Science Education International
Vol. 27, Issue 1, 2016, 117-135

Patterns of Reasoning about Ecological Systemic Reasoning for Early Elementary Students

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ABSTRACT: Systems and system models are recognized as a crosscutting concept in the newly released framework for K-12 science education (NRC [National Research Council], 2012). In previous work, I developed a learning progression for systemic reasoning in ecology at the elementary level. The learning progression captured five levels of students' reasoning patterns across four progress variables—dimensions of ecological systemic reasoning. In this study, I used the rank correlation and qualitative examples to investigate the extent to which students used the same level of reasoning across the various progress variables. The results showed a wide range of students' reasoning patterns, some of which used the same level consistently across the four progress variables, while others did not. The results have practical implications for curriculum and instruction. I recommend using specific strategies to teach each progress variable, and providing students with opportunities to reason within and across the progress variables.

KEY WORDS: Systemic reasoning, Ecosystems, Inconsistent reasoning, Crosscutting concept, Learning progression.

INTRODUCTION

The latest Framework for K-12 science education in the United States identifies ecosystems and their interactions as a core idea in the life sciences:

> The second core idea LS2: Ecosystems: interactions, energy and dynamics explore organisms' interactions with each other and their physical environment. This includes how organisms obtain resources, how they change their environment, how changing their environmental factors affect organisms and ecosystems, how social interaction and group behavior within and between species, and how these factors all combine to determine ecosystem functioning. (National Research Council [NRC)], 2012, p. 140).

In addition to this core idea, the latest framework identifies systems and systems models as a cross-cutting concept that should be considered when dealing with complex systems. Taking the ecosystem as an example, one can find that it

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is a complex system, which has hierarchical levels of organizations. Scientists use systemic reasoning to interpret and analyze complex systems across disciplines. A key characteristic of a complex system is that the properties at the system level are different from the properties and behaviors of its constituent parts (Capra, 1997). Systemic reasoning about ecosystems influences understanding and decision-making about environmental issues (Hogan & Weathers, 2003; Mohan, Chen & Anderson, 2009). Odum (1992) emphasizes the importance of understanding the input and output of matter and energy. For example, a forest influences external factors and is in turn influenced by those factors. Hence, understanding complex systems requires the understanding of how the interactions and relations among the parts of a system give rise to the collective behaviors and patterns at the system scale, and of how the system interacts with its environment. In fact, the *Benchmarks for Scientific Literacy* advocated teaching systemic reasoning:

> 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. (American Association for the Advancement of Science [AAAS], 1993, p. 262).

In a previous study (Hokayem & Gotwals, Accepted), we fused a core idea (ecosystem interactions) and a cross-cutting concept (systems thinking) to construct a five level learning progression across four distinct progress variables for ecological systemic reasoning. In this study, I investigate whether students' responses were consistently at the same level of learning progression for the four progress variables. The research question is: *To what extent do students' use the same level of reasoning across the four variables of the learning progression for ecological systemic reasoning?*

The results of this question have two significant outcomes. First, it enhances the understanding of how students each variable of systemic reasoning concerning ecosystems. Second, it directs educators to propose appropriate instructional methods that support student's reasoning of ecosystems in a systemic manner.

LITERATURE REVIEW

Various empirical studies have investigated students' reasoning about ecosystems. Some studies explored students' reasoning patterns and misconceptions about species interactions in ecosystems at the middle or high school level (e.g., Alexander, 1982; Barman et al., 1995; Gallegos et al. 1994; Hogan 2000; Griffith & Grant, 1985; Web & Glott 1990; White, 2000). In those studies, students participated in interviews or written assessments about the effects of changing one population on other populations in the ecosystem. The studies uncovered that students tended to recognize simple predator-prey relationships, but ignored other relationships. Other studies considered other ecosystem concepts such as matter recycling in the ecosystem. Hogan and Fisherkeller (1996) investigated 5th and 6th graders' reasoning of various concepts (nutrient cycling, food webs, and decomposition), and noticed that students did not recognize that carbon is recycled in the ecosystem. Most of above studies focused on only one aspect of the understanding of ecosystems (either matter recycling or predator prey relationships), and did not examine the consistency of students' reasoning across various concepts. In this study, we plan to contribute to this literature by exploring the consistency of students' ideas across several key ecosystem concepts that we address in our conceptual framework below.

Systemic reasoning is important for understanding complex systems. Bertalanffy (1968) is the first to advocate studying systems as a whole. He explains that systems have complex organizations that originate from emergent properties. Bertalanffy's approach calls for a holistic instead of an analytic method when dealing with systems: Rather than analyzing the mechanisms of how each element of the system works, Bertalanffy calls for identifying the emergent property that arises from various interactions of the different systemic elements. This means that when considering a system, one ought to recognize the complexity that emerges from its elements rather than studying each of its elements in isolation.

Empirical research on teaching and learning of systemic reasoning has given mixed results. While some researchers thought that reasoning systemically is difficult for middle, high, and even college students (Sweeny & Sterman, 2007; Raia, 2008), others provided evidence that explicit teaching could improve students' ability to think systemically even for elementary students (Roberts, 1978; Plate, 2010). However, research investigating systemic reasoning of lower elementary students remained sparse. To address this research gap, this study targets lower elementary students. It investigates the consistency of students' systemic reasoning in ecology before students receive any formal instruction about the topic of ecosystems.

Conceptual Framework

The conceptual framework for this study uses a learning progression for systemic reasoning. The National Research Council [NRC] (2007) define learning progressions as:

> "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)

A learning progression describes student development in terms of progress variables and achievement levels. A progress variable is a representation of the knowledge, skills, and other competencies one wishes to increase through the learning activities associated with a curriculum (Wilson & Sloane, 2000). Each progress variable contains a sequence of achievement levels that describe increasingly sophisticated ways of reasoning or thinking.

Chandler and Boutilier (1992) identified four properties of systemic reasoning. Since these four properties reflect the four dimensions of scientific reasoning about complex systems, I adopted them as the progress variables for ecological systemic reasoning:

- *Systemic Synthesis* refers to recognizing that all elements of the ecosystem are connected. If one element in the system is disturbed, it affects all other elements. For example, if the top predator is removed, the whole food web will be affected and could significantly influence the producers.
- *Systemic analysis* refers to identifying the essential elements of an ecosystem without which the ecosystem will collapse. Even though a change in any element of the system influences other elements, the changes of essential elements are more crucial. For example, the sun and producers are essential elements for complex ecosystems.
- *Circular connectivity* refers to constructing a complex ecosystem using constituent elements and identifying various feedback loop connections. For example, when asking students to construct an ecosystem from scratch, I checked if students include the various feeding relationships in their choice.
- *Dynamic recycling* refers to matter recycling within the ecosystem and connecting the ecosystem and the outside environment. For example, when an animal dies, it decomposes and matter such as carbon and nitrogen are recycled into the environment.

In a previous study (Hokayem & Gotwals, Accepted), we have constructed a fine-grained learning progression for ecological systemic reasoning. The learning progression contains five levels of reasoning patterns for students from first through fourth grade:

- *Level 1. Anthropomorphic reasoning.* Students explain ecosystem interactions based on personal feelings or characteristics and aesthetic beauty. (Example: If insects die, we will be sad.)
- *Level 2. Concrete or practical reasoning.* Students explain ecosystem interactions in terms of physical rather than psychological reasons, but their explanations are primarily descriptions of everyday experiences, which do not contain a causal mechanism. (Example: If insects die, we will not see them anymore.)

- *Level 3. Simple causal reasoning.* Students identify a physical factor that influences or is influenced by an event. However, students' explanations are based on a simple cause-effect chain, which does not take into consideration indirect causes or effects within the ecosystem. (Example: If insects die, the frogs will not have food and die.)
- *Level 4. Semi-Complex causal reasoning.* Students identify multiple causes and effects in an ecosystem and provide causal explanations about the relations among them. (Example: If insects die, the frogs will die, and plants will not be pollinated.)
- *Level 5. Complex causal reasoning.* Students identify the network of relationships and recognize the complexity of the ecosystem. (Example: If insects die, the frogs will die, and the birds will die, and, this means there is no food for the top predator birds so all the system will be affected.)

Despite a fine grained categorization of the levels for all the progress variables, an important question which remained unanswered in the previous work was: To what extent do students' use the same level of reasoning across the different progress variables of systemic reasoning? This question is important to: 1) determine whether students could recognize the systemic nature of the ecosystem across all variables, 2) recommend specific instructional techniques to support students' learning of ecosystems in a systemic manner.

METHODOLOGY

Participants and their Background Knowledge about Ecosystems

The participants in this study were 44 students (20 males and 24 females) from first through fourth grades who attended a Mid-Western public elementary school. The study included 12 students in each of first and second grades, and ten students in each of third and fourth grades.

Knowing that a major knowledge source is the school, I investigated what students learned about life science in their school. I found that the school used the Battle Creek Curriculum[†] for science. This curriculum has one life science unit for each grade level: life cycle for animals at first grade, plants' needs for growth at second grade, classification of animals at third grade, and organisms and their environment at fourth grade.

Having an assigned curriculum, does not always mean that teachers' follow it literally. Therefore, my conversations with teachers showed that teachers spend a maximum of two -40 minute-periods of teaching science per week due to the

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[†] The Battle Creek Science curriculum is provided by the Battle Creek Area for math and science that provides materials for the improvement of Science and Mathematics in Mid-Michigan. More information about this center can be found at https://www.bcamsc.org/

pressure of teaching more reading and mathematics. Moreover, the curriculum is supposed to cover ecosystem interactions and transfer of energy and matter at fourth grade, but the fourth grade teacher told me that she did not have enough time to cover this topic. This means that the participants' knowledge concerning ecosystem was solely informal. This fit the purpose of the study, which was to understand how students reason about the ecosystem before any formal instruction, thus, allowing to better capture their ideas and think how to build effective instruction at a very young age.

Data Sources

Due to the young age of students (ages six through ten), I used semi-structured interviews to collect data which were better suited to probe younger students' reasoning (Southerland, 2000; Stromen, 1995). I used questions about two scenarios to examine students' reasoning for the four progress variables of systemic reasoning. In the first scenario, I provided students with a picture of a forest ecosystem that has various animal and plant populations. I then asked students questions targeting three variables: systemic synthesis, systemic analysis, and dynamic recycling. In the second scenario, I gave students pictures of animals and plants. I then asked the students to choose as many animal or plant populations as possible to construct a sustainable environment for a long period of time. The questions about this scenario target the circular connectivity variable. This task was revised from an interview task designed by Leach, Driver, and Scott (1995).

I used an iterative process to continuously revise the interview questions. Table 1 presents the final version of the questions for the four progress variables, which was used to collect the data reported in this article.

Data analysis

After developing the learning progression levels, I developed a coding scheme based on those levels. I used the coding scheme to score students' responses at different levels of the learning progression. When students reasoned at different levels within one question, I chose the higher level as the final score.

The score therefore indicates the highest level that the students were able to achieve in the course of interview. The following is an example for the systemic synthesis variable:

I: What would happen if all black birds died?

S32G2F[‡]: Then there will be more spiders because they eat spiders, and this will hurt us because spiders can bite people, I hate spiders.

[‡] S# refers to student number (e.g. S32 refers to student number 32), G# refers to grade level (e.g., G2 refers to grade 2), F (gender so F is for female and M is for male).

The above example can be scored at two different levels. It can be scored as level 3 because the student recognizes that spiders will increase in number due to the absence of predator. It can also be scored as level 1 because the student reasoned in terms of human's feeling (i.e., dislike to spiders). Because the student recognized the effect of one population (i.e., the black birds) on another population that has direct connection with that population (i.e., spiders), I scored her responses as a level 3. I had several rounds of revising the coding scheme, whereby I fused and split levels (Shea & Duncan, 2012) to arrive at the final learning progression. For a more detailed discussion of the iterative coding process see Hokayem, Gotwals & Weinburgh (2014).

Table 1 Progress variables and sample questions

Progress Variable	Sample Questions
Systemic synthesis: Recognizing the effect of changing specific populations on others food web.	What would happen if all insects died? **(Insect SS)**[§] What would happen if all the foxes died**? (Fox SS)** What would happen if all plants died? **(Plants SS)** What would happen if all black birds died? **(Birds SS)** What would happen if a poison was sprayed on the grounds that killed insects? **(Poison SS)**
Systemic Analysis: Identifying the importance of producers and sunlight energy.	What is the most important element in this picture of the environment? **(Most imp SA)** Do you think anything is missing from this environment? (Note that the sun was not depicted in the picture we gave them). **(Missing SA)**
Circular connectivity: Constructing an interconnected food web	Each of those pictures represents a population. Given that in a certain environment you have air, water, soil and sun, choose as many of those pictures as you like to make up an ecosystem that lasts for long period of time. Why did you choose those? And why did you leave out the others? **(Pic CC)**
Dynamic recycling: Recognizing matter recycling through decomposition	What happens to the fox's body after a week from its death? After 6 months? After a year? **(Fox DR)** What happens to the fish's body after a week from its death? After 6 months? After a year? **(Fish DR)** What happens to the mouse's body after a week from its death? After 6 months? After a year? **(Mouse DR)** What happens to the grass after a week from its death? After 6 months? After a year? **(Grass DR)**

[§] All bolded in Table 1 are the abbreviations representing each question used in the correlation tables and bar graphs in the results

The learning progression levels across the four progress variables resulting from the above analysis were reported in Hokayem and Gotwals (Accepted). In the present study, I focused on patterns regarding students' consistency in using the same level of reasoning. I performed correlation analysis of students' levels across the four progress variables (Cohen et al., 2003), and within the systemic synthesis and dynamic recycling progress variables. As shown in Table 1, the interview contains 13 questions. One question was used to assess the circular connectivity variable. Two questions were used to assess the systemic analysis variable. Six questions were used to assess the systemic synthesis variable. Four questions were used to assess the dynamic recycling variable. I performed Cronbach alpha to examine the consistency across questions within a variable and consistency across all questions. The result affected the follow-up correlation analysis. For the systemic analysis variable, the Cronbach alpha analysis was low (α=0.150), suggesting that the questions within the variable are to a certain degree independent and should be considered separately. The Cronbach alpha for the systemic synthesis question set (α =0.725) and the dynamic recycling question set (α = 0.702) were high, suggesting high consistency across questions within each variable. Therefore, for each of these two variables, I used average scores of responses to different questions for the follow-up correlation analysis.

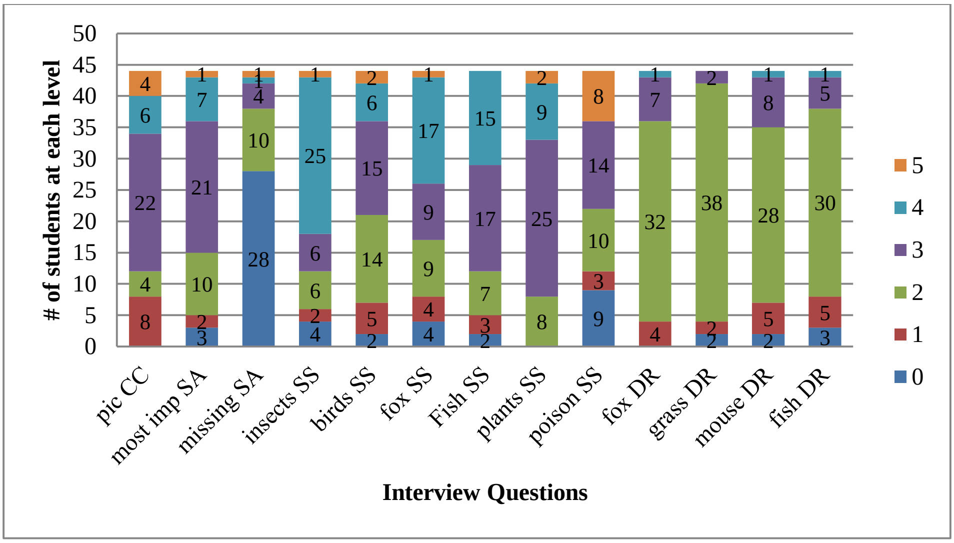
Next, I used the constant comparative method (Straus & Corbin, 1998) to identify a qualitative case, where a student used the same level of reasoning consistently and across the variables progress variables; and cases, where students were inconsistent across progress variables.

RESULTS

In this section, I first report the frequency of each level in the interview data followed by the correlations analysis results across and within the different progress variables. Then, I provide two qualitative examples, one representing students who answered at the same level of reasoning for all progress variables, and another representing those who had responses of different reasoning levels across the progress variables.

Frequency of Levels in the Data

The distribution of the levels in the interview data is represented in Figure 1. In students' responses, the low levels such as Level 1 and Level 2 are the most frequent levels, while Level 5 is the least frequent level. In addition, students did not provide any Level 5 responses to the dynamic recycling questions, and Level 4 appeared more frequently in responses about the systemic synthesis variable than those in other variables. Next, I describe the patterns to which students' used a certain level of reasoning within each progress variable. For each progress variable, I first describe the most frequent levels, and then provide qualitative excerpts regarding the responses to different questions/parts within the variable.



Level	pic CC	most imp SA	missing SA	insects SS	birds SS	fox SS	Fish SS	plants SS	poison SS	fox DR	grass DR	mouse DR	fish DR
5	4	1	1	1	2	1		2	8				
4	6	7	1	25	6	17	15	9		1		1	1
3	22	21	4	6	15	9	17	25	14	7	2	8	5
2	4	10	10	6	14	9	7	8	10	32	38	28	30
1	8	2		2	5	4	3		3	4	2	5	5
0		3	28	4	2	4	2		9		2	2	3

Figure 1 **Distribution of learning progression levels for all questions.**

Circular connectivity. Only one question was used to assess the circular connectivity variable (selecting animal/plant populations to construct an ecosystem). As shown in Figure 1, Level 3, where students were able to identify either habitat or feeding relationships as an essential factor in an ecosystem, appeared most frequently in the interview data. A close examination of students' explanations of different populations suggests that the majority students' responses chose the producers as a source of shelter and/or food. For example, 34 students chose trees because trees can provide food and/or shelter. S4G4F's response illustrates this pattern. He explained, "We need a lot trees for animals to live and eat like birds, squirrels and rabbits."

Systemic analysis. Two questions were used to assess the systemic analysis variable. For the question that required students to think of the most important part of the system, Level 3 responses, which meant that students identified a logical reason for their choice of the most important without it relying on the energy, appeared most frequently. A closer inspection of students' responses to this question suggests three qualitative patterns. *First*, 25 out of 44 students identified plants as the most important element (Level 3). A common reason provided by students was that plants gave food, oxygen, or shelter for animals. For example, S5G4M explained, "Plants are the most important because they give us oxygen and they are food for animals." *Second,* 3 out of 44 students recognized the importance of the sun in helping plants make their food (Level 3). For example, S35G1F said, "I think the most important is the sun because it makes plants grow and plants give food." *Third,* the rest of the responses identified other populations as the most important in an ecosystem (Levels 1, or 2). Some responses in this group provided anthropomorphic reasons such as strength. For example, S43G1F said, “The most important is the fox because it is very strong”. Other responses specified reasoning such as the requirement for keeping insect population down. For example, S31G2M said, “The most important are frogs because they eat bugs.” In summary, although many students mentioned the “plants” and the “sun” as important, their reasoning did not recognize them as essential elements without which the whole ecosystem will collapse.

For the question that required students to think if there was anything missing in the picture, Level 0 responses, which did not recognize anything missing from the ecosystem, appeared most frequently. A close examination of students’ responses shows that 28 students did not think that anything was missing. The responses from the rest of the students included the following. Five students stated that the sun was missing and its importance lay in giving warmth (Level 2). Two students stated that the clouds were missing and their importance lay in being part of nature (Level 3). Five students stated that more food and shelter were missing for the animals (Level2). Three students stated that rocks or water were missing because the frogs needed them (Level 2). Only one student mentioned the importance of the sun as the primary source of energy, without which the system collapses (Level5). As one can see, the majority students did not recognize the sun as an essential element for ecosystems.

Systemic synthesis. Six questions were used to assess the systemic synthesis progress variable. Two questions asked students to predict what would happen if a population disappeared (i.e., the insects or foxes died). For these two questions, Level 4 responses, which meant that students thought of more than one population being influenced by the change, appeared most frequently (An example is shown in Table 7). For the other three questions, Level 3 responses, which meant students thought of only one population being affected by the change, appeared most frequently. An example was a response to what would happen if black birds disappeared: S6G4M “Wild cats won’t be able to get some food.” Note that no Level 5 responses were found for the question about the fish population dying.

Dynamic recycling. Four questions were used to assess the dynamic recycling variable. The questions were about where the matter went when organisms die. For this variable, Level 2 which was just a description of what they might have seen in real life appeared most frequently. For example, when asked what would happen to the body of the fox when it died, S3G4F said: “Fox, it will be skinnier and drowsier and start dissolving in the ground, like if there’s rain and storm it will get saggy and fall apart and other animals like possum rats, birds and flies will come and eat him.” In addition, no level 5 responses were found for any of the three questions.

Correlations

I calculated correlations across the four progress variables. The results are presented in Table 2. As elaborated in the methods section, I calculated correlations based on the results of Cronbach alpha analysis. In particular, I treated the two questions within the systemic analysis variable separately

(MostimpSA and Miss SA) due to low alpha between the questions. I used average scores of the responses to the six questions within the systemic synthesis variable due to the high consistency of responses across the questions (SS Average). I also used average scores of the responses to the four questions within the dynamic recycling variable due to the high consistency of responses across the questions (DR Average). The circular connectivity only contained one question (PicCC).

Table 2 Correlations across systemic reasoning progress variables (N=44)

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

* Correlation is significant at p ≤ 0.05 level (2-tailed).

** Correlation is significant at p≤ 0.01 level (2-tailed).

The results revealed a modest positive correlation between systemic synthesis variable and the other three variables: circular connectivity (r=0.331; p<0.05), systemic analysis (r=0.416; p<0.01), and dynamic recycling (r=0.435; p<0.01). Moreover, the question concerning what was missing in the picture (MissSA) had a modest positive correlation with the questions within the dynamic recycling variable (r=0.329; p<0.01). The above evidence suggests a weak correlation among some progress variables indicating that the variables are independent.

The systemic synthesis variable contained five questions. Therefore, I performed a correlation analysis within this variable. The results are provided in Table 3.

Table 3 Correlation within systemic synthesis progress variable (N=44)

	Insects SS	BirdsSS	FoxSS	FishSS	Plants SS	PoisonSS
InsectsSS	1	.433(**)	.292	.500(**)	.303(*)	.476(**)
BirdsSS		1	.541(**)	.417(**)	.458(**)	.302(*)
FoxSS			1	**.211**	.415(**)	.182
FishSS				1	.554(**)	.409(**)
PlantsSS					1	.493(**)

* Correlation is significant at p ≤ 0.05 level (2-tailed).

** Correlation is significant at p≤ 0.01 level (2-tailed).

The results suggest a modest correlation among most of the questions. However, the question about fox (FoxSS) had a low correlation with the question about insect (InsectsSS) and the question about poison (PoisonSS). Moreover, the highest correlation was between the question about the fish (FishSS) and the question about the plants (PlantsSS): $r=0.500$; $p<0.01$.

The dynamic recycling variable contained four questions. Therefore, I performed correlation analysis within this variable. The results are presented in Table 4. There was a low correlation between the question about grass (GrassDR) and the question about fox (FoxDR) or the question about fish (FishDR). However, there was a high correlation between the question about fox (FoxDR) and the question about mouse (Mouse DR): $r=0.758$; $p<0.01$.

Table 4 Correlation within dynamic recycling progress Variable (N=44)

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

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

Consistency of Reasoning within Questions for Each Student

I also examined students' consistency within interview questions for each student. I constructed a table that showed the consistency of students' responses within each of the 13 interview questions.

Table 5 Sample of four students' consistency of responses[**]

Student/ Most frequent level	Q 1	Q 2	Q 3	Q 4	Q 5	Q 6	Q 7	Q 8	Q 9	Q 10	Q 11	Q 12	Q 13
S1G4M (3)	0	0	**-2**	**1**	0	**-2**	0	0	**2**	**-1**	**-1**	**-1**	**1**
S11G3 F (2)	**-1**	**-1**	**-2**	**-2**	0	0	0	**1**	**-2**	0	0	0	0
S36G1M (4)	**1**	0	**-2**	0	0	0	0	0	0	0	**-2**	**-2**	**-2**

When responding to interview questions, the results showed different levels for different questions. Similar to Jin (2010), I used "the most frequent level" in one student's responses as the baseline (labeled as a "0"). If a student also provided a response at a different level, the difference is captured by a number. For example, if the most frequent level is 2, then any responses at level 2 will be

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

counted as the baseline “0”. Level 3 responses will result in a difference as “1”. Level 1 responses will result in a difference of “-1”. Table 5 shows an example of the score difference for three students.

Next, I calculated the percentages of baseline responses. The results showed that 49.65% responses were consistently at a certain level, indicating that almost half of the students’ responses used the same level of reasoning across all interview questions. When examining the consistency across the six systemic synthesis questions alone, 58.85% had the same level of responses. The frequency of the same level of responses for the four dynamic recycling questions alone was 82.95%. This method of analysis was consistent with the correlations analysis because that highest correlation indicating same level of responses was for the dynamic recycling progress variable followed by the systemic synthesis variable. It is also consistent with the correlations across all variables because the correlation across variables was modest and so is the consistency in this analysis of approximately 50% responses being at a certain level.

Examples of Consistency Patterns

The quantitative results suggest that some used the same level of reasoning across the various progress variables while others did not. To illustrate this with qualitative examples, Table 6 provides an example of a student using the same level of response across the four progress variables.

As shown in Table 6, the student was consistently using simple causal reasoning (Level 3) to identify a physical factor that influences the ecosystem.

Despite some responses using the same level of reasoning consistently, many students provided responses of inconsistent level of reasoning across the various progress variables. Table 7 shows an example of inconsistent responses.

As shown in Table 7, the student reasoned at different levels across the four progress variables. Whereas he was able to think of one or more factors which influence the change in the ecosystem (Level 3 or 4), his reasoning was still at an anthropomorphic level (Level 1) when it came to the dynamic recycling variable (i.e., decomposition).

Summary of the Results

Overall the results showed three patterns. First, the majority of responses fell within the middle levels. Second, the consistency of the students’ responses using the same level of reasoning across progress variables was moderate as shown by the modest correlations and by the consistency table. Third, the consistency of students’ responses using the same level of reasoning within the systemic synthesis and dynamic recycling variables was higher than across general variables, with questions within the dynamic recycling variable showing the highest correlation.

Table 6 Example of one student using same level of reasoning across responses S12G3M

Systemic synthesis: 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
S: Then the frogs will die because they have nothing to eat.	S: Trees and plants because they help you breathe.	S: I would choose the trees because trees make oxygen and if there were 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 be here, centipedes are under the ground.	S: It will disintegrate because the sun shines on it.
Level 3 because he is thinking of one population directly related to the insects.	Level 3 because he is considering one reason for the importance of plants.	Level 3 because he is considering the habitat as the main reason for choosing the populations.	Level 3 because the he is thinking of one factor for disintegration.

Table 7 Example of one student using different levels of reasoning across responses S14G3M

Systemic synthesis: 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
S: 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.	S: Plants because without plants the fox will have nowhere to hide.	S: 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.	S: His family would bury him and they will be sad.
Level 4 because he is considering several populations that feed on the insects.	Level 3 because he's considering plants as shelter.	Level 4 because he is considering the habitat and the feeding relations as reasons to construct the environment.	Level 1 because he is considering anthropomorphic reasoning.

DISCUSSION AND CONCLUSION

As mentioned earlier, the significance of investigating students' consistency of responses has implications for an in-depth understanding of students' reasoning across each progress variable dimension of the learning progression, and for envisioning proper curriculum and instruction for ecological systemic reasoning.

The results show modest correlations across and within the progress variables in addition to most responses falling within the middle levels. This implies that students often reason about different questions in a fragmented rather than a coherent manner, and have not yet reached the complete scientific understanding for each variable. Below I discuss the results for each progress variable, and the recommended instructional strategies that support students' scientific reasoning for each variable.

For the systemic synthesis variable, 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 the question 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. Most probably, students think of some populations behaving in a similar manner depending on how many food chains it participates in. For example, the results showed that birds were correlated to foxes, fishes, insects and plants. This was similar for the plants, where the responses concerning the plants were moderately correlated with all other populations. However, the fox did not participate 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 using the same level responses within this progress variable, 59% of responses had consistent levels. This leads one to think that the more students knew about a set of populations, the more similar they reasoned about them, and that could explain why the consistency was high for some questions but not for others. Gotwals and Songer (2010) found similar inconsistencies when they asked students about various populations in the food chain. Knowing that the participants of this study did not have formal instruction about ecosystems, students' informal knowledge is yet another factor that could influence the inconsistency of students' reasoning. Hokayem (2012) showed that the students had various experiences with regard to different ecosystem concepts, which might lead to different ideas about ecosystems. For example, a student whose father was a scientist had vast amount of knowledge about insects, and that made his response at a level 5 with regard to the insect question. However, his responses regarding other populations were at low levels of 2 or 3. Therefore, an instructional recommendation would be to provide more background knowledge about the various populations of the food web. This increases the chance of having consistent higher level reasoning of the systemic synthesis questions.

For the dynamic recycling variable, the strongest correlation was between the question about the fox and the question about the mouse. This is not surprising knowing that the fox and the mouse were both terrestrial animals, and therefore students expected the same thing would happen to both bodies once they were dead. There was a modest correlation between the question about the mouse and the question about the grass. Similarly, a modest correlation was found between the question concerning the fish and that concerning the grass. However, there was no correlation between the question about the grass and the question about the fox. In many responses concerning the grass, the students said that the grass dried up, changed color and was blown away by the wind. Therefore, they did not treat the grass similar to other living organisms where it could also decay. This might be related to students' everyday experiences of observing that grass dries up, while dead bodies of animals' rot. Moreover, the consistency of students' reasoning within the dynamic recycling variable was the highest (82.95%). Similar pattern was found in Jin (2010), where students' accounts of carbon transformation across various types of interview questions were around 80%. This suggests that students need opportunities to relate macroscopic phenomenon (what they see as decay or rot) to microscopic phenomenon (carbon recycling).

With regard to the systemic analysis variable, there were two questions which were considered separately and the responses fell more frequently at the lower end of the learning progression level, but were qualitatively different. However, a common pattern was that very few students considered the correct reason behind choosing plants or the sun as essential elements of the ecosystem. Hence, we recommend explicit emphasis on the role of producers and the sun as the foundations without which the whole ecosystem will collapse. Modeling the extent of disturbance of various elements of the ecosystem would be an appropriate method to emphasize which elements are more crucial. Whether using a play model (Grotzer & Bell, 2003), or computer simulation models (Evagorou, Korfiatis, & Nicoloaue, 2009) to illustrate the extent of influence a change of a certain population causes, students will have a chance to construct appropriate scientific knowledge of distinguishing essential from non-essential elements of the system.

With regard to the circular connectivity variable, half of the students' responses were at level 3, which means that the students either recognized habitat as a reason for constructing an ecosystem, or recognized food in a simple predator prey relationship. Lehrer and Schauble (2012) also found similar results, that is, habitat and simple food relationships were among the primary emerging concepts when investigating students' modeling practice in ecology. Moreover, previous analysis of this question showed that students had mixed-level reasoning responses. This means that half of the students' responses used two levels of reasoning simultaneously when answering the question (Hokayem & Gotwals, Accepted). Knowing that this open question required students to construct rather than analyze an ecosystem, one could say that it required a different kind of reasoning; that is, it may lead students in different directions (e.g. habitat, food, predator-prey relationships, or complex food web) to answer this question. Therefore, two instructional techniques might be helpful to support students' consistent scientific reasoning about circular connectivity. First teachers could explicitly draw students' attention to the importance of feeding relationship among populations in supporting a viable ecosystem. Second, teachers could support students' small and whole group discussion about the viability of their constructed ecosystem when compared to the already natural ecosystems such as a pond or a forest.

In general, this analysis concerning the consistent or inconsistent levels of reasoning and the kinds of students' responses across the progress variables suggests two implications for curriculum and instruction. *Firs*t, despite the young age of the students, the results showed that some of them demonstrated high level reasoning for some progress variables for systemic reasoning. This suggests that explicit teaching of systemic reasoning could lead to productive learning. In current school science in the United States, topics such as population interactions, and the importance of all the elements of an ecosystem in preserving biodiversity are usually introduced at the middle school level. Those results call for innovative instructions to introduce these topics to elementary students through focusing on each of the four progress variables. For example, capitalizing on students' informal knowledge from the media, or inviting expert parents about the topic are ways to guide students towards the desired scientific concepts (Hokayem, 2012). *Second*, the results suggest that students' reasoning level is to a certain degree inconsistent across the four progress variables of systemic reasoning. In particular, a student reasoning at a high level when reasoning about the effect of removing the herbivores from the ecosystem (systemic synthesis variable) may reason at a much lower level when explaining what happens when the mouse dies (dynamic recycling variable). This calls for more explicit instruction on the connections among the progress variables. Students need various opportunities (e.g. using museums, media programs such as Animal Planet, natural and virtual ecological laboratories) to learn about each progress variables and also to make connections among those variables.

ACKNOWLEDGEMENT

I would like to thank Dr. Hui Jin for her feedback on an earlier version of this manuscript. Her comments were extremely helpful in shaping the final version.

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