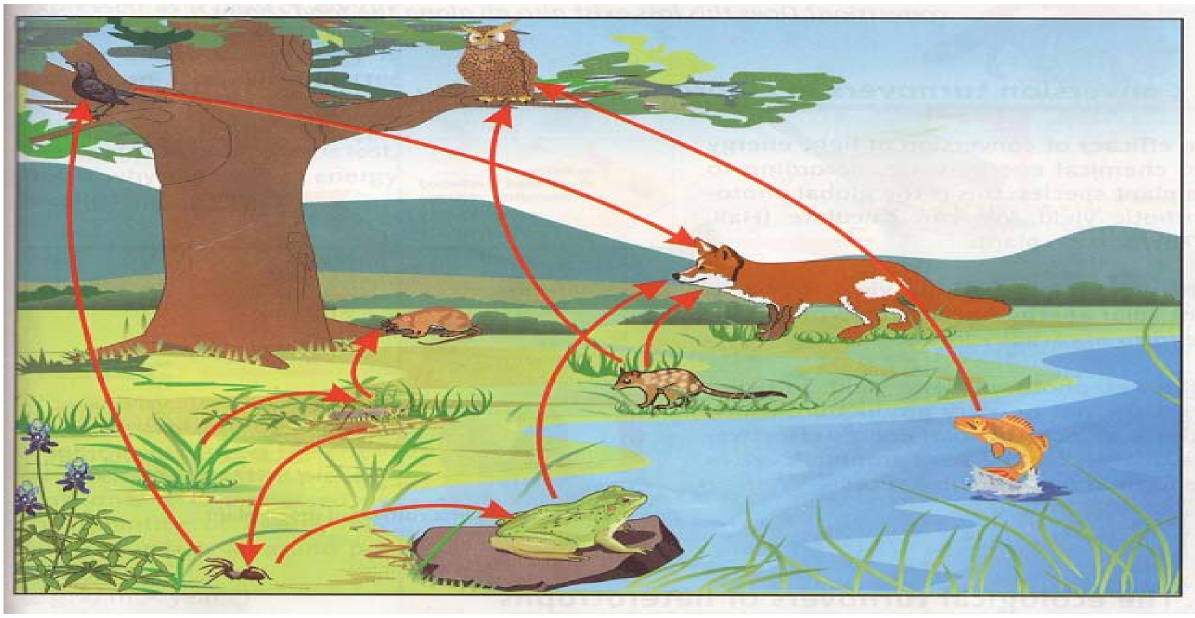

Figure 9: Scenario with Arrows (Adopted from Dagher et al, (1999)

1- What does the picture show?
2- How would you explain the relationships among owl, insect, frog and plants? What do you think the arrows mean?
3- Which organisms or parts of the environment are the most important in keeping this system working?
4- Do you think that this environment is missing something to keep living or is what is shown enough to keep it living?
5- Which one of those organisms would be the most in number?
6- What do you think may happen if all insects disappeared?
7- What do you think will happen if all black birds disappeared?
8- What do you think will happen if all the foxes disappeared?
9- What do you think will happen if all the fish disappeared?
10- What do you think will happen if all the grass, trees, and green plants disappeared?
11- For the fox to survive and have babies, what would it need?
12- For fish to survive and have babies, what would it need?
13- If the fox died, what do you think will happen to the fox after one week? After two weeks? After one month? After one year?
14- If grass died, what do you think will happen to the grass after one week? After two weeks? After one month? After one year?
15- If the fish died, what do you think will happen to it with time?
16- If the mouse died, what do you think will happen to it with time?

17- If someone sprayed a poison that killed insects, would any other creature in the above picture be affected?
18- If you were to do something "bad" to the environment, what would that be and how would you do it?
19- If you were to do something positive to the environment above, what would that be and how would you do it?
20- Name what is living in the picture above, name what is not living? Is there a relation between them?
21- Have you learned about this subject before? Where?
22- What are your experiences with animals and nature?
23- How did you learn about feeding habits of different living things in nature?
24- You seem to know a lot about this topic, where have you learned all of that from?

Knowing that a lot of species interaction in the food web entails predator prey relations, I specifically probed students' ideas of predator-prey relations (Figure 10) in order to find out how they think when we isolate one predator and one prey in the environment.

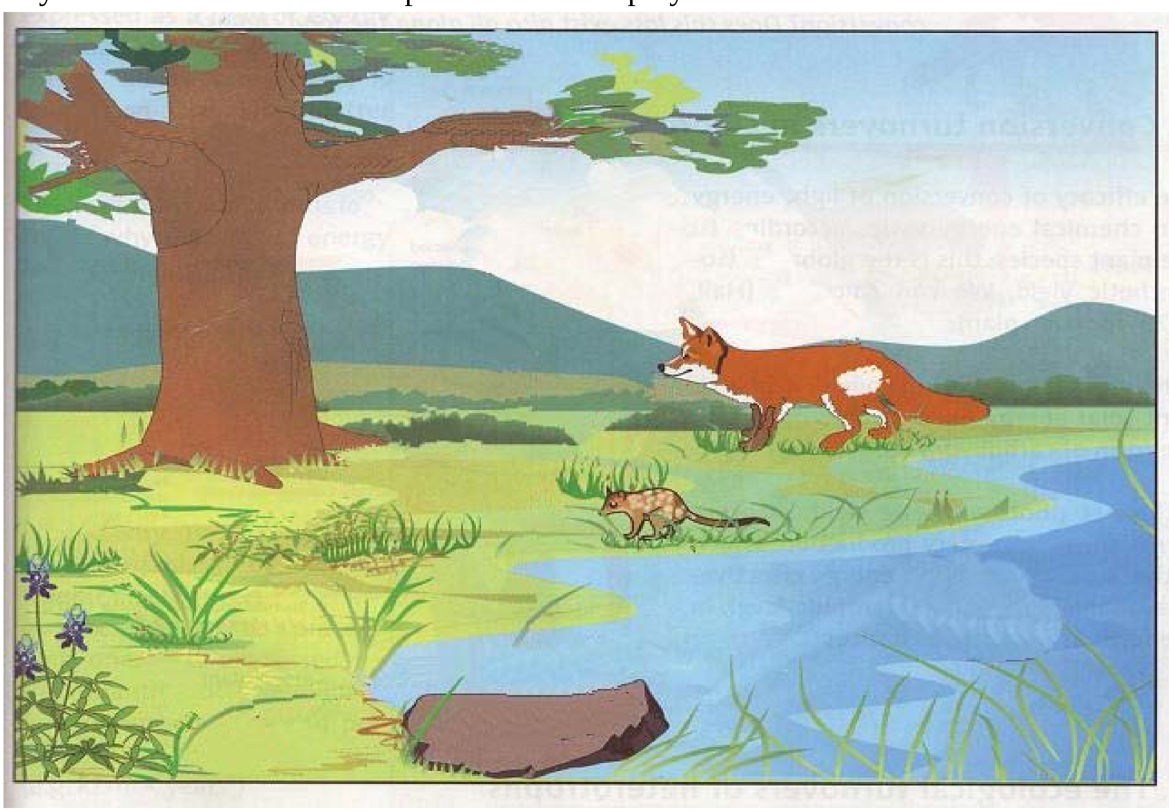

Figure 10: Feedback Loop Reasoning

1- Assume in the environment above, all animals died and what was left was 200 foxes and 200 rabbits, how many rabbits and will we have after one week? After one month? After 6 months? After one year? And why?

2- Assume that all animals died except the mice? What would happen to those mice after one week? After one month, after 6 months? And after one year?
3- Have you learned about this subject before? Where?

APPENDIX II: CIRCULAR CONNECTIVTY QUESTIONS

Scenario II (Constructing a food web)

The picture of question (Figure 11) that has been used by Leach et at. (1995). The original form of this question was choose 6 of those organisms that could live together for a long period of time without needing anything, and the second question was to choose the population which is highest in number. When using this question with some pilot students, I found out that students often chose them in pairs, and students were often confused about the picking 6 organisms. Therefore, I decided to use the organisms but modify the question in order to help me elicit the students' "circular connectivity" about the system. I will have each organism on a card and so I will present those cards on the table and tell the students that each organism represents its species.

Having each of the following as separate picture I will ask them the following

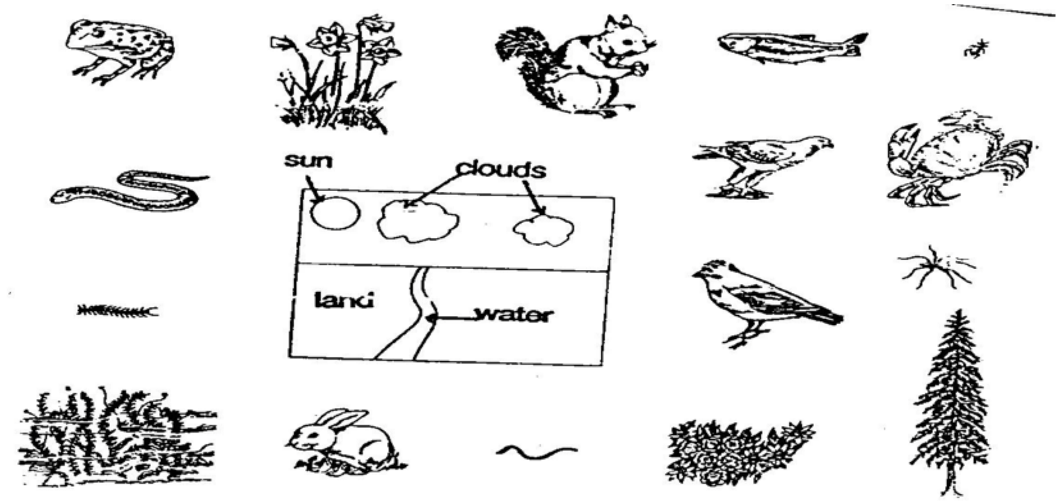

Figure 11: Circular Connectivity Scenario (Adopted from Leach et al., 1995)

1- Now we will play a game where you get to create an environment. Knowing that you have the box in the center (sun, clouds, land, water), imagine an environment in nature and then pick as many of the other pictures as you think is necessary that can be in this environment?
2- Give an name to this environment
3- Why did you choose the ones you did?
4- Draw lines between the ones that have a relation between each other?
5- Tell me the story of this environment of how everything lives in this environment?
6- Which one of the populations you choose would be the most in numbers? Why do you say so?
7- Have you learned about this subject before? Where?

APPENDIX III: TEACHER INTERVIEWS

I am trying to find out where students get their knowledge so I have some general questions about the science curriculum and then specific questions about certain students and any experiences you may know about.

1- Do they follow a specific science curriculum? What book or curriculum? would it be possible to have a look at it

2- How many science periods do they teach per week?

3- Do students have a science book or copybook they take home?

4- What is the policy for science homework? Do they get any science homework?

5- Do they receive a grade for science that they take home?

6- What are the science topics that are covered?

7- Do you cover the same topics every year or does curriculum change from year to year?

8- Do you cover topics such as living non living, what plants need to live, what animals live in a pond or forest and they need to live, food chains and food webs, how to preserve the environment?

9- Do you show them any movies or videos in science? Specifically about how populations of animals and plants interact in the ecosystem? Any field trips or nature walks?

10- When you told me what levels the students are, it was their overall achievement, do you have a general grade for the students that parents know about or that is used internally?

11- In addition to what is taught in school, some students have information from home, do you find that some students read or have other activities that makes them ahead of others in what they know? any of the ones In the list? Do their parents teach them or do they expose to books or do the kids themselves watch any movies and then come and talk about it in class? **(ASK about specific students in mind)**

APPENDIX IV: INTERVIEW WITH ONE PARENT OF (S7G4F)

I was impressed by your daughter's answers about the ecosystem and so I would like to know about the experiences that Josie is exposed to, I asked her and she said that reads books, she watches planet earth and other experiences, I would like to know more about those experiences. This would help me think of how students' home experiences expands their science knowledge specifically in the topic of biodiversity.

1- You have mentioned in the email that she's been the science person at home, why is that?

2- What learning style does she have, does she like to learn on her own?

3- What does she read? She mentioned the dinosaur book and how they got extinct? Do you know about that book, Do you discuss what she reads? What other books does she read?

4- Does she read on her own, do you have reading sessions together? Does she lean with peers?

5- What movies does she watch about animals and how they interact with each other? mentioned she goes to the cottage in summer, and she observes and the animals and how they live, do you all do that, or does she do it on her own? Any interesting story you can tell me?

6- You're a teacher and have an experienced and inside view as to what kids should know. how does that influence how you direct your kid's learning? Do you discuss what they learn in school at home

7- What are some of the experiences that you make sure your kids have? That you feel will help them learn school curriculum, whether science or other subjects

8- Anything you would like to tell me about what Josie's experiences, story of learning about the ecosystem of animals and plants?

9- How are your eldest daughter's experiences with learning about the ecosystem similar or different from your younger daughter?

APPENDIX V: SAMPLE INTERVIEW ORGANIZATION FROM S23G2M

Table 35: Transcript of Circular Connectivity question for S23G2M

1- If you were to create your own environment having water sun clouds and soil, choose some of those organisms that can live there in such a way that the environment is working well? 2- Why did you choose the ones you did? 3- Are there any relations among the ones you chose? Why? Tell me the story of this environment of how everything lives in this environment?	Worms on the land, I'll put the birds in the clouds and on land. And for water I'll have fish, and we'll have a tree right on the land and one more I'll pick a crab in the water and worms. I chose those because like to stay in the ground and in the cloud and I know crab are by the beach and fish in the water and the worm help the environment and tree is where birds live I: do they need each other S: the tree needs the water and clouds and sun keeps some of the animals alive and the land needs the water. The birds need the fish and worms for eating. The crab will eat the fish like minnows and I know that worms need the land so that can stay in the soil Story: when I go to the ice cream story, every time I go there's some birds and when I took a little piece of my ice cream and the birds are coming over and flying in the sky because of the ice- cream. I: do you want to give a name to this environment S: I'll just call it nature
Which one of the populations you choose would be the most in numbers? Why do you say so?	Probably the trees because they're all over the world
You seem to know a lot about this, where did you learn all of this information from	I went to a lot of camps that had natures, we did a lot of nature walking, we caught frogs and I go camping two or 3 times every year. I: what other animals did you see S: I saw squirrels, bushes and seaweeds I:besides nature walk, do you have a pet S: I have a leopard kicker (a kind of lizard and needs a lot of sunlight so that it can live and eats cricket and sometimes horn worms like a caterpillars) and a dog I: do you feed the lizard S: I keep her in my room in a special place and I gave it some decorations and when it goes out of the house it's like a little garden. I: do you have a garden S: not anymore because all it has is weeds, the apple tree died normally because no water but the other tree lived for 200 years

Table 36: Transcript for Picture without arrows for S23G2M

Look that picture, and tell me where you think you can find such an environment in nature?	When you go camping, and when you're on the road
Have you visited such a place in nature? With whom? What did you do there?	Yea but I haven't seen any foxes or owls, I've seen a baby fox in the road I:when you go camping do you see those animals S: I could see frogs, fishes, sometimes beavers, I've seen a possum at the zoo
Do you think there are any relations among the organisms above? Do they interact with each other? How?	Frogs wants the fish, the bird probably wants the fish and owls wants the fish, the possum needs berries and flowers and I know the frog needs the insects and the fox needs possums beavers and kind of birds too because it's a meat eater and the beaver needs the water
Pick one animal and tell me what you think it needs in such an environment to survive? What other things does the animal you picked (e.g. frog, fish, or wolf) need to survive? How does the animal you picked (e.g. frog or fish or wolf) depend on other living things to survive?	Probably the bugs, because me and my dad have the biggest collection of bugs we've ever had, we put little pins in them and its cool. We put in picture flame and there's a glass and sometimes we put bugs and pins. I have cool moths one I found on the ground it was dead and one my dad got by the gas station. when I dad went to Chicago, he caught two pinching beetles. I: how d you know the names S: I have a book that tells us what their names are, I got it for my birthday. I: why do you do this activity S: because I want to be physicist when I grow up like my dad
Do you think plants are important in this environment, why?	The trees keep all the animals alive because they need air. The possum needs flowers and berries from plants. The sun is the most important part
What would happen if all plants died?	Everything will die because the trees give air and air will be gone because the trees make it

Table 37: Transcript for Picture with Arrows for S23G2M

What does the picture show? How would you explain the relationships among owl, insect, frog and plants? What do you think the arrows mean?	The foxes eat the foxes and the birds needs the spiders and these need the possums If all of those died S: there would be nothing left I: why is that S: they would die one by one because they need the others

Table 37 (cont'd)

Which organisms or parts of the environment are the most important in keeping this system working?	The sun and the trees and the berries, I:why the sun S: the sun makes the food for the plants and if no sun we have no plants and if we have not plants there is no air to breathe and everything dies, also the berries are food for the possums so they are important because many animals feed on them I:anything else why sun and trees and berries are the most important I:any thing else S: no
Do you think that this environment is missing something to keep living or is what is shown enough to keep it living?	The sun makes some of the food in the leaves, like the water goes in the leaves and the sun helps it and makes the food for the plants, because the water goes into it and the sun comes and helps I: why is that important S: because if there are no plants we have no air and we die I: how do you know all that S: my dad, nature camp and teacher
Which one of those organisms would be the most in number?	The most would be the fish, because there's a lot of fish, I know because I go fishing a lot and a lot of people catch them
What do you think may happen if all insects disappeared?	Insects, the plants will die because the bugs help the plants I: how do they help them S: some of the flowers have nectar and bees take the nectar so some flowers will die I:After that what will happen S: the frogs will probably die and if frogs will die, the owl and some birds will die because they don't find anything to eat, and plants and flowers are the same thing the possums will die because berries will be gone and if the beavers didn't have berries or stuff, he will die and the fox could only get the fish and it won't be enough because there's would only be fish so he would die and the fish will be the only left I: how do you know all that S: my dad, nature camp and teacher I: what do you learn in camp S: we go and they teach us songs about nature songs and about plants and animals, I remember one: " this is your land, this is my land"

Table 37 (cont'd)

What do you think will happen if all black birds disappeared? What do you think will happen if all the foxes disappeared? What do you think will happen if all the fish disappeared? What do you think will happen if all the grass, trees, and green plants disappeared?	Bird: that helps the plant by pollinating them but because the scarecrows fight them away, so if there are no birds there will be less plants I: anything else might happen S: no If all the foxes died it would be helpful and bad, if the foxes are gone then some of the animals will be gone because they don't get enough meat. I: what do you mean S: I mean the animals that eat the fox will die I: how come, the animals don't eat the possum S: if foxes died then some animals like possums need the fox to eat it once it is dead Fish: beaver and foxes died because they feed on fish and birds die but beavers may still live because they can eat berries Plants: all animals and we will die because we will have no air
For the fox to survive and have babies, what would it need? For fish to survive and have babies, what would it need?	It needs a lot of fish because the babies could only eat fish, they need mostly fish and beavers so they the big ones are eat
If the fox died, what do you think will happen to the fox after one week? After two weeks? After one month? After one year?	It will get rotten I: how S: it will be really old and super hard to eat I: what will happen after one year S: it will turn into soil, the bones kind of disappear and turn into soil and the skin gets eaten by worms and it disappear I: how will it disappear S: I don't know how it disappears but I know that bones disappear in the soil, I really don't know the reason I'm still trying to learn that.

Table 37 (cont'd)

If grass died, what do you think will happen to the grass after one week? After two weeks? After one month? After one year? If the mouse died in the environment above died, what would happen to it after 10 years? And why? If the fish died, what would happen to it after 10 years and why?	Plants It will turn rotten and will be orange and yellow and all the animals will die because they need grass, if it doesn't have the tree attached to it so it gets rotten I:how does it get rotten S: I don't know how but it does Mouse: the same thing will happen to it like the fox Fish, will land on an island and I've seen that once I: what if it doesn't land anywhere S: it will make the ocean stink and no one will want to go into it I: will it stay there or disappear, how will it disappear S: it will disappear maybe the sand will make it disappear
If someone sprayed a poison that killed insects, would any other creature in the above picture be affected?	Frog because it eats bugs and insects I: what if only this bug died, if the frog S: yes because of the poison they will die I: any other creature affected S: birds eat frog so if they eat it they will die and the bird and frogs gets the poison and the fox gets affects and nothing else is alive
If you were to do something "bad" to the environment, what would that be and how would you do it? If you were to do something positive to the environment above, what would that be and how would you do it?	Bad: kill all the trees, if trees died everything died except the fishes so everything dies because they need air I: do you think we have plants in the ocean Yes I: what will happen if plants in ocean die S: all fish will die as well Good if I find a baby fox I'll tell my parents and my dad will help it live
Name what is living in the picture above, name what is not living? Is there a relation between them?	I pretty much don't see anything I: do you think the water is living S: no I: mountain S: no and rocks are not living I: any relation between water rocks and mountains S: fish wants the water and the water needs the fish and the trees need mountains I: why do they need mountains S: I'm not sure

Table 38: Transcript for Feedback loop system reasoning for S23G2M

Assume in the environment above, all animals died and what was left was 200 foxes and 200 rabbits, how many rabbits and will we have after one week? After one month? After 6 months? After one year? And why?	Probably a 100 foxes and 5o possums, the possum will be eaten by foxes and the foxes might because they won't have enough of meat so they will 100 left. I: will they make more of themselves S: yes I: how many will be have after 100 year S: about the same amount 200 boxes and 200 possums because they will have babies, wait, they may stay the same in the beginning because they make babies
Assume that all animals died except the mice? What would happen to those mice after one week? After one month, after 6 months? And after one year?	Possums will the winners, they will be more and they will keep making more babies I: is this good or bad S: B A D I: why S: there will only be possum walking all around because there will be one kind of animal in the whole world
Have you learned about this subject before? Where?	Any books or movies S: I have a lot of books, I forgot their names, but I have books that are signed, it was about the horned owl that lived for 13 years then he died, he was like part of the family because he watched the kids. I: any movies S: I watch videos for kids, I forgot the names. I have a laptop too, I have 2 sister and no brothers, I'm the oldest, my second sister is 4.5 and my other sister is one year old. Sometimes they pick me up from child care and sometimes from school. They bring me to school or early child care. There's another's kid website but Evan knows it we kind of share my email. Somehow we kind of share the email, even we don't live in the same house but we share the email.

APPENDIX VI: INITIAL LEARNING PROGRESSION

Table 39: Preliminary Learning Progression Coding scheme

	Effect of population changes	**Identifying crucial elements of the system**	**Constructing an interconnected food web**	**Recycling of matter through the example of decomposition**
Lower Anchor	Anthropomorphic or aesthetic reasons *e.g.,* " *if plants died, the air will not be good and we will not be able to eat vegetables"*	Identify irrelevant elements such as top carnivore due to size *e.g., "the wolf because it can eat them all*	Recognize pair relations that are dependent for anthropomorphic reasons *e.g.,* "these birds because they are both birds because they eat seeds and have fun together	Recognize random events such as air or temperature that do not involve matter recycling *e.g., "when the plant dies, it will disappear after some time because of the air."*
Middle level 2	Recognize the effect on the direct organism	Identify a mixture of irrelevant and relevant elements	Recognize a web like relation with most organisms but not all without reference to abiotic relations	Recognize that the soil's condition of dampness and heat can cause breakdown of the dead and do not involve recycling
Middle level 3	Recognize the effect on more than organism but not on all related organisms	Identify some of the relevant elements but not the all of them	Recognize the connection of various biotic interactions without any reference to the abiotic factors	Recognize that worms can break down dead organisms that can be recycled
Upper Anchor	Recognize the domino effect of changing one population on the rest of the food web	Identify the producers and sunlight as crucial for a viable system	Recognize various connections between various populations and relations between biotic and abiotic factors	Recognize Microscopic organisms change matter to usable components in the system

APPENDIX VII: CONSISTENCY TABLE FOR ALL 44 STUDENTS

Checking for students consistency

There are 13 items are used to check for students' consistency
Q1: Question that requires students to make up their environment choosing populations and justifying their choice (Scenario II)
Q2: what is the most important element of the ecosystem (Scenario I)
Q3: What is missing in the ecosystem (Scenario I)
Q4: What would happen if all insects died?
Q5: What would happen if all black birds died?
Q6: What would happen if all foxes died?
Q7: what would happen if all fish died?
Q8: what would happen if all plants died?
Q9: if someone sprayed poison that killed insects, would any other creature be affected? Why or why not?
Q10: What would happen to the foxes body with time when it dies ?
Q11: What would happen to the grass when it dies?
Q12: What would happen to the mouse with time when it dies?
Q13: What would happen to the fish with time when it dies?

Table 39 below shows the students most frequent level, and the deviation from the most frequent level (baseline) calculated by subtracting the level form the baseline, and number of questions with baseline frequency in the last column.

Table 40: Consistency Table

Student/ most frequent level	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	**# of baseline**
s1g4m (2)	0	0	-2	1	0	-2	0	0	2	-0.5	-0.5	-0.5	1	**5**
s2g4m (2)	0	-1	-2	0	0	0	0	0	-1	-0.5	-0.5	0	-0.5	**7**
s3g4f (2)	0	1	0	0	0	0	1	1	2	0	-0.5	0	-0.5	**7**
s4g4f (2)	2	1	-2	0	0	0	0	0	2	-0.5	-0.5	-0.5	-0.5	**5**
s5g4m (1.5)	-0.5	0.5	-1.5	1.5	0	1.5	0.5	1.5	0.5	0	0	0	0	**5**
s6g4m(2)	0	1	-2	1	0	1	1	0	-1	0	-0.5	0	-0.5	**5**
s7g4f (4)	-1	-1	0	0	0	0	-1	0	0	-1	-2.5	-1	-2.5	**6**

Table 40 (cont'd)

s8g4m (2)	0	0	-2	0	0	0	0	0	2	0	-0.5	0	-0.5	**9**
s9g4f (3)	0	-1	-1	0	0	0	0	1	1	-1.5	-1.5	-1.5	-1.5	**5**
s10g4f (1.5)	0.5	0	-0.5	1.5	0.5	1.5	1.5	0.5	0.5	0	0	0	0	**5**
s11g3f (1.5)	-0.5	0.5	-1.5	-1.5	0	0	0	0.5	-1.5	0	0	0	0	**7**
s12g3m (2)	0	0	-2	0	1	1	0	0	0	0	0	0	0	**10**
s13g3m (1.5) 6	0.5	0	0.5	-1.5	0	0.5	0.5	0	-1.5	0	0	0	-1.5	**6**
s14g3m (2) 4	2	0	-2	1	-0.5	0	1	0	0	-0.5	-0.5	-1	-1	**4**
s15g3f (1.5)	0.5	0.5	0	-1.5	0	1.5	-1.5	0.5	-1.5	0	0	0	0	**5**
s16g3f (3)	1	0	-3	0	-1	0	0	0	-1	-1.5	-1.5	-3	-1.5	**5**
s17g3m (2)	-0.5	0	-2	1	-1	0	1	1	-0.5	0	0	0	0	**6**
s18g3f (2)	0	-0.5	0	1	0	1	0	0	4	-0.5	-0.5	-0.5	0	**6**
s19g3m (1.5)	1.5	1.5	0	1.5	0	0.5	0.5	0.5	0.5	0	0	0	0	**6**
s20g3f (3)	-1	0	-3	0	0	0	0	0	-1.5	-1.5	-1.5	-1.5	-1.5	**6**
s21g2f (1.5)	0.5	0.5	-1.5	1.5	0.5	0	0	0.5	0	0	0	-0.5	-0.5	**5**
s22g2m (1.5)	0.5	0.5	1.5	1.5	2.5	1.5	1.5	0.5	0	0	0	0	0	**6**
s23g2m (3)	1	0	0	0	-1	0	0	0	1	-1	-1.5	-1	-1	**8**
s24g2m (2)	0	0	0	1	0	0	0	0	0	-0.5	-0.5	-0.5	-0.5	**7**
s25g2m (1.5)	-0.5	0.5	-1.5	0	-0.5	0	0	0.5	0.5	0	0	0	0	**7**
s26g2f (1.5)	0.5	0	0	0	0	0.5	-1.5	0	-1.5	0	0	0	-0.5	**8**
s27g2f (1.5)	0.5	1.5	-1.5	1.5	0	1.5	0	0.5	0.5	0	0	0	0	**6**
s28g2m (1)	1	1	-1	2	0	0	2	1	0.5	0	0	0	0	**6**
s29g2f (1.5)	1.5	0.5	0	1.5	-0.5	1.5	-0.5	0.5	0.5	0	0	0	0	**5**
s30g2f (1.5)	0.5	0	0	1.5	0	0	1.5	0.5	0.5	0	0	0	0	**8**
s31g2m (0)	1	2	0	2	0	1	2	1.5	1.5	1	0	0	0	**5**
s32g2f (2)	0	0	-2	0	0	1	0	0	-1	-0.5	-0.5	-0.5	-0.5	**6**

Table 40 (cont'd)

s33g1f (1.5)	0	-1.5	-1.5	0.5	0.5	0.5	0.5	0.5	0	0	0	0	0	**6**
s34g1f (1.5) 5	0	0.5	-1.5	1.5	0.5	0.5	1.5	0.5	0	0.5	0	0	0	**5**
s35g1f (1.5) 9	0.5	0.5	0	0	0	0	0.5	0	-1.5	0	0	0	0	**9**
s36g1m (3)	1	0	-1.5	0	0	0	0	0	0	-1.5	-1	-1	-1	**7**
s37g1f (1.5)	-0.5	0	-1.5	1.5	0	0	0	0	0	0	0	0	0	**10**
s38g1m (1.5)	-0.5	0	-1.5	0	0	0	0	0	0	0	0	0	0	**11**
s39g1f (1.5)	2.5	0	0	-0.5	1.5	1.5	1.5	1.5	0.5	0	0	0	0	**6**
s40g1f (1.5)	0	0	0	1.5	0.5	0	0.5	0	0.5	-0.5	0	-0.5	0	**7**
s41g1f (1.5)	-0.5	0	-1.5	0	0	0	0	0	-1.5	-0.5	-0.5	-0.5	-0.5	**6**
s42g1m (2)	1	0	0	1	0	1	0	0	0	-0.5	-0.5	-0.5	-0.5	**6**
s43g1f (1.5)	-0.5	-0.5	0	0	0	-0.5	-0.5	0	0	0	0	0	0	**9**
s44g1m (1.5)	1.5	0	-1.5	-0.5	-0.5	-0.5	0	0.5	-1.5	0	0	0	0	**6**

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