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Knowledge Sources of Ecosystems and Learning Progressions

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ABSTRACT

In a prior study, we developed a learning progression (LP) for systemic reasoning in ecosystems at the early elementary level (Hokayem & Gotwals, 2016). The LP captures increasingly sophisticated reasoning patterns used by first through fourth graders to explain interdependent relationships in ecosystems. The present study investigates students' background knowledge—the knowledge sources that students use to develop the reasoning patterns on the different levels of the LP. In particular, we explored where and how students acquired their ideas about interdependent relationships in ecosystems in light of their learning progression levels. We collected two data sets, using a "purposive sampling" method: 1) student interviews, and 2) parent interviews. Forty-four first to fourth graders participated in a student interview to talk about where they have gained information to explain questions about interdependent relationships in ecosystems. Eight student parents, whose children were involved in the student interview, participated in a parent interview to explain their children's informal experiences at home. The results showed that the media, followed by books, personal experiences and parental involvement, were the most common knowledge sources for early elementary students. More importantly, students who frequently drew upon out-of-school knowledge sources tended to demonstrate understanding represented by the higher levels of the LP. We discuss the implications of those results for learning progression research and for curriculum and instruction.

Keywords: ecosystems, knowledge sources, learning progressions, lower elementary students

INTRODUCTION

Understanding ecological systems is the basis for recognizing the importance of preserving biodiversity and endangered species (Franklin, 1993). Ecologist E. Odum (1977) points out, "We are abysmally ignorant of the ecosystems of which we are dependent parts" (p. 1289), emphasizing the need to increase public awareness of species interaction in ecosystems. Capra (1996) calls attention to systemic reasoning, which focuses on the various interactions and processes in ecosystems. For example, emergent properties are a concept of systemic reasoning. It emphasizes that patterns at the system level are very different from the characteristics and behaviors of the components of the system. To foster systemic reasoning about ecosystems, we first need to understand how students understand ecosystems and apply relevant scientific concepts related to ecosystems.

We used a learning progression approach to study systemic reasoning at the early elementary level. Learning progressions (LP) are "descriptions of successively more sophisticated ways of thinking about a topic that can follow one another as children learn about a topic over a broad span of time (NRC, 2007, p. 214). Along with many science education researchers (Anderson, 2008; Duncan & Hmelo-Silver, 2009; Gotwals & Alonzo, 2012; Hokayem, Ma & Jin, 2015), *A Framework for K-12 Science Education* (NRC, 2012) calls for using

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learning progressions to align standards, curriculum, and instruction. An LP is a learning pathway that usually contains a "lower anchor" describing the prior knowledge, skills, and reasoning of students as they enter the progression; an "upper anchor" specifying the scientific knowledge and reasoning that students are expected to master at the end of the progression; and middle levels linking these two anchors (Duncan & Hmelo-Silver, 2009). In previous work, we used a learning progression approach to study how elementary students (first through fourth graders), who have not received formal instruction on ecosystems, reason about interdependent relationships in ecosystems. Based on the student interview data, we developed an LP for systemic reasoning in ecosystems. The LP consists of four progress variables, with each variable containing five levels of increasingly more sophisticated reasoning patterns (Hokayem & Gotwals, 2016). In this study, we examined the knowledge sources of students' ideas that are at different levels of that LP. Students draw upon a variety of knowledge sources to construct their explanation of the phenomena in the natural world. Knowledge and information from school science learning is only one of them. Other knowledge sources such as parents, media, and museums also affect their learning. Such contextual information is very useful for teachers to understand where students obtain their ideas from and how they develop those ideas (Wylie & Ciofalo, 2008). Understanding students' intuitive ideas is very challenging for teachers, especially at the elementary level. The LP for systemic reasoning is about early elementary students' understanding of ecosystems before they receive any formal instruction on that topic. In such a situation, the knowledge sources is especially valuable for researchers, curriculum developers, and teachers to develop curriculum and instructional approaches that are relevant to students' daily experience. Therefore, our research questions are:

1. What are the knowledge sources that early elementary students use to understand interdependent relationships in ecosystems?
2. How do students' knowledge sources relate to their learning progression levels?

Conceptual Framework

An LP is a cognitive model that describes students' understanding and development in a science topic. Students may draw upon different knowledge sources to generate ideas about ecosystems and those ideas are captured at different levels of reasoning in an LP. We develop a conceptual framework to illustrate this viewpoint (**Figure 1**). In this section, we first describe the structure of the LP for systemic reasoning. Then, we discuss the possible influence of knowledge sources on the reasoning patterns at different levels of the LP.

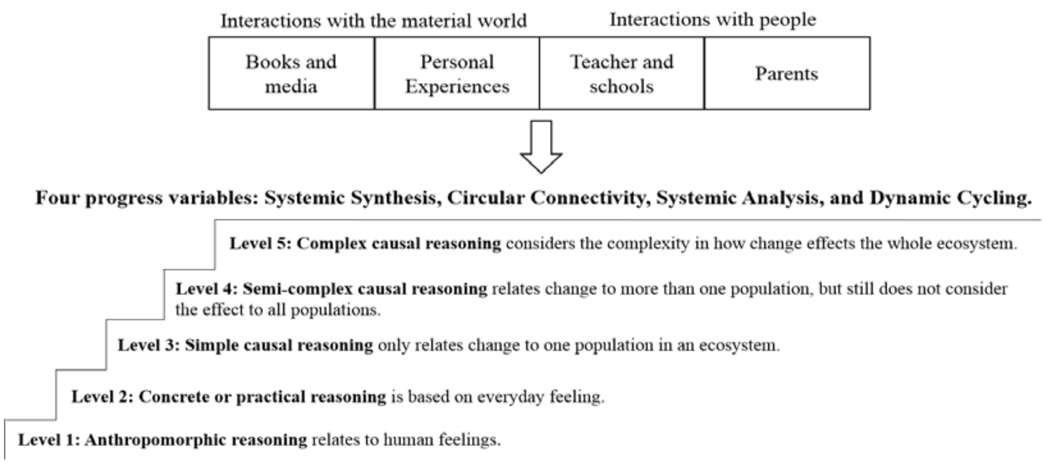

Figure 1. Conceptual framework: Drawing upon knowledge sources to construct reasoning patterns at different levels of the LP

The LP for systemic reasoning in ecosystems. The LP assessed students' reasoning on interdependent relationships in ecosystems, using four progress variables. These progress variables are systemic synthesis, systemic analysis, circular connectivity, and dynamic cycling. The results of the students' responses suggest five general reasoning patterns across the four progress variables. Note that the specific ideas for different variables at a certain level are different, but they all share the same reasoning pattern. We present the levels on one variable in **Table 1**. For more information on the progress variables and levels on the variables, see Hokayem & Gotwals, 2016).

Table 1. The Levels on the Systemic Synthesis Variable

Levels for the Systemic Synthesis Variable	Sample Student Responses to the Question: What would happen if insects were removed from this ecosystem? (The interviewer shows the picture of a pond and forest environment with several populations)
Level 1: *Anthropomorphic reasoning* which relates events to human feelings.	All the friends of the insects will be very sad.
Level 2: *Concrete or practical reasoning* which is based on everyday experiences.	They will disappear, and we will not see them anymore in this nature.
Level 3: Simple causal reasoning which relates a certain change to one population only in the ecosystem.	The frogs will not have food and they will all die.
Level 4: *Semi-complex causal reasoning* which relates the change to more than one population in the ecosystem, but still does not consider the effect on all populations.	The frogs and the small black birds will not have food anymore and will die.
Level 5: *Complex causal reasoning* which considers the complexity in the ecosystem. It relates the change to all other populations across whole ecosystem.	The frogs, the black birds will not have food and this means that snakes which feed on birds will not have food. The big birds and cats will also die because no small birds. Many plants will not be pollinated and the whole environment will be affected

Knowledge Sources. Investigating students' knowledge sources is critical, especially when dealing with young students who have not received formal instruction on a science topic. Strike and Posner (1992) emphasize the importance of "conceptual ecology"—conclusions about student learning should take into account students' beliefs, culture, everyday knowledge, epistemological commitments and even emotional factors. Indeed, 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 Strike and Posner (1992) point out:

> 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" into which human beings are initiated is likely to be reasonable (p. 170).

Investigating students' knowledge sources is important for LP research for two reasons. First, an LP is a cognitive model that capture students' characteristic ways of reasoning, and the knowledge sources provide the contextual information that tell about where those reasoning patterns come from. Kola-Olusanya (2005) notes that "children's knowledge is a product of their interactions" with home life, media, museums, zoos, and nature as examples of free-choice learning (p. 298). These knowledge sources may expand children's reasoning of environmental concepts, including ecosystems. Yardimci and Leblebicioglu (2012) conducted a qualitative study on the impact of a one-week nature camp on fourth and fifth grade students' understanding of nature. Before the camp, students tended to define nature by only biotic components, whereas in post-interview responses, students included both biotic and abiotic components including soil, air, and water. Students' knowledge sources about the environment may relate to their reasoning of ecosystems.

Second, characterizing the knowledge sources may provide useful information for teachers and curriculum developers to develop lessons and instructional approaches that target students' daily experiences. Stern and Roseman (2004) analyzed nine textbooks to determine if they facilitate students' understanding of key ideas on matter and energy and found little support. The textbooks also provided sparse information to teachers regarding students' prior ideas and how to address their misconceptions. Identifying students' knowledge sources may help teachers make connections between their everyday experiences to understanding ecosystem concepts. This may also promote the design of effective inquiry-based curriculum and teaching practices to support students learning. In this study, we specifically focus on students' knowledge sources before any formal instruction about ecosystems, and investigate how students' informal knowledge sources before any formal instruction relate (or not) to their learning progression level.

METHOD

Participants

This study took place in a suburban school in a Midwestern state. During the year when we collected the interview data, the student population in the school was 72% white, 11% Hispanic, 7% African American, 5% Asian, and 5% American Indian, American Hawaiian or a mixture of two races. About 31% students received free or reduced lunch. In the school, 44 students from first through fourth grade participated in our prior study on LP for systemic reasoning (Hokayem & Gotwals, 2016). In this study, we collected additional data from the 44 students and focused on eight of those 44 students to interview their parents as well. We selected two students from each grade. Six students were white American, one student was Asian American, and one student was half white American and half Pakistani. All of the eight students come from the middle class.

Interview Data Collection

Southerland, Smith, and Cummins (2000) discussed the importance of interviews and the wealth of information they provide about student understanding. In this study, we used an interview approach to examine if students' knowledge sources are linked to their reasoning along the learning progression. More specifically, we conducted two rounds of data collection and analysis. In the first round, we interviewed the 44 participating students about their knowledge sources. Based on the data analysis, we selected eight representative cases for the second round of data collection and analysis. We interviewed the teachers who taught the participating students and the parents of those students.

First Round of Data Collection and Analysis

In a prior study, we developed an LP based on interviews with 44 early elementary students (Hokayem & Gotwals, 2016). The interviews focused on students' reasoning of two ecosystem scenarios. One scenario showed students an ecosystem with several populations and asked students to predict what would happen if one population was removed (systemic synthesis), what is the most important element in the ecosystem (systemic analysis), and what happens to the body of organisms when they die (dynamic recycling). Another scenario presented students with pictures representing several populations and required them to choose as many of those such that they could construct a viable ecosystem (circular connectivity). We asked each student about the knowledge sources. In particular, after we finished the discussion about each scenario, we asked the student where the student had learned about the scenario; we also encouraged the student to talk about the experiences with the natural world. When a student explained the scenario in an unexpected way, we always asked the student to explain how the student had learned that information.

When analyzing student interview data, we first read the transcripts and identify the knowledge sources that each student mentioned. Then, we grouped these knowledge sources into seven general categories: media, personal experiences, books, parents, museums, and others. In this process, we checked the teacher interview and parent interview facilitate our interpretation of student interview data. Next, we counted the frequency for each of the knowledge sources for all 44 students.[1] In addition to these knowledge sources, we found that many students referred to learning opportunities with their parents. Therefore, we realized that parents would be an important source of insight concerning student's knowledge sources. To accomplish this, we first discuss the importance of speaking with the teacher to select specific students and their parents for the additional interviews, and then discuss how the parent interviews were conducted.

Second Round of Data Collection and Analysis

Case Selection. The analysis in the first round generated only descriptive results—categories of the knowledge sources that the student draw upon. Therefore, we used "purposive sampling" (Noor, 2008) to select cases for a more in-depth interpretation. We considered the following criteria for selecting cases. First, the cases had to include students at different levels of the LP to allow the analysis of the linkage between the knowledge sources and the reasoning patterns at different levels of the LP. Second, teachers' recommendations helped us to identify students who were at different performance levels and students whose parents were willing to participate. With the teachers' help, we identified students at different performance levels in school science learning (low level, medium level, and high level) and students whose parents were expected to provide

[1] Note that each category was counted once for each student. For example, if a student mentioned TV several times, we counted that as one time for this particular student.

useful information for researchers. Based on the above criteria, we selected three students (one high level student, one medium level student, and one low level student) from each grade. From the perspective of the teachers who taught the students, the parents of these students would provide rich information for their children's experiences. The predominant reasoning patterns of these students cover the whole range of the LP.

Data Collection. We interviewed four female elementary teachers who taught the participating students and used the teacher interview data to validate the information collected from the student interviews. The teacher interview focused on how the participating students might have come up with their ideas. For example, when we found that a student mentioned that she learned a topic from the teacher, we asked the teacher about it. Moreover, knowing that the teachers knew their students well, we consulted with them about specific answers that the students gave.

We interviewed eight family members of students (two from each grade level) whom we interviewed: six mothers, one father, and for one case (first grade male), we interviewed the whole family (mother, father, sister and the student who came all together for the interview). The interviews had questions concerning general activities parents did with their children, the learning style of their children, and the way they see themselves influencing their children's education, specifically in science education. After the general questions, the interviewer then quoted certain sections from the student's interview and asked if they knew how their child got this information. For instance, if a student exhibited knowledge about dinosaurs, then the interviewer would show the response to the parent and probe further about the students' experience. This part was different with each parent depending on what the student said.

Data Analysis. To find out where students obtained their ideas, we identified the different sources mentioned by all 44 students. Then we focused on the eight cases. The first author constructed a profile for each student which included the knowledge sources, what the teacher said about each student, the main points about the students' experience as reported by the parent, and the learning progression level. This served to triangulate information (Yin, 2011, see **Table 2**). Then another researcher examined the interview transcripts and the profile and corroborated the information. Any disagreement was resolved through discussion.

Table 2. Sample of Triangulating Data

Student: Grade 4	Teacher	Parent	Interviewer Comments
Interviewer: Have you read books or movies? *Student*: I watch Animal Planet a lot and I've read a lot of books.	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 we 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.

RESULTS

In this section, we first describe the various knowledge sources and general frequency of those sources, and then we focus on the patterns found in the analysis of the eight cases.

Students' Knowledge Sources

Table 3 presents the frequency of the knowledge sources mentioned by the students during the interviews. In general, most students reported at least 2 knowledge sources as an average. 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* (eight students) and *Animal Planet* (eight students), followed by *Wild Kratts* (four students 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 Chipmunks* at PBS Kids and *National Geographic* channels. Books that were mentioned included *All About Insects* and *Animals of the World,* among others.

Table 3. Knowledge Sources and their Frequency of Occurrence

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

Below, we present three examples of how students used these knowledge sources to explain the ecosystem scenarios.

- Media as a knowledge source: A second grade female was asked what would happen when fish died and she stated, "the owl would have nothing to eat...if there's [a] bear here, it would starve because [a] bear's favorite food is fish." When asked about where she learned that bears eat fish, she stated that she saw it on *National Geographic*, "...they always go on waterfalls and find fish." A second grade male learned about a food chain from *Wild Kratts*. He stated "...It's all about animals like monkeys and about [the] food chain...it's when animals eat other animals." It is worth noting that he understood the basic concept of the food chain.
- Personal Experiences as a knowledge source: A fourth grade student stated "One time I went into the forest and we saw a snake so we were careful." Students had personal experiences (e.g. nature walks in the woods, backyards, or going camping or hunting with one of their parents and relatives) which were ways of learning about ecosystems.
- Museum as a knowledge source: A second grade female student visited a local science museum called *Impression 5* [2] with her class and stated that "she [a staff member] showed us how to make a biosphere and she told us that plants make oxygen." Students reported that museums such as *Impression 5* helped them learn topics related to ecosystems.

Linkage between Knowledge Sources and the LP Levels

We wanted to make a closer examination to determine if students' knowledge sources related to their LP levels. To accomplish this, we focused on eight selected cases out of the 44 students to see if any patterns emerged from the data. When we looked at the eight students' amount of knowledge sources and the levels of the learning progression, we noticed two patterns. One pattern was that students who have fewer knowledge sources tended to have lower LP levels. The other pattern we noticed was that students who had richer knowledge sources tended to have higher learning progression levels. While we cannot establish causation between the knowledge sources and the learning progression levels, we noticed this pattern and therefore grouped the eight students into two groups. The first group included the students whom we could detect a link between their knowledge sources and their high reasoning at the LP spectrum, and the second group included the students whom we could not relate their knowledge sources to their reasoning using our LP.

These patterns should be interpreted with the following considerations: 1) It is hard to find a direct causal relation between students' informal experiences and their learning progression reasoning pattern. The reason lies in the fact that all experiences, learning styles, or parents' influences are too complex to tease apart during one interview. 2) Teacher's evaluation of the students' performance level did not always match the students' most frequent learning progression level of reasoning. 3) It is possible to show the influence of certain knowledge sources of some, but not all students' reasoning levels.

Drawing upon Knowledge Sources

As shown in **Table 4**, four cases, students (Jane, Olinda, George, and Evan) frequently used their knowledge sources to construct explanations for the ecosystem scenarios. These students also tended to achieve a high LP level. Jane's (Grade 4) main source was her extensive reading about the dinosaurs and *Animal Planet*. With Olinda (Grade 4), she also noted watching *Animal Planet*. With George (Grade 2), the main source of information was camps and learning about insects and nature with his dad. Similarly, Evan (Grade 2) knowledge sources were his dad and the *Magic School Bus*. Despite the links revealed during the interviews with students and parents, one cannot say that is it is possible to identify the links to every

[2] *Impression 5* is a science center located in Lansing, Michigan.

Table 4. Students that made connections between Knowledge sources and Systemic Reasoning

Student and Grade	Major source of knowledge as identified by the student and the parent	Student Achievement		Comments on relating the source of information to the students' learning progression average
		Most frequent Learning progression level	Teacher evaluation of performance level	
Jane (Grade 4)	Watching Animal planet and reading non-fiction books about dinosaurs	5	Middle	The connection between what she read about dinosaurs and transferring this knowledge to the interview was clear in several instances during the interview
Olinda (Grade 4)	Watching Animal planet and reading books, especially about dogs	4	High	The connection between Animal Planet was at one instance during the interview but not necessarily in all questions
George (Grade 2)	Nature and science camps, learning with his father about insects during camping	4	Middle	There was a clear relation about what he learned with his father and from camps in many answers
Evan (Grade 1)	Watching Magic School Bus and learning with his father about various science topics	4	High	There was a clear relation between what he learned with his father, the media and the most of the interview answers

response, considering that no student was coded at the same level for all questions. There was also a mixture of responses regarding their learning progression level in relation to their level of achievement (middle or high) perceived by the teacher. Olinda (Grade 4) and Evan (Grade 1) were judged as high achievers and their answers were indeed at a high level during the interview, whereas Jane (Grade 4) and George (Grade 2) were judged as middle achievers by the teacher even though their responses ranked at the higher level of the LP. In the paragraphs that follow, we explain the linkage between knowledge sources and LP levels for these four cases.

Jane (4th Grade): The dinosaur lover. Jane had several knowledge sources about ecosystems, noting that she has observed animals such as "snakes, birds, frogs, and tadpoles" surrounding the lake at her family's vacation cottage. She also discussed how she watched *Animal Planet* and read fact books about animals. Her mother also discussed additional knowledge sources including a dinosaur fact game, *National Geographic* magazines, attending two science camps at *Impression 5*, zoos, and museums (e.g. *Children's Museum of Pittsburgh*, a Cincinnati museum, and the *Field Museum* in Chicago).

During Jane's learning progression interview, she showed a holistic understanding of the ecosystem (mostly level 5 responses). She immediately recognized the food chain in the first scenario which showed the environment with several animal populations. To further probe her understanding, she was asked to think about what might be missing in the picture of the ecosystem:

> *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.
>
> Interviewer: So, it's 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.*

Interviewer: what did you learn about dinosaurs?

Jane: I learned about 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.

Interviewer: Did it affect the environment?

Jane: It affected it very much, after it hit, there was enough smoke to cover up the sun for a 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 were no sun, the whole ecosystem would be affected in a "domino-like" manner. Throughout the interviews with Jane and her mother, it became clear that Jane's reasoning of ecosystems was influenced by these various resources and that her parents encouraged her interest and learning.

Olinda (4th Grade): The dog lover. Olinda had various knowledge sources including media, museums, zoos, aquariums, and books. In particular, she likes dogs and her teacher noted that "she created a poster with picture and various facts about Golden Retrievers." Her mother stated that Olinda had a natural interest in animals and "absorbs" information on this topic.

Olinda's interests, knowledge and experiences were brought to bear on some of her responses. The majority of Olinda's responses showed sophisticated answers (mostly level 4) along the learning progression. She was incorporating some of what she learned from *Animal Planet* in her reasoning about the ecosystem. For example, Olinda was asked what would happen if black birds disappeared. She noted that "there would be more insects and that crocodiles will have diseases" from the lack of birds "coming and cleaning their teeth." She stated that she learned this information from *Animal Planet*, which she watched frequently. Olinda was only one of a few students to consider mutualistic relationships in her reasoning. 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 stated:

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 ate 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 either food or shelter separately. Her combined interests, knowledge, and experiences were transferred to some of her responses.

George (2nd Grade): The insect lover. George had several knowledge sources about ecosystems. In particular, he communicated that he observed insects with his father and kept an insect collection. His father confirmed this, noting how they use a field guide to identify the insects and learn about their basic ecology of where they live and what they eat. His father also discussed George's other knowledge sources:

I care about conservation, so I give him seeds of ideas of how populations interact in an 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 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.*

During the learning progression interview, George exhibited high level responses (mainly level 4 and 5). Several instances during the interview revealed how thought of every element of the ecosystem influenced the whole system. One prominent example was when he was asked what would happen if all insects died and he answered:

> *George:* The plants will die because the bugs help the plants.
>
> Interviewer: How do they help them?
>
> *George:* Some of the flowers have nectars and bees take the nectar so some flowers will die.
>
> Interviewer: Will anything else happen?
>
> *George:* After that, the frogs will probably fie 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.
>
> Interviewer: How do you know all that?
>
> *George:* My dad, nature camp, and teacher.

This information about George showed that he was very involved in science outside of school, specifically from camps and from discourse between him and his father. His responses were clearly related to the learning profession responses, which revealed a high level of thinking about ecosystems for his age.

Evan (1st Grade): The environment lover. In having a conversation with Evan's parents about his knowledge sources, they revealed his knowledge sources include media, research information on the internet, camps, walks, and reading. During the interview, his parents mentioned three times that the main show he watches is *Magic School Bus*. When Evan was asked to describe what would happen to fish when they die, he stated that "fish will disintegrate." His father confirmed that he learned the word "disintegrate" from *Magic School Bus*. Evan's father likes the show because he stated that "*Magic School Bus* is a very good primer to start the conversation about something else." Evan's father fosters additional learning opportunities:

> *Evan's 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 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 the learning progression interview, most of Evan's responses revealed a high level of reasoning (level 4). 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, [and] the crab.
>
> Interviewer: What else would you choose?
>
> *Evan:* Squirrel and all the rest.
>
> Interviewer: 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.

Evan was considering interdependent relationships as he explained how all animals need each other in the ecosystem. Sometimes during the interview, he digressed from the main question, but presented interesting science facts (e.g. he shared facts about seaweed and mentioned how the tree rings can tell the age of a tree). It was intriguing to see his broad knowledge of science including ecosystems. It was clear that Evan expressed high levels of reasoning about ecosystems, and was also engaged in talking about scientific topics.

Table 5. Students with no connection between Knowledge sources and Systemic Reasoning

Student and Grade	Major source of knowledge as identified by the student and the parent	Student Achievement		Comments on relating the source of information to the students' learning progression average
		Most frequent Learning progression level	Teacher evaluation of performance level	
Ron (Grade 3)	Watching Magic School Bus and reading books in general	3	High	There was no clear relation between his knowledge sources and the interview answers
Cory (Grade 3)	Reading about horses	2	High	There was no clear relation between his readings and interview answers
Macy (Grade 2)	Going to zoos and personal observations	2	Middle	There was no clear relation between her experiences and the interview answers
Annie (Grade 1)	Mainly concrete observations of nature	2	High	There was no relation between her experiences and interview answers

Students Who Made No Relationships to Outside Knowledge Sources

Another pattern that was revealed was that the students Ron, Cory, Macy, and Annie did not make connections between their knowledge sources and reasoning about ecosystems (**Table 5**). Moreover, students who were judged as high achievers by the teachers (Ron, Cory, Annie) did not have many of their responses corresponding to the higher levels of the learning progression. Macy (Grade 2) who was judged by the teacher as a middle achiever had low level answers during the interview. This is understandable knowing that the teachers' evaluations were influenced by reading scores and by completing school tasks. We present each case study below.

Ron (3rd Grade): The book worm. Knowledge sources for Ron include museums, science centers, and nature centers (e.g. *Impression 5*, *Ontario Science Center*, and *COSI Science Center*). Ron also regularly watches TV including *Magic School Bus* and *Peep and Big Wide World*, and more recently *Animal Planet*. When Ron was asked about what books he read, he was not specific about book names and nor was his mother. She confirmed his love for reading and described him as a "bookworm" as he "observes and thinks about it mentally," although they do not discuss what he is reading.

During the learning progression interview, Ron had a few answers at levels 4, but mostly at levels 2 and 3. For instance:

> *Ron:* Some of the animals would die, the frog might be extinct, the bird and maybe the fish.
>
> Interviewer: Why?
>
> *Ron:* Because they eat insects, 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 insects 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.
>
> Interviewer: Anything else?
>
> *Ron:* We would get a lot of spiders.
>
> Interviewer: 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 as simple causal reasoning, but at the same time, he was thinking of the practical reasoning of the lack of need for scarecrows. This answer is a mixture of low 1 and 2 levels. 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 that his experiences or readings transferred to high level responses during the interview.

Cory (3rd Grade): The horse lover. Cory's mother indicated that he has a "huge passion for horses; we've got hardcover books about horses that has the terminology and not just fiction." In addition to books on horses, other knowledge sources include, nature walks in the woods, visiting zoos, and media such as *Animal Planet* (although he does not watch it regularly) and the horse movie *Flicka*.

His learning progression answers during the interview were mainly level 2 with few answers at level 3. For instance, when reasoning about the environment Cory, was able to consider the simple feeding relationship of the birds which is level 3, but when asked in a different scenario what would happen if birds died he answered at a level 2: "We wouldn't have birds anymore so we can't see them and that's a bad thing." 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:

> *Cory:* 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 choose the crab because the crab fights with other crabs, once my teacher got crayfish and it died because it fought with another one.
>
> Interviewer: How do you know worms clean other animals?
>
> *Cory:* My dad told me.
>
> Interviewer: Do you know how they might clean animals?
>
> *Cory:* No.

From the interviews with Cory and his mother, it was hard to determine how he drew upon his experiences to answer the interview questions. His experiences with horses were not necessarily supporting his reasoning about the ecosystem as a whole–especially because the interview scenarios did not have horses as one of the populations in the picture.

Macy (2nd Grade): The zoo lover. Macy's knowledge sources included books (e.g. topics on fairies and horses), media through Disney movies such as the *Lion King* (but does not watch many TV shows), and personal experiences such as museums and the zoo. Her mother confirmed this and stated:

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

Macy's learning progression levels were mainly at levels 1 and 2. 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.
>
> Interviewer: Why those?
>
> *Macy:* Because they are all animals and some live on the ground like the 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 aesthetic aspect of the environment for organisms without thinking of the feeding relationships. Similarly, low level responses were shown when asked to predict what would happen if black birds died when she stated, "They can't get babies anymore and no black birds exist anymore and they wouldn't have any more chirping." Although Macy had knowledge sources, they did not support her thinking about ecosystems.

Annie (1st Grade): The grasshopper lover. Annie's knowledge sources include reading (which her parents emphasize), media such as cartoons (but not necessarily about animals), the zoo, museums (e.g. *Field Museum*), nature walks, and observations of nature. Her mother stated that her uncle is an entomologist and gave her grasshoppers to experiment with their food preference. In addition, Annie's parents are high school math teachers so they emphasize math and give her problems to solve in informal settings.

Annie's learning progression levels were mainly at level 2 with a few responses at level 3. For instance, 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 level 2 answer is based on concrete practical experiences that she observed without thinking of other external reasons to how the ecosystem functions. A level 3 response was when she was asked to consider what would happen if all insects died, she recognized that "Some of the animals won't have food so nature dies because they won't have food to survive." Although this response showed sophisticated reasoning of ecosystems, most of Annie's reasoning was based on observational or hands-on experiences with animals. Her personal experiences and knowledge sources did not necessarily translate to higher level reasoning of ecosystems.

DISCUSSION

Implications of Knowledge Sources for Learning Progression Research

The learning progression literature has mainly adopted a cognitive perspective to identifying 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. For example, Alonzo (2010) calls for adopting a discourse approach to the learning progression could help address the challenges of students' inconsistencies and the students' use of everyday language. Lehrer and Schauble (2015) discuss the importance of fine-grained learning progressions that take into consideration a small grain size which provides a detailed road-map for teachers. Such learning progressions should take into consideration students' knowledge sources and background experiences, and potentially aid teachers with resources they can use to support students' conceptual development along the learning progression. This study highlights the importance of such knowledge in understanding certain patterns of reasoning. Therefore, future learning progression studies might find it useful to identify the knowledge sources and experiences in relation to influencing students' conceptual understanding. Even though it is difficult to reach a causal relationship, more studies are needed to examine the combination of cognitive reasoning levels with knowledge sources. This is necessary to move forward with a more complex definition of learning progressions.

Students' Knowledge Sources in Relation to Curriculum and Instructional Materials

The results from students' accounts of their knowledge sources revealed that the media, books they read at home, museums, parents, and personal experiences were 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 to the upper anchor level of 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. Roncone (2002) reports on a case where students who were taught about the solar system using the *Magic School Bus* series retained the information more than 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 retain more information and perform better in solving mathematical problems. 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. 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 as a concrete experience 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. One limitation to this study is that the sample size of students is limited. It is likely that we may not have captured all of the knowledge sources that contributes to students' understanding of ecosystem concepts, including students' misconceptions. Identifying misconceptions is important to support teachers' instruction around students' understanding. Wylie and Ciofalo (2008) worked with teachers on the Diagnostic Items in Mathematics and Science (DIMS) project which uses multiple choice questions to diagnose student misconceptions. They found that teachers were often not aware of the scope of misconceptions that students held, the diagnostic items helped inform their instruction, and also provided them guidance with writing their own diagnostic items to evaluate students' learning. Relating this to learning progressions, future work is needed to identify how knowledge sources may help identify both correct conceptions and misconceptions of science concepts. This may provide teachers with information-rich resources they can use to support their instruction.

Parental 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 for seventh grade student, and similar results were found for eighth and tenth grade students (McNeal, 1999). A major part of the involvement was related to the opportunities that parents provided their children (e.g. 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 on learning the science concepts were not sufficient 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. However, we realize that some students may not obtain additional support from their parents to foster higher level thinking on science concepts. One limitation to this study is that we did not assess how socioeconomic status related to students' access to knowledge sources. Future work might assess how the parents' background relates to the knowledge sources and experiences that influence students' understanding of science concepts. Even though it is not possible for every parent to be a science teacher at home and create intentional learning opportunities for their children, 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 interesting science discovery. 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 their children at home or in school. This strategy can open up the floor for parent's involvement and contribution to their children's science learning.

As a conclusion, this study showed that the knowledge sources of students in our sample mattered in shaping their discourse about the ecosystems. Therefore, more qualitative in-depth studies are needed to help identify the relationship between a specific learning progression level and the learning opportunities. This leads to constructing meaningful learning experiences that begin with students' interests and experiences to support them in developing appropriate scientific understanding.

Disclosure statement

No potential conflict of interest was reported by the authors.

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