# Addressing the Challenges in Understanding Ecosystems: Classroom Studies

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## ABSTRACT

Research shows that students have difficulty achieving understanding of many fundamental ecosystems concepts. Our previous research demonstrated that focusing on the underlying causal patterns (e.g. Grotzer, 1989; 1993; Grotzer, Donis, & Bell, 2000; Grotzer & Basca, 2003) can further students' understanding of the concepts. This paper reports on qualitative classroom research carried out in five sixth grades while teachers taught a unit focused on the underlying causal patterns to address the kinds of difficulties that students typically have. The research investigated students understanding before, during, and after learning. Additional materials were designed to surmount particular difficulties as they arose in students' learning. The paper analyzes data collected from pre- and post interviews, written assessments, class discussions, in-class responses and drawings. We identified difficulties that students had in understanding passive energy transfer, connectedness in the food web, matter recycling, and the role of microbes in decay—many of these consistent with those found in earlier research. As we attempted to address these, students made progress in their understanding, but encountered new challenges in relation to how they viewed the connectedness of food web, conservation of matter, and the dynamics of balance and flux. Teachers' reflections on their attempts to teach the concepts through simulation activities and other classroom activities suggest that some concepts are more difficult to learn in the classroom than others. We discuss the implications for the findings, including the idea that simulated computer environments might offer affordances that make them a useful resource in teaching the concepts.

## INTRODUCTION

### Background:

*Difficulties in Understanding Ecosystems Concepts.* Content knowledge about ecosystems and populations is an important strand of the life science content standards, and the processes underlying ecosystems exemplify sophisticated causal mechanisms (e.g., systems dynamics) foundational for advanced science and mathematics. However, even after instruction, students often hold inaccurate interpretations about ecosystems' structural patterns and systemic causality.

There is some growth in students' understanding of ecosystems concepts as students get older. Still, there are many persistent misconceptions that older students reveal as well as younger students, and these misconceptions impact how they understand and model ecosystems relationships. For instance, young students tend to focus on simple, direct, one-step connections in the food web; older students often focus on these one-step connections as well. For example, children may realize that green plants are important to the primary consumers (Grotzer, 1989). However, they may not recognize extended effects such as the effects on secondary and tertiary consumers if there were no green plants (e.g. Griffiths & Grant, 1985; Grotzer, 1989, 1993; Webb & Boltt, 1990). By ages ten and eleven, students are beginning to realize some of the more complex, less direct connections of food web relationships and will often speak in terms of these larger principles. They can typically apply these large-scale principles to individual relationships and can recognize extended effects in food-chain relationships (Grotzer, 1989). However, these students may still overlook key ideas such as our critical connection to the sun and the important role of green plants.

Young children find it difficult to think in general terms about the roles animals play within ecosystems: they tend to reason about effects on individual animals, not on populations of animals (Leach, Driver, Scott, & Wood-Robinson, 1997). While the concept of populations of organisms in the wild is established in children older than age 13, students still tend to focus on individual animals: students' reasoning about relationships are often descriptions such as 'birds live in trees' or 'foxes eat rabbits' (Leach et al., 1997), rather than an ability to reason well about how populations depend upon each other and compete with one another. The concept that animals compete for resources is not considered by students until a much later age. Reasoning about population level effects involves not only moving beyond reasoning from one's own perspective, it also involves reasoning about multiple interacting organisms which presents a problem of cognitive load.

Students are often unaware of the role of decomposers and think that "things just deteriorate" or "break down." After learning about decomposers, they tend to focus on obvious decomposers, eventually learning about non-obvious decomposers (e.g. Hogan, 1994). Middle-school aged children are aware that some kind of cyclical process takes place in ecosystems, but think of the process of matter recycling in terms of sequences of direct cause and effect events: they think matter is either created or destroyed and then the sequence starts over again (e.g. Bell, Grotzer, Donis, & Shaw, 2000). Even when students are aware of the role of microbes, they still don't realize just how critical microbes are to the process of matter recycling and how matter recycling is important in making elements available for new life forms.

*Focusing on the Underlying Causal Structures.* Elsewhere Grotzer and colleagues have argued for focusing on underlying causal structures when teaching science (e.g. Grotzer, 2000; Grotzer, 2004; Perkins & Grotzer, 2005).Given the information that is perceptually available to us and our tendencies towards efficiency, people tend to make limiting assumptions about the nature of the causality that structures their explanations. Students make a number of default assumptions that simplify the underlying causality (for instance, that it is linear, direct, sequential, intentional, and so forth (as elaborated in Grotzer, 2004. See Table 1.) These assumptions can distort science concepts. For example, many students use linear causal, force models to explain air pressure-related phenomenon instead of relational causal models—where the differential between the pressures accounts for an outcome (Basca & Grotzer, 2001)—limiting other understandings such as weather patterns, how planes fly, and how straws and syringes work. This work argues for teaching students about the patterns and features of the underlying causality that structures concepts that they are learning. Here, causal patterns refer to the forms of causal interaction, for instance, linear, cyclic, mutual or relational forms of causality. Features refers to characteristics that describe the dimensions of different causal patterns, such as how causes and effects behave over time (sequentially, simultaneously, or delayed) or across space (locally, systematically, distributed and/or at a distance).

*Earlier Attempts to Teach Ecosystems Concepts by Focusing on Underlying Causal Structure.* Our earlier research (e.g. Grotzer, 1989; 1993; Grotzer & Basca, 2003) revealed broad patterns in how students reason about the causality in ecosystems concepts that relate to the above misconceptions and limit learning and attempted to impact these patterns. For instance, using a simple linear causality, reasoning that one thing directly makes another thing happen limits understanding of the indirect, extended connections. We exposed some students to activities and/or discussions designed to help them focus on the underlying causal patterns (Grotzer & Basca, 2003). Those students who experienced both (Causal Activities and Discussion Group (CAD)) detected significantly more multi-step connections between organisms in the food web than control students (CON) ($t(26) = 2.08$, $p = .04$ with least squares means were 1.2, 2.7, and 7.5 ($SE = 2.13$) for the Control, Causal Activities Only (CAO), and CAD groups, respectively). This suggests that the intervention helped them to see connections that extended beyond direct producer-consumer relationships. There were also significant differences in how students in the CAO and CAD groups characterized the causal mechanisms associated with decay as compared to the CON group. A regression analysis plotting group and pre-interview version against gain scores in how students characterized the causal mechanism for decay showed the significant effects of group ($F(2, 28) = 5.88$, $p = .008$) with the CAD group and the CAO group significantly outperforming the control students ($t(26) = 3.38$, $p = .002$) and ($t(26) = 2.60$, $p = .0159$), respectively, than that of the control group with respective mean gains of 1.04; 0.737; and -0.60 ($SE = .37$). Structural-micro explanations increased from 7 to 16 (CAD = 9; CAO = 5; CON = 2) as did explanations that focused on decay from 2 to 6 (CAD- 3; CAO- 2; CON- 1) and matter recycling and 2 to 6 (CAD- 3; CAO- 3; CON- 0) respectively, from pre- to post-interview. Explanations using unreliable causal mechanisms (e.g. a tree fell on it) declined from 25 to 15 (CAD- 2; CAO- 4: CON- 9).

This research suggested the promise of engaging students directly in activities and discussions focused on the underlying causal structures in grasping ecosystems concepts. As a result of this work, collaborating with teachers, we developed an ecosystems curriculum designed to teach the underlying causal patterns relating to ecosystems understanding. This unit, developed as part of our earlier work, is available on line at: http://www.pz.harvard.edu/ucp/curriculum/ecosystems. We are in the process of testing these materials with teachers across the country. As part of this process, we have been conducting qualitative studies in some of the classrooms. A portion of this work is described below. These investigations elaborate and extend the previous research in an attempt to further investigate through a qualitative study what student understanding looks like before, during, and after learning to further understand what difficulties students might be having. We investigated students' reasoning as they were learning, considering how they framed and understood; the concepts. As we observed the classes, we developed, with the teachers, further lessons and discussion guides to support the students' learning. (See Appendix B.) The materials were designed to address the underlying causal patterns and features of the concept and to see how understanding shifted with instructional support.

## METHODS

**Design and Procedure:**

The *Causal Patterns in Ecosystems Unit* is being tested in middle school classrooms across the United States. This larger study is on-going. This paper reports on findings from qualitative investigations that accompanied the teaching of the unit in a set of local classrooms where the materials were tested the year prior to the larger study and where we were able to observe the teaching in process. The data reported on here include teacher-administered written assessments, open-ended interviews conducted before learning, videotaped observations of in-class activities and discussion, students' in-class responses, drawings, and students' written explanations, as well as interviews with the teachers. We anticipate presenting and publishing the results of a more extensive quantitative data set at the completion of our study.

Subjects:

The work described here was carried out primarily in three sixth grade classes (n = 64) in the Cambridge Public Schools and two sixth grade classes (n = 35) at the Edward C. Brooke Charter School in Boston. The choice to include Cambridge was made because the students there have regular involvement with the Maynard Ecology Center located at nearby Fresh Pond as part of their studies. They benefit from regular outdoor, hands-on activities to complement their classroom learning. These communities each represent an ethnically and socio-economically diverse population of students. The Edward C. Brooke Charter School population is drawn from Boston's inner city neighborhoods and is largely Latino and African American.

Materials:

The primary curriculum unit used in the classes, Causal Patterns in Ecosystems (2002), was developed in response to earlier research on students' learning about ecosystems. It includes six sections as follows. Each section is designed to address difficulties identified in previous research and in the extant literature in how students understand ecosystems concepts. Section one introduces domino causality to help students move beyond noticing only direct effects. Domino causal models describe how, like dominoes falling, effects can in turn cause other effects. The dominoes can fall in different types of extended patterns, for instance branching or radiating. For branching patterns, events closer to the "stem" have a greater effect on the rest of the branch than ones that are further away. In radiating patterns, one event can have many direct and indirect effects. Food webs are introduced and discussed through a Web of Life Connections Simulation Game using cards for animals and strings to show connections. The discussion engages students in thinking about the domino-type relationships in the web. The discussion also encourages students to think about the food web in terms of passive transfer of energy instead of active "eating" relationships.

Section two introduces students to the cyclic causal pattern involved in decay. It focuses on the idea that the same atoms are continuously recycled between the living and non-living parts of an ecosystem. It differentiates between matter recycling which is cyclic and energy transfer which is domino-like. This can be very difficult for students to realize because they “travel” together. In some curricula, decomposers are introduced as *the end* of a food chain. Decomposers ARE the end of the food chain in terms of being the end point of energy flow. They are NOT the end of a nutrient cycle because the matter can be used again. The activities in this section underscore that the relevant causal pattern is a circle, not a line. Matter is being recycled. Energy is not. New energy enters the system from the sun. These ideas are introduced through stories and simulation games.

Section three introduces the idea of microbes as a non-obvious cause of decomposition. Some decomposers that we can see are worms, mites, and sow bugs. Other decomposers are microbes, tiny organisms such as fungi and bacteria. They are not easily visible. Whereas larger decomposer organisms that children are familiar with are responsible for some of the physical breakdown of organic matter, microbes are the primary agents that recycle dead matter into its basic elements. It is common to focus only on obvious causes of events unless there is some evidence to suggest that the obvious causes one can detect do not completely explain what is going on. The activities in this section help students notice the role of non-obvious, or in this case microscopic, decomposers. It does this by comparing two tanks of decomposing matter and revealing that even the one without the obvious decomposers is decaying. This encourages many students to believe that there could be microscopic decomposers at work.

Section four focuses on the nature of time delays and how such delays can make it difficult to see the underlying causal interaction pattern, such as the cyclic pattern in decay. Time-lapse videos are introduced as a means to help students clearly see the cyclic nature of decay despite the time delay.[1] Linking the concepts in this lesson to those of the lesson on non-obvious decomposers helps students to see that slow accumulation of effects is the result of many microbes doing their work, and will eventually result in a discernible change.

Section five uses stories and computer simulations to help students realize that two-way (or mutual) causality plays a role in ecosystem dynamics. There are many ways in which relationships in an ecosystem are two-way or mutual. This means that two organisms affect each other in some way. While domino models are helpful for conceptualizing the one-way process of energy flow, a different type of model is needed to address relationships where there are mutual effects. In two-way or mutual causal models, each organism acts as both a cause and an effect. For instance, when a bee pollinates a flower, the bee and the flower are affected. The bee gets the nectar it needs for food energy and the flower gets pollen that the bee picks up from other flowers. The pollen enables the flower to reproduce. Mutual causality can also come into play at the population level. The lesson uses a computer simulation called StarLogo (Resnick et al, 2001). StarLogo is a program created by researchers at the MIT Media Lab to show what happens at a population level when individuals act according to a given set of rules. The resulting outcome is not usually one that can be predicted from the individual interactions, so it can be quite surprising.

Section six uses a combination of stories, discussions, and games to help students realize that balance and flux are natural states in an ecosystem and that each state plays a role in ecosystem dynamics. There are many interdependencies within ecosystems. Events that affect one population typically have ripple effects—affecting other populations. When the size of one population becomes too large or too small for its niche (or role) in the ecosystem, it is out of balance and may throw others out of balance too. The simulations in Section 5 revealed some of the patterns of boom (when a population grows beyond the resources that it needs to support it) and bust (when a population size is too small to sustain itself) that can occur. Ecosystems are not only about balance. Ecosystems involve both balance and flux. Typically, studies of ecosystems stress balance. Indeed there is a great deal of redundancy and adaptability in ecosystems that provides balance. Redundancy means that organisms have multiple acceptable food sources or habitats. The ability to adapt means it is possible for organisms to switch food sources or habitats. However, ecosystems typically include some fluctuations. Flux is not necessarily harmful to an ecosystem: it can create patterns in an ecosystem that are ultimately healthy. For instance, flux can allow for new species to become established. For some populations, flux is a necessary part of their existence. Further, flux doesn't always mean that a population will die out. It can simply mean that the population size changes over time.

The lessons in the unit are sequential, but teachers chose to stress different lessons and to spend more or less time on each. Therefore, there was variation between the classes in how the units were carried out and the amount of time spent on each. Also, in the spirit of good teaching, teachers responded to questions and difficulties of the students, leading to some variations, for instance, one teachers added fish to the eco-column such as in the STC NRSC unit on Ecosystems (2004). Given these variations and the design elements described below, we do not interpret the findings of this study in any way that suggests a controlled intervention—rather as a qualitative means of gathering information that suggests what is possible in terms of student learning and the kinds of supports that may be necessary.

*Development of Additional Materials: Design Study Approach:* We also developed and introduced new materials designed to focus on concepts as we observed students struggling with the concepts. Design studies are sometimes used in education to assess, in a formative way, potential educational interventions (Brown, 1992; Collins, 1999). There is an iterative and interventionist nature to design studies. As the studies unfold over time, new interventions are developed and assessed with a recognition that all that comes later may build in particular ways on that which came before it. This resulted in additional materials that were designed as part of the study and shared with other teachers testing the curriculum. These materials include additional activities focused on concepts of balance and flux, predator/prey relationships, energy transfer, and microbes as well as discussion guides to help teachers talk to students about the concepts. (See Appendix B.)

Data Collection:

The results reported here draw upon the following data: student interviews conducted prior to learning; classroom observations and videotaped classroom discussions; written assessment data, and students' in-class written work and drawings.

*Open-Ended Clinical Interviews.* Students from two classes (n = 8) were interviewed in depth on their responses to an open-ended interview that contained four sections (See Appendix A). The interview questions were developed and piloted for an earlier study. The interview proceeds to more scaffolded questions to see how students respond to the information with greater structure. The questions are designed to reveal misconceptions about ecosystems concepts as well as how students structure the underlying causal patterns. The first section presented students with a set of cards picturing food web components and asked the students how the things in the cards were important to each other. All of the diet information or other relevant information (i.e. green plants make their own food using energy from the sun) was available on the cards so as to not confound content knowledge about the food web with the ability to make connections (Grotzer, 1989). After giving students an opportunity to present their ideas on how the organisms are important to each other and probing those questions in depth, students were then asked about sets of connections where there were both direct and indirect connections. A next set of questions probed students' understanding of decay. Students were asked what happens over time after a tree in the forest dies. Students were also asked questions about balance and flux and how populations depend upon each other.

*Written Assessments.* Students in each class took a pre- and post-assessment before and after their participation in the curriculum unit. The written assessment was also developed and piloted for an earlier study (See Appendix A). These assessments were teacher-administered and scored by the researchers. The questions were open-ended and designed to reveal how students structured their explanations and to reveal misconceptions about ecosystems concepts. Each assessment took approximately 45 minutes to complete.

*Student Work:* We also collected examples of students' work and drawing at various points in the unit. This included their critiques of a high school food web and their own drawings of food webs. Some of these assignments were spontaneous and so there was variation between the classes in what additional student work data we collected.

*Classroom Videos:* Classroom discussions were videotaped and were viewed by the teachers and researchers as we considered what learning supports might be useful. Excerpts from these videos are reported here to document student ideas and how these were addressed in classroom conversation.

**Scoring and Analysis:**

Given the qualitative nature of the study and the emphasis on using the outcomes towards instructional design support, much of the data analysis was conducted in a form of open coding where we sought what patterns emerged from the data. This was a bottom up process where multiple researchers, including teachers, independently consider the data to see what patterns emerge from it and then meet to discuss convergences, overlaps, and divergences in the categories detected.

The data was also analyzed using a top-down thematic coding to assess the causal patterns that it revealed. Here we looked for particular kinds of language and patterns related to the science concepts and underlying causality (How often do the students address causal structures? What features do they see clearly see? For instance, in analyzing student conceptions of decay, we asked a set of seven questions: Did the student realize that: 1) change would take place over time?; 2) the change would be at the structural level?; 3) that the change is actually caused by something?; 4) that obvious and non-obvious decomposers are involved?; 5) that there needs to be reliable causes of decay (not happenstance)?; 6) that decay is part of matter recycling?; 7) that matter is conserved and that the release of matter in decay is necessary for new life/becomes a part of that new life? Each of these was analyzed along a continuum (See Appendix A.) The written assessments were scored by two independent scorers with one scoring all of the assessments and the other scoring 25% with inter-rater reliability assessed at between 83% and 95% for each category and discussion until there was 100% agreement.

## FINDINGS

The following patterns were identified in students' thinking at various points in learning and were addressed by instruction as follows.

**Learning about Indirect Effects**

In the pre-interviews and at the outset of the unit, students typically missed indirect effects--they didn't realize that if all the green plants disappeared, it would affect just about everything in the food web, not only the things that directly eat green plants. This fits with earlier work by Grotzer and colleagues (1989; 1993; Grotzer & Basca, 2003).They realized that the sun gives us essential warmth, but not that the entire food web depends upon it. For instance, when asked, "What if the green plants disappeared?" The following kinds of responses were common, "The voles would have one less thing to eat and it wouldn't really matter to the foxes because they have other things to eat. It would matter to the other things because they would be cold." (S1b)

A reasoning pattern that appeared to support this dividing up of the food web into direct relationships was a focus on eating as opposed to energy transfer. Many students constructed food web relationships in terms of the actions of eating. For instance,
"The [food web] arrows show what eats what."(S5b)
"It's a food chain. They all eat each other." (S40c)
"The owls eat mice, earthworms, and green plants. The insects, earthworms, skunks and mice all eat green plants. The toads eat green plants and insects." (S13c)
"Owls are the main predator that can eat everything on this list. So can skunks eat almost everything." (S34c)

“The owl eats, but never is eaten, the skunks eat and are eaten by owls. The mice and toad are eaten by skunks, the bugs and worms are eaten by mice. The toads, the bugs, and the worms eat plants which do not eat anything.” (S6c)

Passive causality was harder to detect than active causality. Students tended to focus on who is "doing something" and on individual feeding relationships (see Fig. 1). They reversed the arrows in the food web to show "what eats what" instead of energy transfer. (See Figs. 2 and 3.)

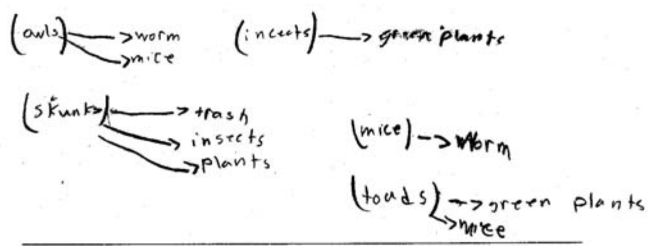


Fig. 1. Individual Feeding Relationship (S55c)

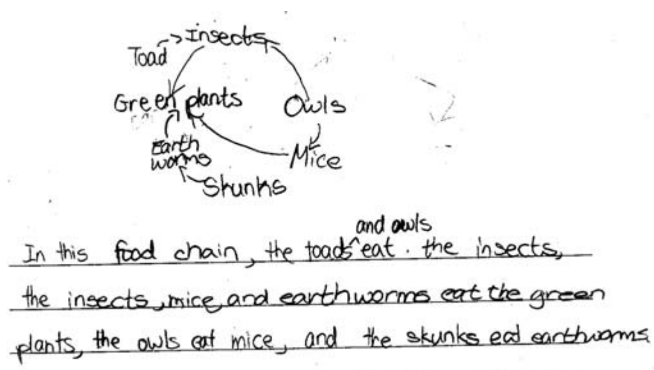


Fig. 2. Arrows Show What Eats What (S43c)

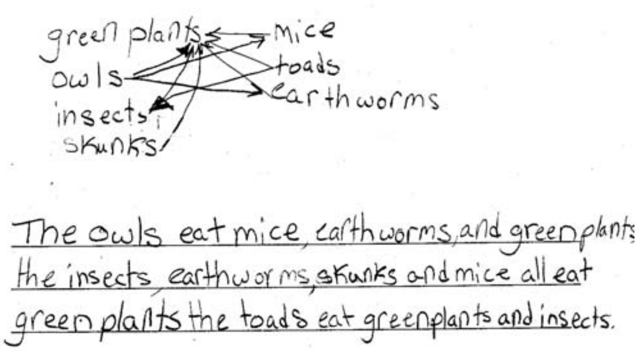


Fig. 3. Arrows Show What Eats What (S42c)

A finding that was particularly surprising to the researchers (but not to the teachers because they had noticed this in increasing numbers) was the number of students who drew the food web with a focus on predator-prey as who attacks what. A few students in each class drew food webs that focused on guns and killing as opposed to feeding or energy transfer relationships. (See Fig. 4.) One teacher remarked that he had been seeing more and more of this in the past few years. In terms of ecosystems concepts, it seems to be a step beyond helping students transition from the role of "active eaters" to the more passive causality of energy transfer. However, in some respects, it is more connected to the role of a predator or predatory behavior than mere passive energy transfer might suggest. It certainly connects to the idea that if one is going to eat meat, they are going to need to kill something.

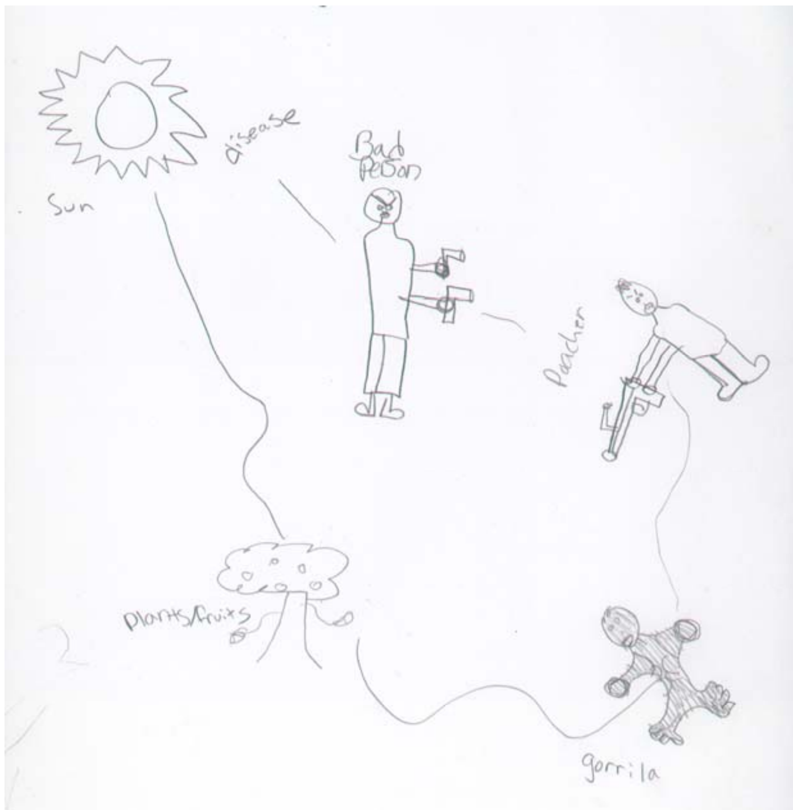


Fig. 4. A Focus on What Kills What (S63c)

A focus on the actions of eating or killing reduces the food web to individual actions instead of an interconnected system of relationships. This has been found in other studies (e.g. Hogan, 1994). When asked to critique a food web with energy links, it was common for the students we interviewed to say that the arrows were backwards. During the course of the unit, teachers asked students who struggled with this concept to think about the arrows as showing "what goes into the mouth of the thing that eats it." Hogan (1994) had devised this technique and found it to be useful in getting students to draw their food webs in the direction of energy transfer which then made it possible to discuss the broader systems effects. The teachers also talked about the food webs as energy webs and in terms of energy transfer rather than who eats what. The students were at various stages in accommodating the switch from active to passive language on the post-test as the examples below and in figures x-y suggest.

"The arrows are explaining what things give energy to." (S45c)
"Plants take energy from the sun, earthworms, insects. Mice take energy from plants, skunks, and toad take energy from those creatures. Owls take energy from those. (S33c)
"This web shows what gives energy to what." (S59c)
"I made this food web because it shows where the energy is going to." (S27c)

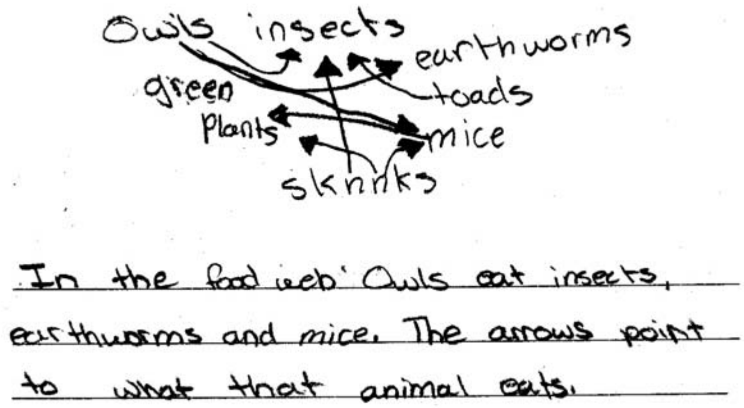


Fig. 6. A Mixed Focus on What Eats What with "What that Animal Eats" (S11c)

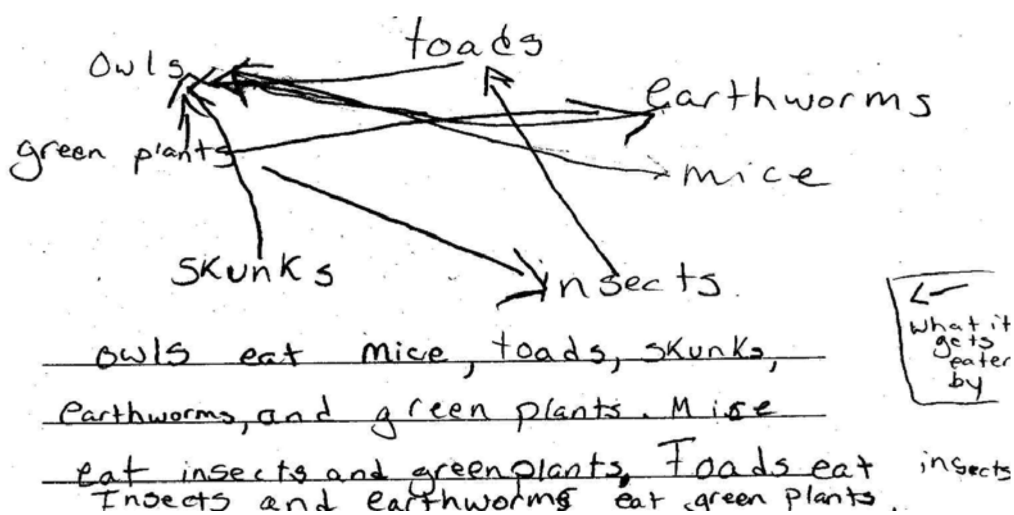


Fig. 7: A Mixed Focus on what Eats What and "What It Gets Eaten By" (S64c)

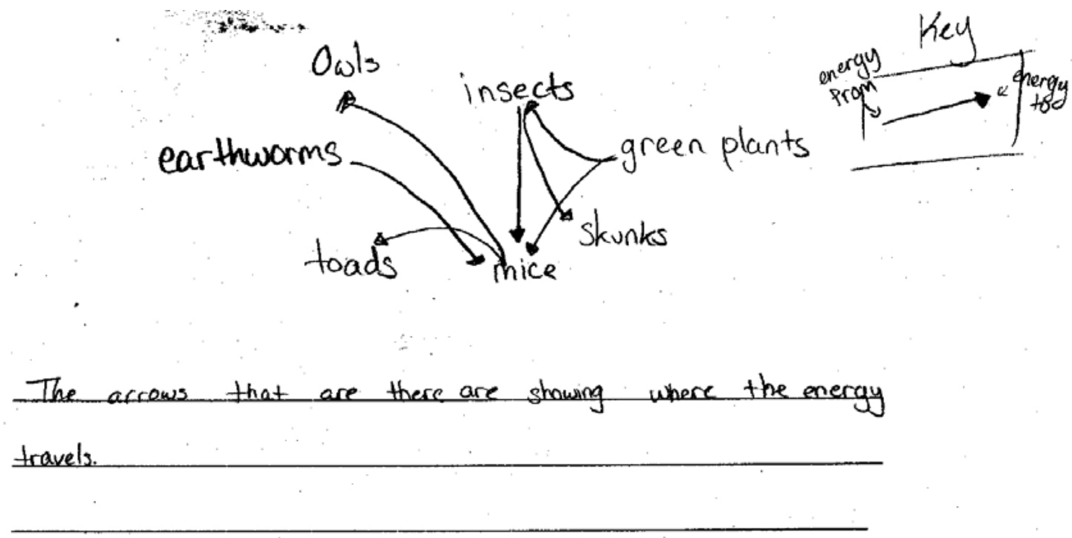


Fig. 8. Arrows Indicate "Where Energy Travels" (S35c)

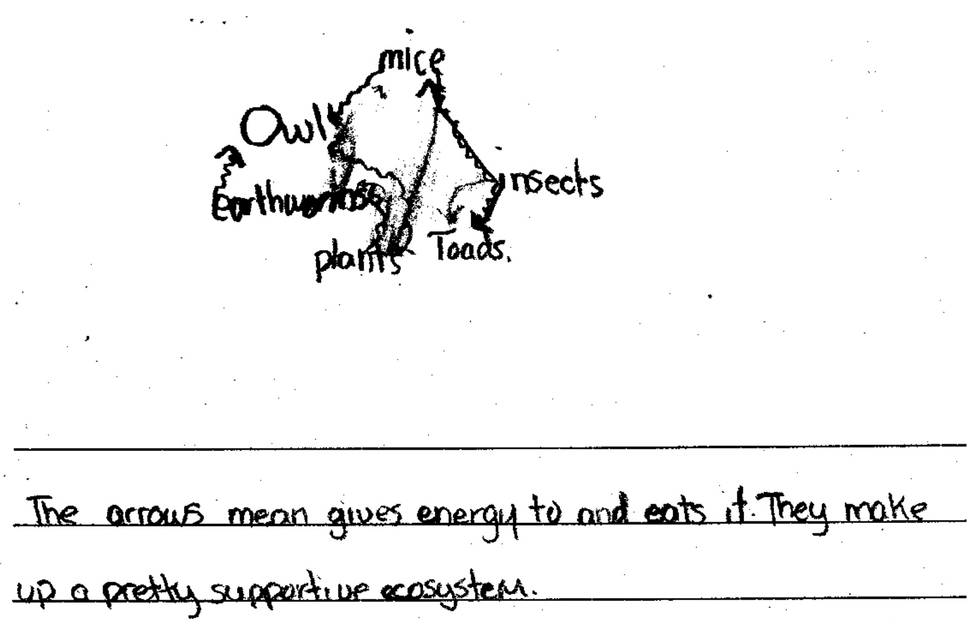


Fig. 9. Lines Depict Energy by Squiggly Lines (S32c)

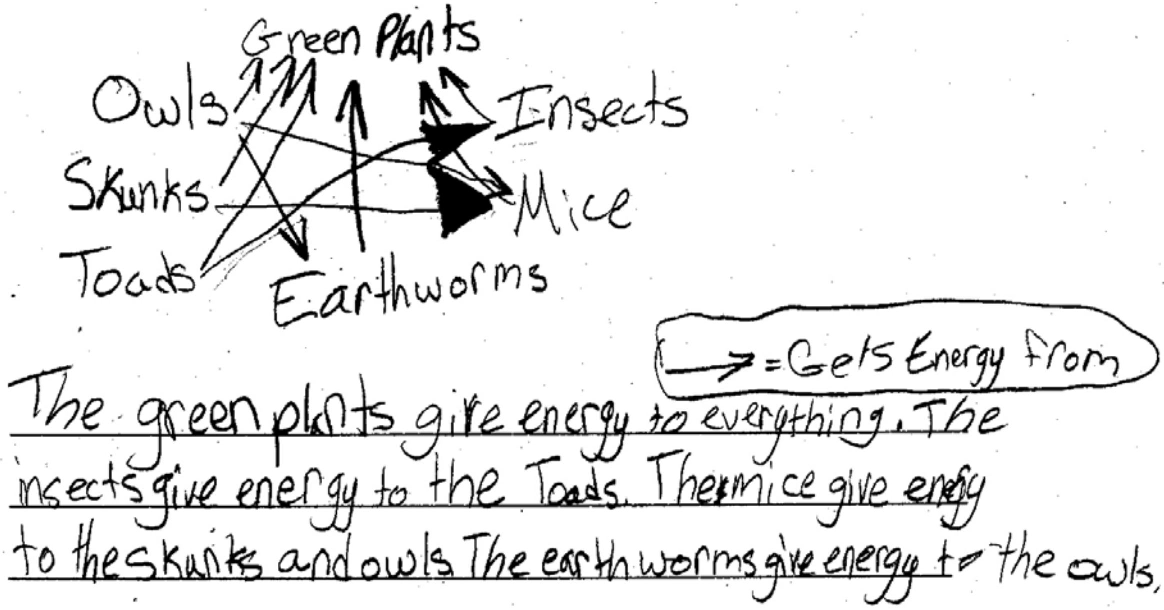


Fig.10. Transfer of Energy (S43c)

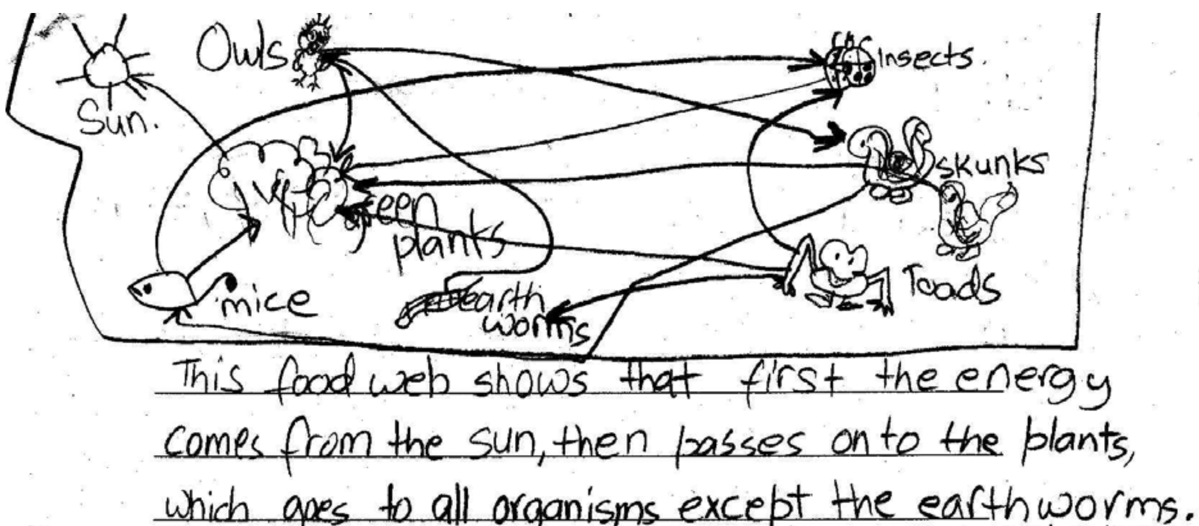


Fig. 11. Transfer of Energy (S28c)

After participating in the simulation games in lesson one focused on domino causality and food web relationships, most students expressed deeper understanding of the connectedness in the food web and were more likely to refer to indirect connections and patterns of *domino causality*, a trigger event initiates a domino of effects where each effect in turns acts as a cause for a new effect. Energy moves through the food web in a domino-like manner from the sun to producers to primary consumers to secondary consumers and so on.  For instance, class discussions such as the one below from the Brooke Charter School, suggest that students were reasoning about connectedness to a greater extent than in their pre-interviews.

S1: “I think that each time one animal dies, the other animals would die because they won’t have nothing to eat.”
S2 “If the plants died and the sun is covered with ashes, that means that the mice, plants, and the sun are the cause for me to die.”
S3: “I think it’s a domino causality, because when the sun is blocked out, then it basically, the next organism will die and the next one will die because they don’t have anything to eat.”

However, one of the issues that arose was extending the concept of connectedness too far. Once students got the idea of the connectedness in the food web, some of them applied it indiscriminately and thought that if any animal died, the whole web would collapse. (See Fig. 12.) For instance,

> “The owl is the main predator, it eats all of the things that eat producers. The worms, insects, skunk, and mice all eat green plants which get energy from the sun. The organisms that eat the grass now have it’s energy, which they use for many things like reproduction, sleep, movement, etc. The energy that is in the animal goes into the toads or owls who have to eat more to get enough energy. It one thing dies it affects the entire food web.” (S20CA)

This can lead students to miss forms of insurance and flexibility built into food webs. Ecosystems scientist, Steward Pickett (1999), has written about this over-focus on connectedness on behalf of teachers. Whether the over-focus is necessary before moving to the subtleties is an open question for further exploration.

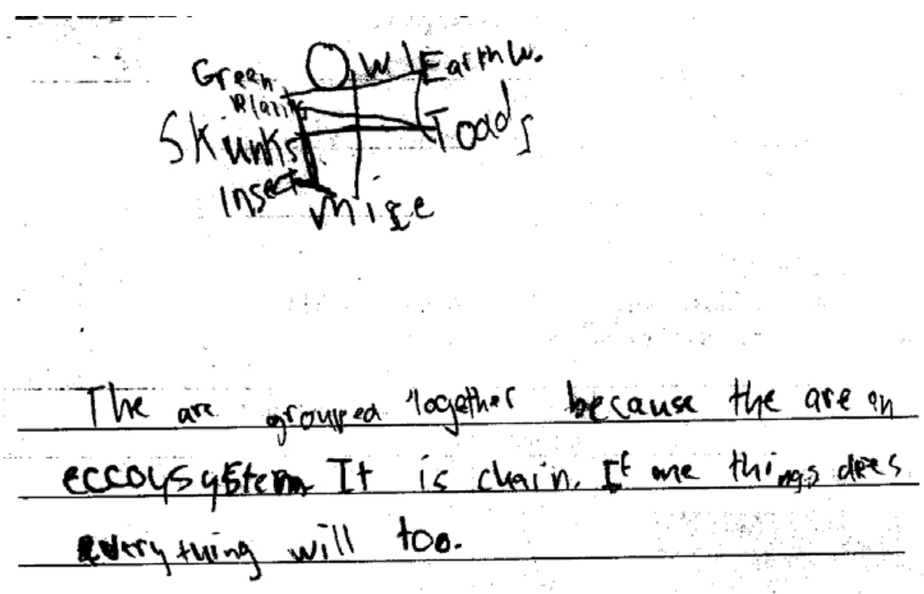


Fig. 12: Over-Extending Connectedness (S9c)

**Learning About the Causes and Impacts of Matter Recycling**

On their pretests, students missed non-obvious, microbial causes of decay. Students talked about processes such as aging, weathering, erosion as factors in the structural change of the things that decay. Or they referred to more obvious decomposers such as worms, animals or kids stepping on it, etc. Many of these more obvious decomposers were also unreliable or depended upon happenstance (someone happened to come along). These patterns fit with the earlier research (Grotzer & Basca, 2003; Hogan, 1994). Students did realize that without decay, dead matter would accumulate and there would be a lot of it around. For instance:

(Following up on student's response that they might break down if people walked on them)
I: What if no one stepped on them or no kids played in them?
S: Maybe the whole pile will still be here. (S6a)

Unless students have experiences witnessing decay, they do not necessarily have ways of realizing that decay does occur even if no children are around to step on the piles of leaves that they see on city sidewalks. The city sidewalks eventually get swept clean so students do not have the experience over time of witnessing the process. Time delays are difficult enough to deal with because we often stop attending to such processes, however, in this case, many or the students don't have the experiences to support an understanding of what happens over time. This complicates their opportunity to witness what happens and to realize that tiny microbes play a role.

During the course of the unit, students began to understand that dead matter somehow went into the soil and benefitted the plants. The lesson focus on microbes revealed the role of these tiny, non-obvious decomposers. Students talked about the dead matter in new ways and were less likely to see it as accumulating:
"It provides food for decomposers and when it is soil, it gives nutrience to plants." (S33c)
"It turns into new soil that helps more plants to grow." (S10c)
"It can help the soil." (S36c)

*Matter as Benefitting Plants but Not Conservation of Matter.* However, only two students realized that matter is conserved and without the cyclic pattern of matter recycling, essential elements would be locked up in dead matter—unavailable for new life. While the curriculum materials include a story about an atom traveling through the biotic and abiotic components of the environment, the broader message about conservation of matter did not come through. This is a complex concept given how much matter is around us in the world and the non-obviousness of atoms. It involves thinking about the environment in ways that are unlikely to occur just from reasoning about what we see around us.

*Merging of Matter Recycling and Energy Transfer.* During the pre-interviews and the class discussions, students struggled with differentiating matter recycling and energy transfer. The following kinds of comments drawn from a class discussion in one of the classes in Cambridge were common:
"Where does it go if no one eats the plant?"
"Seeds will replant and energy will go in a circle. The sun's energy will go to the plant and it never stops."
"Earthworms make nutrients."
"The cricket eats the grass, that gives the cricket energy, then the cricket dies, that gives the grass energy."
"Energy goes to the soil."

The unit materials stress the difference between energy transfer and matter recycling referring to one as a domino causality and one as a cyclic causality. However, some students still merged the two and ended up thinking that energy can be recycled, some students still merged the two. Even when students understood that the food web is about energy transfer, they still weren't sure how to think about the relationships between food, energy, and matter. For instance:
I: What do the arrows stand for?

S: energy, most of them are
I: how does the energy get from the insect to the frog?
S: because it eats it, so it gets in its body, so when the frog eats it, it brings the energy to the frog
I: What happens here? (pointing to the end of the food chain that the student has drawn with a lion and then a hunter at the end)
S: I don't think there's much energy because I don't know that many people who eat lions.
I: What if we took the hunter off and just had the lion?
S: That would be the predator
I: Okay, so what happens to the energy here after the lion, the energy that has gone from the bird to the lion?
S: If the hunter kills the lion, I guess it decomposes them. It goes back to where it started right there (pointing to the plants)
I: Why don't you draw what you are thinking there about the lion?
S: the lion decomposes
I: and when the lion decomposes, what do you think happens to the energy?
S: I guess the energy helps the dirt become fertile. (S6a)

This merging makes sense since energy and matter "travel together" to some extent, but leads to difficulty understanding our critical dependence on the sun and green plants for sustaining life on Earth.

**Learning About the Importance of Balance and Flux**

On the pre-interviews, most students saw flux as bad and did not have a sense that flux could create new opportunities in ecosystems. They appeared to view all oscillations as devastating to ecosystems. They had little sense of how to think about scale of time involved in balance and expected balance in each "snapshot." They said things like:
"It is good for an ecosystem to be balanced. I think it is because if something falls out of place, the whole food chain or ecosystem is thrown off and things start dying because of it." (s28)
"If ecosystems weren't in balance, a lot of plants and animals would be dying." (s30)

The original curriculum materials had one lesson on balance and flux. This lesson attempted to communicate the ideas through stories about lemmings and lynx-hare cycles. In order to reason well about the dynamics of flux and balance, students needed to hold a lot of information in their heads and imagine what would happen. Teachers asked for additional discussion guides and demonstrations which we developed. (See Appendix B.) Following the teaching of these activities, students talked more about balance and flux. They seemed to have a good sense that balance was important, but some flux was inherent to the system as in this discussion between the students and teacher.

> T: What do we call that?
> S9: Flux.
> T: Definitely. Is flux a bad thing?
> S1: It could, if you have too much of it on one side – like a scale – if you have too much on one side the other side will collapse.
> T: Very good. It's exactly like a scale. And it's – and an ecosystem's always going like this, isn't it? (Moves hands up and down) It's always changing. There's always an increase and a decrease. Is death a bad thing? In an ecosystem?
> S2: No.
> T: Can you have an ecosystem without things dying?
> S2: No.
> T: You have to have all of that, don't you. If nothing ever died, what would happen if no snakes ever died?
> S9: It would kill – they'd eat everything.
> T: Yeah. So part of that flux is dependent on, on organisms dying.
> S10: If nothing could die wouldn't the snakes just starve then all of – wait. If nothing ever dies –
> T: If nothing ever died then they couldn't eat...

S1: ‘Cuz like, what would happen if nothing died these would already away.
T: So, so, we need this – as you called it – flux, we need all of these constant changes.

Most students still expressed that balance was desirable. As one student put it, “If ecosystems are in balance, than everything will be in a perfect pattern so there will be just the right amount for everything.” (S40CA).

An emergent finding that might contribute to difficulties talking about balance and flux was a tendency to focus on menu-driven as opposed to opportunity-driven feeding relationships. Many students spoke about the food web in terms of what consumers could *choose* to eat. (“If there were no mice, the fox could always eat berries.” If the mice disappear, the fox will decide to eat a skunk instead.”) A small number of students spoke about having to kill prey and the chance associated with that event. (“A lion could eat a gazelle if he could catch one.”) No student introduced the concept of opportunistic feeding in terms of seasonal variation or opportunity based on balance and flux for other reasons. It is possible that they are able to reason about these concepts but just did not mention them, however, we view this as an area where further probing and perhaps instructional support would be helpful. This is likely to impact students’ understanding of concepts such as caloric loading and fluctuations in population size as well. This will be an important area for further investigation.

The more the teachers attempted to teach about balance and flux, the more the challenges became evident. Students found it difficult enough to reason at the level of populations rather than individuals (such that if something was bad for a certain animal, such as being eaten, it was difficult to see it as good for the population.). Thinking about balance and flux takes this a step further – it engages students in reasoning at the ecosystems level and invites the idea that certain populations may die while others flourish. It relates to why diversity is important to stability and ultimately leads to the realization that the processes in nature bear no vested interest in which species survive.

It also quickly became clear that reasoning across time and at different time scales was also hard. In a shorter time scale, students would perceive something as being in flux that would look balanced in a broader time scale, but without the expert knowledge of what time scale to apply, they couldn’t know which was relevant. This is a challenge of novice-expert shift. We subsequently discussed this issue with the students in two ways. We considered the difference between “snap-shot reasoning” where you just have information at points in and “video-reasoning” where you have information across time. We considered how the implications that could be drawn in each case would differ. In earlier research (Ritscher, Lincoln, & Grotzer, 2003), we found that students tended to think about certain physics problems in terms of compelling snapshot images instead of processes over time, therefore we think that this differentiation might be more broadly useful as well in helping them learn to think in science more broadly. We also considered data that they were familiar with over different time scales to see the differences in how the patterns are interpreted differently. Using the batting averages of a well known baseball slugger, the students realized that different-sized slices of the picture would lead to very different interpretations of whether or not he was a good hitter and that if a slice was very small, it might do a very poor job representing the larger picture (Grotzer & Muldoon, 2007).

## DISCUSSION AND POTENTIAL IMPLICATIONS

Ecosystems are highly complex systems where causes and effects are non-obvious, play out over time and across space, and involve effects at many different levels. As we have worked with teachers to help students move towards more complex notions of how ecosystems work, we addressed some of students’ difficulties and surfaced new ones at new levels of reasoning. One of the main purposes of this work was to suggest how previous curriculum modifications were working and to consider what other instructional moves might be made.

*Further Instructional Modifications to Consider.* The tendency to “over-apply” the concept of connectedness in the food web might be one step on the way to a more nuanced understanding. How might we support students in getting there? One way to address the problem of "over-applied connectedness" might be to talk about the connectedness of the food web organisms as being branch-like and the closer to the main stem, the more parts of the web that would be affected. Holding the many connections in mind and reasoning about them also produces significant cognitive load. Having means to download some of this information and being able to see how different events have an impact on different parts of the food web would be powerful. It would allow students to discover that impacts closer to a "stem" or "main branch" have more far reaching impact. It could also introduce the concept of insurance in terms of multiple diet sources in food webs without asking students to hold so much information in their heads. It might also help to make sure that the teachers illustrate and discuss many possible scenarios when playing the food web game.

The continued tendency to merge energy and matter makes sense given that it involves both obvious and non-obvious aspects. The matter can be seen in the macro-sense and the energy is unobservable. How to illustrate this distinction will be important in how we revise and redesign portions of the curriculum. While some lessons make this point clear, others (such as a simulation game on matter recycling) may lead students to again merge the two. This suggests that more explicit contrast between the domino causality in energy transfer and the cyclic causality in conservation of matter would be helpful. In some curricula, decomposers are introduced as *the end* of a food chain. Decomposers ARE the end of the food chain in terms of being the end point of energy flow. They are NOT the end of a matter cycle because the matter can be used again. Matter is being recycled. Energy is not. This underscores our crucial dependence on the sun as new energy enters the system from the sun. The capacity to illustrate how the two "travel together" but follow different paths in some respects is an important challenge in helping students understand the concepts of energy and matter well.

Reasoning about balance and flux presents many challenges. Unless students are able to experiments with effects on different time scales, they will not necessarily realize that flux is a part of larger patterns that we would call balanced and that flux can infuse new forms of energy and life into a food web. This can shift the dynamics in various ways and can introduce change, but that is not necessarily problematic in terms of the continued existence of the ecosystem. A problem with only examining historical cases in terms of balance and flux, is that in hindsight pattern may look different and we might attend to features that only became salient looking backwards.

*Experiences of the Student Cohort*. As we worked with the classes, it appeared that in the span of time since our earlier studies, this cohort of students had different sets of experiences than students in the same schools eight to ten years ago. There were a number of instances, where it was clear that either experiences that students had or didn't have, influenced how they reasoned about the concepts. If one does not have the opportunity to see how certain plants, seeds, and berries are seasonal in the woods and can be bought every day of the year in the local supermarket, the opportunistic nature of a food web is unlikely to come across without explicit attention to it. In addition to change over time, we expect that we would see differences between urban and rural students as well, based on the experiences that students had available to them. If students don't go into the woods and the sidewalks are swept clean, they are unlikely to understand the process of decay that the leaves go through. When asked if she had ever walked in a in a forest, one student shook her head and replied, "I'm scared of forests. I don't know what would happen. Unless I'm with somebody, I'm not gonna go.' [Okay, so do you see lots of leaves in the picture?] "Yes, they'll stay there… unless somebody cleans them up."

*The Challenge of Teaching Complex Concepts.* The challenge of helping students deeply understand many of the complex concepts embedded in ecosystems was apparent. While teachers generally found that the lessons helped them reach a deeper level of understanding on behalf of the students, some concepts were difficult to address through simulation games, class activities, and field trips to the local ecology center (and the woods, ponds, and meadows that surround it.) Teachers who had also taught causal patterns in other topics found aspects of ecosystems especially challenging: population effects, time delays, etc. They said things like; "I found it much easier to teach the density RECAST activities. You could see it happen right away. The kids really got it." "The simulation games really help, but it is harder for students to play with the concepts the way that they could in the density unit."

Understanding the causal dynamics involved, especially with regards to recognizing non-obvious causes and indirect effects; dealing with time delays between causes and visible effects; thinking about population effects versus individual effects; and reasoning about balance and flux involves significant cognitive load and the ability to reason dynamically. In the middle grades, the NSES call for a shift in students' thinking from focusing on individual organisms and species to recognizing the patterns and causal relationships between various populations in ecosystems (NRC, 1996). This shift in focus from the micro to the macro is a complex step that is difficult even for many adults to fully grasp. The above research underscores the difficulties that students have in reasoning about causality in a systemic sense or to recognize an ecosystem's structural patterns and the difficulties that teachers have in addressing these challenges using typical classroom games and simulation activities.

It is difficult to simulate time delays and spatial gaps between cause and effect, yet these too can have significant impacts on ecosystems: for example, the effects of environmentally damaging actions on a particular ecosystem may not become apparent until months or even years have passed. Thinking about population effects versus individual effects is also difficult, yet important. For example, when an owl eats a mouse, the individual mouse does not benefit; however, the owl population benefits as a whole since an owl received energy, and the mouse population benefits as a whole since the mouse population is kept it check. It is also easy to get caught up in the idea that balance in ecosystems is always good. While it is true that balance is what enables stability in the ecosystem, flux also plays an important role, creating new opportunities within an ecosystem and enabling new species to become established.

*The Promise of Technology in Addressing Ecosystems Complexity.* While conventional classroom instruction can help students overcome some of these types of misconceptions about ecosystems – and causality – these are limited in effectiveness by both practical and pedagogical constraints. This classroom work and conversations with teachers has led us to consider that perhaps being outdoors and directly experiencing the environment along with classroom activities is not enough to reveal the complex relationships that students need to learn. Advances in information technology are creating new possibilities for using multi-user virtual environments for learning and assessment (NSF Cyberinfrastructure Council, 2000; NRC, 2001).

Chris Dede and colleagues have developed MUVEs (multi-user, virtual environments) in an attempt to teach complexity in other science subjects such as epidemiology. A MUVE is an Immersive microworld where avatars move around and interact. It includes multiple linked representations of a phenomenon (graphs, equations, behavioral dynamics) with embedded hints and tutoring. Visualizations and other aids to facilitate understanding of complex phenomena can be imposed on the world. Distributed teams are possible. These simulated contexts provide rich environments in which participants interact with digital objects and tools and explore a richly detailed environment. Moreover, this interface facilitates novel forms of communication between students and computer-based agents, using media such as text chat and virtual gestures (Clarke, Dede, & Dieterle, 2008).

Simulated, virtual worlds may be able to assist teachers with the challenges found here in our work with students learning about ecosystems. In response to the research here and the difficulties that teachers have expressed, Chris Dede, Shari Metcalf, Jody Clarke and I are currently building and testing an EcoMUVE with the following kinds of features: 1) The ability to zoom-in to the microbial world or out to macroviews (such as a population view); 2) The ability to speed up time, slow down time, advance to different points in the past or future, illustrate possible scenarios; 3) The ability to show parallel interacting objects/beings and their emergent effects (distributed causality); 4) The ability to monitor the on-going state of systems; 5) Ways to graph patterns and show the relationship between individual behaviors and population level outcomes; and 6) Ways to illustrate different causal patterns in play. Simulated environments allow for specialized tools and abilities that may help students to learn concepts that are difficult to attain in the real world.

It has become clear through these classroom studies that addressing the underlying causality can be helpful and that with careful attention to how students are developing understanding and the difficulties that arise along the way, classroom activities can further understanding. It is also clear that ecosystems concepts are difficult on many different levels and that engendering deep understanding requires that students are able to engage with and play with the concepts. Simulated environments should enable powerful experiences for students to do so. Familiarity with the outside world, hands-on activities with discussion, *AND* computer simulations in the classroom with the kinds of affordances outlined above that allow for active processing of complex concepts may be the best combination for engendering deep understanding of the natural world.

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Table 1. Nine Default Assumptions About the Nature of Causality That Impede Science Learning

| Students assume that causality is: | Example | Instead of: | Example |
|---|---|---|---|
| Linear | When I suck on the straw, I make the juice come up. | Nonlinear | There is less air pressure inside the straw than outside, so the imbalance results in the juice getting pushed up the straw. |
| Direct without intervening steps | Green plants matter to animals that eat them but not to animals that eat the ones that eat green plants. | Indirect | If the green plants disappeared, it would eventually affect everything in the food web. |
| Unidirectional | Bees take pollen from flowers for their food. | Bi-directional or mutual | Bees take nectar from flowers for their food and they cross-pollinate the flowers so that the flowers can produce fruit. |
| Sequential with step-by-step processes | The electrons crowd onto the circuit and go to each bulb so the first one gets the most power. | Simultaneous | The electrons move like a bicycle chain turning in a circle all at once making the bulb light when it moves. |
| Constructed from obvious, perceptible characteristics | The object sinks because of its weight. | Constructed from non-obvious or imperceptible variables | Density affects sinking and floating. |
| Due to active or intentional agents | The electrons move to make static electricity. | Due to passive or unintentional ones | Protons and electrons are attracted to each other. Bridges stand because of balanced forces. Seat belts passively cause us to stop when the car stops. |
| Deterministic--effects always follow “causes” or the causal relationship is questioned | I did it before and I didn’t get sick, so I’m not going to get sick now. | Probabilistic | Getting sick depends upon many things. Even if I didn’t get sick before, I can still get sick now. |
| Spatially and temporally close to its effects | Satellites have a force in them that makes them move as they do. I can’t see any bad effects of getting a suntan right now. | Distant or having delays | The forward motion of the satellite and the gravitational attraction result in a satellite’s path. The hurtful effects of getting a suntan accumulate and show up after a long delay between cause and effect. |
| Centralized with few agents | The queen bee directs the activity in a beehive. | Decentralized with distributed agency and emergent effects | The interactions of many bees result in an organized system. |

APPENDIX A:
ECOSYSTEMS WRITTEN ASSESSMENT

**Name**______________________________ **Date**______________________________

**Instructions:**

1. Answer each of the following questions to the best of your ability. You may not have studied some of the information that is being asked. Just answer based on what you think is right.

2. Write as complete an answer as possible so that we really know what your thinking is. Draw a picture or model where it asks you to and include labels.

3. Define any special terms that you use.

4. Answer every question, even those you are unsure about.

5. If you need extra space, use the back of the page.

**1a.** Sun, owls, insects, green plants, skunks, mice, toads, and earthworms are all found in an area near the school. Draw and explain the food web that they make up.

**1b.** Are the green plants important to the other things? If so, circle the things below that the green plants are important to.

Owls
Mice
Insects
Earthworms
Skunks
Toads

Explain the reasons why the green plants are important to the things you circled.

**1c.** Are owls important to mice? Yes or No? Why or why not? Are mice important to owls? Yes or No? Why or why not?

**2.** What happens to a tree in the forest when it dies? What would happen to the tree after a few years?

**3.** What causes this to happen? Tell as many things as you can think of.

**4.** Is what happens to the tree important to the plants in the forest? If so, how? If not, why not? Is what happens to the tree important to the animals in the forest? If so, how? If not, why not?

**5a.** What is balance in an ecosystem and what makes it happen?

**5b**.A student said, "It is good for ecosystems to always be in balance." Do you agree or disagree? Why or why not?"

## APPENDIX A:
## ECOSYSTEMS INTERVIEW QUESTIONS

1. Here is a picture of the forest. Here are some plants and animals from the forest. What are some ways that they are important to each other?

2. Have you ever heard of a food chain? What is it? Can you draw one for me? Explain it.

3. Have you ever heard of a food web? What is it? Can you draw one for me? Explain it.
   >What do these lines show? Can foxes eat other things? Do they eat the same things all year long?
   >What do these pictures show or stand for?

4. One of the kids I talked to said that bigger animals eat small animals in a food web. Do you agree or disagree and why?

5. Show two diagrams. Some kids have said that food webs work like this diagram and other kids have said that they work like this diagram. Which diagram makes the most sense to you? Is there any way that the other diagram also works to tell about something in a food web? (Alternatively, set up the dominoes in a branch or a circle.)

6. Would it matter to the food web if all of the green plants disappeared? Why or why not?

7. One kid said to me that “If anything disappears, the whole thing collapses.” Do you agree or disagree?

8. Owls eat mice. Can you tell me some ways that it helps owls that mice are in the food web? Are there any ways that it helps mice that owls are in the food web?

9. What does it mean for an ecosystem to be in balance?

10. What happens to the ecosystem when there are changes in the numbers of certain animals, etc.?

11. Do some ecosystems have more change than others? How might that affect the organisms living there?

## Appendix B: Materials Developed During the Unit to Teach Concepts

# Ecosystems Discussion Guide: Thinking About Predator-Prey Relationships

One issue that may come up as students are discussing ecosystems relationships is the relative size of predators and prey. You may hear things like:

"The larger animals eat smaller animals"
"Smaller animals can't eat things that are bigger than themselves."
"The biggest animals are at the top of the food web (or food chain)."

Consider this an opportunity to introduce some important ecosystems concepts. First, what are some of the underlying concepts that students may have in mind or may be grappling with?:

- It takes more energy to sustain organisms at the highest levels of the food web than at lower levels.
- There is energy loss as we move from producers and first level consumers to higher level consumers. (This is why we sometimes hear that it is good to eat lower on the food chain or food web.)
- It is often the case that larger animals are carnivores or omnivores.

What are some other important understandings that you can invite through the students' questions during your discussion?

- It is often the case that larger animals are carnivores or omnivores. However, this is not always the case. Animals such as deer, cows, or elephants can be baffling to students. These animals have to consume a lot of green plants to have enough energy to survive.
- Decomposers consume dead matter to get energy for their own survival. These include some of the smallest organisms. In this sense, some of the smallest organisms actually consume some of the largest.

What are some questions or probes that you might use in conversation to get students to think about these concepts?:

- Are there any very large animals that do not eat other animals? If so, what are some of them? What do you know about these animals and how they spend much of their time? *[They spend large amounts of time grazing or eating shrubs, bushes etc.]* Why might they spend their time this way? *[They need to meet their energy needs.]*

- Why are we sometimes told to eat low on the food web or food chain? *[Energy is lost at each level. Plants and lower level consumers make the most efficient use of the energy. With each step up the food web, energy is lost in sustaining life at that level.]*
- What happens to the largest animals when they die? Are they eaten for energy? If so, what eats them? *[Students may not yet know that the smallest decomposers eat the largest dead animals. They may think that the animals just break down or not realize that decomposers break things down to get energy. They often think of them as doing what they do as a public service to the food web. So you may need to post this question somewhere in your room and come back to it.]*
- How have your ideas changed about how bigger things eat smaller things and vice versa?

# Ecosystems Discussion Guide:
# Thinking About Energy Transfer/Conservation in Food Webs

One issue that may come up as students are discussing ecosystems relationships is the issue of energy transfer and conservation of energy. You may hear things like:

"The energy has to do some place, kind of like a circle, I guess."
"The sun's energy goes to the plants and it never stops."
"After a while the energy disappears when the biggest animal dies."

Consider this an opportunity to get students to differentiate between energy transfer and matter recycling.

- Students who know that energy must be conserved, might reason that it is recycled. Other students may also think this in a less examined way. They might just think that it is recycled because they think it travels with the matter always (which it does to a certain extent.)
- There is no easy way to detect energy loss in the system, so students might not think any is lost along the way.
- Some students won't know about conservation of energy and they might assume that it disappears with the largest animal in the food web. This is close to the scientifically accepted understanding for food webs, but is inaccurate from the perspective of what happens to the energy.

What are some other important understandings that you can invite through the students' questions during your discussion?

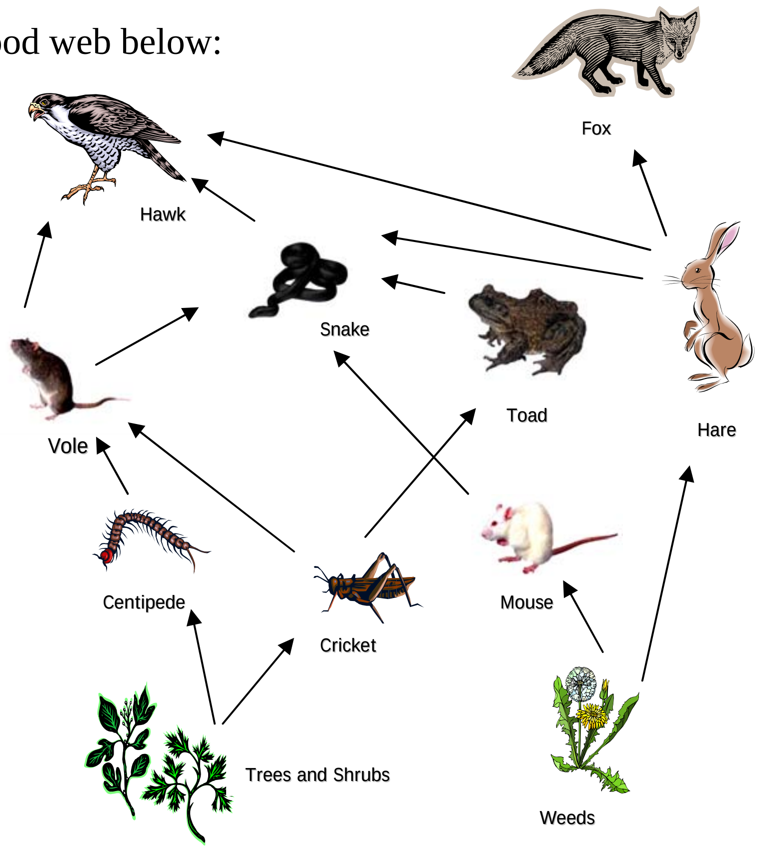
- Energy is lost as it is transferred from organism to organism. It is given off as heat energy and is used to fuel an organism's activities.
- Decomposers get energy to sustain their life and activities when they eat dead matter.
- Energy is given off as heat energy when dead matter decomposes.
- Energy does not cycle the way that matter does. Realizing this helps us to recognize our critical link to the sun.

What are some questions or probes that you might use in conversation to get students to think about these concepts?:

- How does the temperature of a compost bin compare to the temperature of the soil a short distance away or of the surrounding air? What do you think is going on?
- Why are we sometimes told to eat low on the food web or food chain? *[Energy is lost at each level. Plants and lower level consumers make the most efficient use of the energy. With each step up the food web, energy is lost in sustaining life at that level.]*
- Why is it so important that we have green plants to convert sunlight into useable food energy? Can we just store up enough energy that we no longer need green plants? Why or why not?

Name_________________________________ Date__________________

Study the food web below:




What are two things that this food web diagram does a good job showing?

1.

2.

What are two things that you would change to improve this food web diagram?

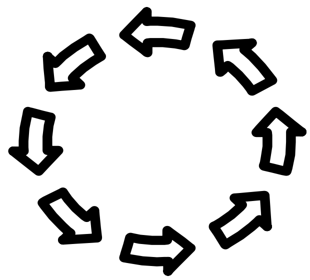
1.

2.

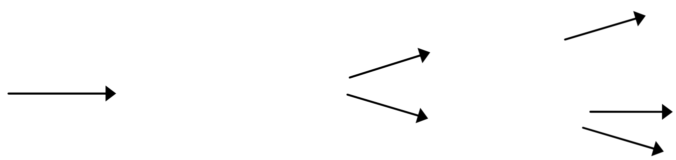
2.

Name___________________________________ Date_________________

Which of the two patterns does the best job illustrating how energy from the sun affects the food web?:



OR



What are two things that the diagram you chose does a good job showing about how energy from the sun affects the food web?

1.

2.

What are two things that the diagram you chose does not do a good job showing about how energy from the sun affects the food web?

1.

2.

Name_________________________________ Date_________________

Think about the microbes growing on the bread. Do you think that there were microbes growing in the place where you rubbed the bread? Explain your thinking.

Draw a model of: 1) what you imagine to be happening in the place where you rubbed the bread and: 2) what you imagine to be happening on the bread. What is different about them?

What do you think the microbes need to grow? What experiments could you design to find out? List your ideas on the back of this sheet.

# Ecosystems Discussion Guide:
# Connectedness vs. Insurance in Food Webs

When students are learning about connectedness in food webs, it is common to over-extend the idea so that they use it absolutely. You may hear things like:

"If anything disappears, the whole thing collapses."
"Everything is connected, so everything depends upon everything."
"If the plants start dying, then everything dies."

In one sense, this is good and it means that they really get the idea of the domino-like connectedness of energy transfer within food webs. Make sure that they solidly get this idea before introducing the idea of insurance. Once they are really clear on that idea, you can back off a little to help them understand that there is some flexibility or "insurance" built into ecosystems. Because kids are growing up in a world of grocery stores when you can get just about any kind of food any time of year, they may not realize that animals in the wild need to eat what is available when it is available. Also, the food webs that they study make the diet sources look definitive and constant. What are some other important understandings that you can invite through the students' questions during your discussion?

- Organisms have some flexibility in their diets. If one food source lessens or dies out, they may be able to eat other food sources.
- Organisms need to be opportunistic in what they eat in order to survive.
- If all the green plants die out, the link to the energy from the sun is lost and then the ecosystem collapses (except in the very rare cases of ecosystems at the geothermal vents.)
- Because organisms have some flexibility, it makes it possible for them to survive variations in their food sources.
- The "insurance" built into the web can make it hard to see when a food web system might be in the early stages of trouble.
- One reason to introduce insurance is that it is part of the larger concept of balance.

What are some questions or probes that you might use in conversation to get students to think about these concepts?:

- What are some of the things that a fox eats?  What might a fox do if he couldn't get one or more of those things?
- Do you think that animals eat the same kinds of things all year long or different kinds of things?  Why might this be so?  *[Berries ripen at certain times of the year and then are gone. Certain animals migrate at certain times and provide food sources. Birds, bugs, etc. lay their eggs at particular times. When a bunch of insects or tadpoles hatch out, there is a wealth of a kind of food for a while.]*
- How might this flexibility in what organisms eat the patterns in the ecosystem? *[The lines in the food web will actually look different at different times. But the food web is less likely to collapse.]*
- How do the food web diagrams that we have been studying make it harder to think about flexibility in what organisms eat?
- What part of the food web is not flexible—meaning that we must have it in order to have life?

Name__________________________ Date________________________

1. We have been talking about balance in ecosystems. What does the word balance mean to you when thinking about ecosystems?

2. Some people think of a balance scale when they hear the word balance. In what ways does a balance scale do a good job helping us think about balance in eco-systems? Draw a scale and explain what it can do a good job showing.

In what ways does a scale NOT do a good job explaining balance in ecosystems? (For example, if you show rabbits on one side and foxes on another, do you need the same numbers or different numbers for balance in the ecosystem?)

Name__________________________ Date___________________________

Balance Between the Grass and the Crickets

In your eco-column, you have grass and crickets. What are some variables that you have to pay attention to in order to have balance between the grass and the crickets? In order for there to be balance, there has to be enough grass to feed the crickets and the crickets cannot eat so much of the grass that the grass can't keep growing.

Draw a model that shows your eco-column with the grass and the crickets.

List the variables that make a difference in whether or not there is balance in your eco-column.

1.

2.

3.

4.

5.

6.

7.

Which of these variables can you measure right now?

Design an experiment to help you measure some of the other variables. For instance, how can you find out how fast the grass grows?

# Ecosystems Discussion Activity:

Read the following text to your students and ask them to think about what happened.

> Mongooses were introduced to Hawaii from India by sugar farmers to protect their crops from rats. While mongooses do eat some rats, they are not nocturnal like rats, so they found other food sources. They eat so many things that they have destroyed the diversity of the organisms on the islands. They have nearly destroyed the bird population by killing them and destroying their eggs. They also eat crabs, fish, fruit, reptiles, frogs, and even small or young mammals. They have no natural predators on the islands so there are now many mongooses on the islands. Hawaii now has more endangered species per square mile than any other place in the world.

Possible Discussion Questions:

1. Why didn't the mongooses eat mostly rats?

2. What kinds of things did the mongooses eat?

3. Why is it good for the mongooses that they eat so many different things?

4. Why is it a problem for the diversity of the Hawaiian Islands that the mongooses eat so many things? Would it be a problem if there were just a few mongooses?

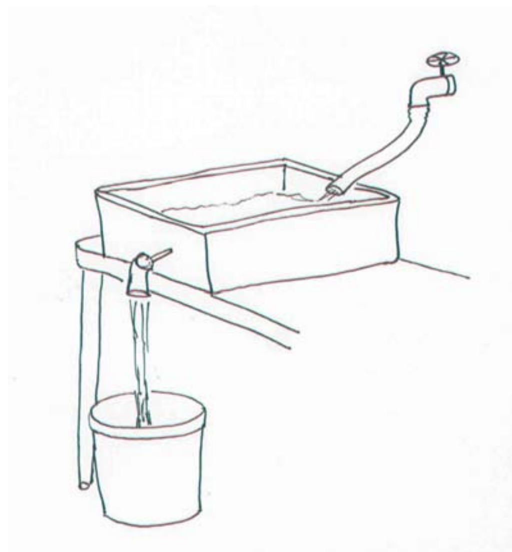
5. Why are there so many mongooses?

6. Do you think that the number of mongooses is increasing or decreasing?

7. What do you predict will happen if the patterns (increasing numbers of mongooses, decreasing numbers of birds and other organisms) continue?

# Thinking about Balance at the Population Level: Demonstration and Discussion

Students get stuck thinking about relationships between individual organisms when thinking about balance rather than between populations. This makes it harder to think about other relationships that come into play such as the energy pyramid for example. One way to focus on the population level is to introduce analogies to energy at the population level. If you undertake this activity, you need to be willing to commit enough time to really discuss it in depth. Analogies can introduce as many misconceptions as they correct if you don't work through them fully enough.



Materials:
>tub or wash basin with an outflow hose at the bottom of the container. It has to have an adjustable rate of flow out and should be at the bottom of the container.
>hose
>water supply
>bucket or catch basin
>marker to allow for measurements

Set the demonstration up as pictured. Turn the water on so it fills at a slow but steady rate. As it is filling, ask the students:

1. What do you see happening? Is this like any systems you have at home? *(bathtub with flow in and flow out, also some toilets)*
2. Could this demonstration help you to think about balance in an ecosystem? Imagine that flow in is the number of rabbits born and flow out is the number of rabbits eaten by foxes.
   >What are some things that the demonstration shows about the number of rabbits and foxes?
   >Is there a point where the system is in balance (or at steady state)? *(when the flow in and flow out are the same)*
   >What happens if there is more flow into the tub than out of the tub?
   >What happens if there is more flow out of the tub than into the tub?

3. What are some ways that this demonstration doesn't work so well to show balance and energy flow? *(If you use it to show flow in as energy that green plants make from the sun, flow out is energy used by other animals, it shows the idea of not being enough flow in to support the animals, but there isn't a problem with overflow or too many green plants. It is also important not to get confused that energy transfer has to do with water—it doesn't. The water is showing the idea of the arrows in the food web.)*

Name ____________________________ Date________________________

# Thinking about the Washtub Demonstration of Balance and Imbalance

Draw model of the tub to help you think about what is going on. What parts must your model show to work like the example in class?

1. What does the hose coming into the tub represent or show? What did it "stand for" in our example?

   What does the size (area) of this hose or the amount that this hose is open show in our example?

   What would happen if you made it bigger or opened it more?

   What would happen if you made it smaller or opened it less?

2. What does the hose coming out of the tub represent or show?  What did it "stand for" in our example?

   What does the size (area) of this hose or the amount that this hose is open show in our example?

   What would happen if you made it bigger or opened it more?

   What would happen if you made it smaller or opened it less?

3. What does the size of the tub show or represent in our example?

4. What would happen in you increased the size of the hose coming in and decreased the size of the hose coming out?

5. What would happen in you decreased the size of the hose coming in and increased the size of the hose coming out?

# Flux in Ecosystems

We often think about balance in ecosystems but flux is a natural part of what happens, too. Flux does not necessarily mean an unstable ecosystem, but it can mean changes in the ecosystem that allow for new opportunities. One way to think about flux in ecosystems is to contrast ecosystems that undergo more or less change over time. Consider the example of Sandy Beaches and Estuaries with your students:

> Sandy beaches are always physically in flux. So there are no permanent communities of inter-tidal plants growing there. The energy to sustain the plants and animals are all imported, mostly from the sea. The ocean brings in phytoplankton and zooplankton. It is captured in the subtidal areas by filter feeders and suspension feeding invertebrates like mole crabs and surf clams. Enormous populations of these animals here but the size of the population is limited by the height of the waves. This is because they capture food best where the sand and organic particles are trapped within the sand and then spread out again by the waves. But they must follow the tides to get enough food. Seaweed drifts ashore and rots to enrich the sands. Beach amphipods and isopods accumulate near the piles of seaweed and are eaten by birds and others digging for prey. Coyotes, rats, seagulls and others scavenge for what they can find.

Ask you students to consider the following questions:

1. What is life on a sandy beach like? How do creatures get the energy that they need to survive?
2. In what ways is this similar and in what ways is this different from how organisms get the energy to survive in a hardwood forest, for example? *[Make sure that your students know that things grow fairly slowly and can be fairly stable in a hardwood forest.]*
3. In what ways is this similar and in what ways is this different from how organisms get the energy to survive in a rainforest, for example? *[Make sure that your students know that things grow fairly quickly in a rainforest and that trees can topple over easily and the physical terrain is less stable than in a hardwood forest.]*

# Balance, Flux and the On-Going Story of Zebra Mussels

In 1985 or 1986, a European cargo ship heading to Canada emptied some of its ballast water (water it takes on to balance the ship) into a lake near Lake Huron and Lake Erie. A species of mussel called the Zebra mussel is believed to have been in the ballast water. The species had no natural predators and grew in amazing and frightening numbers. These mussels colonize the near shore waters and since these are also the places where many fish lay their eggs, they are impacting the birth of new fish and the fishing industry. They began to enter water pipes and to clog them. At first, there was great worry about the mussels and very costly estimates of what would be involved in cleaning the pipes.

It has cost many millions of dollars to remove the mussels from pipes and it has impacted tourism. The big clams that used to live there are gone. On the other hand, some things are not as bad as first predicted. Another mussel seems to have kept the zebra mussel somewhat under control. (However, those two mussels have killed off native mussels and insects.) The mussels have also cleaned up much of the algae and other particulates from the water so that the lakes are much cleaner than they were. (However, this has also caused toxic algae to form so even though the water might look cleaner, the toxin may be harmful to humans and other animals.) Some of the fish have come back because the green algae are gone and they are now eating the small baby mussels!

Questions to Consider:

1. How is the story of the mussels like the story of the mongooses in Hawaii? How is it different?
2. Make a diagram showing some of the effects of introducing the Zebra Mussel to the Great Lakes. Next put a +, -, or ? along the connections to show whether the effect was good, bad, or indifferent/we don't yet know
3. How has the zebra mussel taken advantage of an opportunity?
4. How has the zebra mussel made opportunities for other organisms?

# Causal Patterns in Ecosystems Scoring Rubrics:
# Understandings of Consequence Project

These rubrics are intended to help see whether students have achieved certain understandings and to diagnose the level of students' models and how they are structuring the causal concepts.  The rubrics focus on causal understandings.

Scoring Advice:

- Decide on the answer or level of response that is closest to the student's and record it on the student's summary sheet.
- If a student gives two explanations where a lower level one is elaborated by a higher level one, score for the higher one. If a student gives two competing explanations, average the score of the two unless he or she clearly weights one much more than the other.
- Be sure to include information in any student diagrams when scoring his or her response.
- When scoring for causality, don't punish your less articulate students.  Score for the level of causal model that they most likely understand even if they are not articulate about it. This helps you diagnose whether they understand the causal model even if they could have written a fuller explanation.
- Score with the same level of rigor on the pretest as on the post-test.  Otherwise it will be difficult to see whether learning has taken place.
- Use each rubric to score only the dimension that it focuses on.
- Use the examples to offer an idea of what the level is asking for but don't let it limit your analysis.  Use the description at that level instead.
- When a rubric says "OR" it means that an answer only has to satisfy one part of what it says in order to qualify at that level.  If the student used two or more of the "OR" statements, it still gets scored at that level.

**Question 1a:** Sun, owls, insects, green plants, skunks, mice, toads, and earthworms are all found in an area near the school. Draw and explain the food web that they make up.

<table>
<tr><td colspan="4">Assessment Aim: This question is scored twice: 1) to see if students focus on the patterns in the food web in terms of actions (“what eats what”) or in terms of energy transfer—a more passive process; 2) to assess what students include in their food webs. Do they include only the more obvious actors—the primary and secondary consumers? Or do they also include the less obvious, yet critical, producers and decomposers? Do they include distant parts of the system—the sun?</td></tr>
<tr><td colspan="4">Content Understanding Goal: Energy Transfer</td></tr>
<tr><td colspan="4">Causal Understanding Goal: Passive Causality</td></tr>
<tr><td>Level 1</td><td>Level 2</td><td>Level 3</td><td>Level 4</td></tr>
<tr>
<td>Focuses on active causality: Draws arrows from predator to prey and/or tells what eats what and/or what kills what; dominates with bigger things to smaller things.<br><br>Examples:<br>Skunks → Mice<br>“Skunks eat the mice.”<br>GP → Sun<br>“GP eats the sun.”<br>Adds a human with gun or other animals such as a wolf and tells what each kills.</td>
<td>Mixes active and passive causality: Draws arrows from sun to green plants and/or green plants to consumers, but reverses arrows between predator and prey—showing what eats what. Emphasis on eating but nor arrows (but score no arrows emphasis on sun as an energy source as L 2/3)<br><br>Examples:<br>“The sun gives energy to the green plants. The rabbits eat the green plants.”</td>
<td>Shifts towards passive causality: Draws arrows from prey to predator but doesn’t talk about energy transfer or explains in terms of what eats what.: Refers to food passively “Gives food to”, not energy transfer.; Talks about animals actively and Sun to GP passively BUT shows all arrows passively.<br><br>Examples:<br>Mice→skunks<br>“Skunks eat mice”<br>“Owls kill mice.”</td>
<td>Grasps energy transfer as a form of passive causality: Draws arrows from prey to predator and describes energy transfer relationships. No arrows on the line but describes energy transfer relationships.<br><br>Examples:<br>Mice→skunks<br>“Mice provide energy for the skunks.”</td>
</tr>
<tr><td colspan="4"></td></tr>
<tr><td colspan="4">Content Understanding Goal: Role of Sun, Producers, Primary and Secondary Consumers, Decomposers</td></tr>
<tr><td colspan="4">Causal Understanding Goal: Obvious and Non-Obvious Causes</td></tr>
<tr><td>Level 1</td><td>Level 2</td><td>Level 3</td><td>Level 4</td></tr>
<tr>
<td>Includes obvious components only: Includes primary and secondary consumers<br><br>Examples:<br>Includes skunks, mice, and toads</td>
<td>Includes some obvious and some non-obvious components: Includes producers and primary and secondary consumers OR Includes decomposers and primary and secondary consumers<br><br>Examples: “green plants, skunks, mice, toads” or “skunks, mice, toads, and earthworms”</td>
<td>Includes local obvious and non-obvious causes: Includes producers, decomposers and primary and secondary consumers<br><br>Examples:<br>green plants, skunks, mice, toads, and earthworms”</td>
<td>Includes obvious, non-obvious and non-local components: Includes sun, producers and primary and secondary consumers and decomposers.<br><br>Examples:<br>“sun, green plants, skunks, mice, toads and earthworms”</td>
</tr>
<tr><td colspan="4">**Unscoreable responses include: no response; “I don’t know”; drawing pictures of different animals</td></tr>
</table>

**Question 1b:** Are the green plants important to the other things? If so, circle the things below that green plants are important to: Owls; Mice; Insects Earthworms; Skunks; Toads. Explain the reasons why the green plants are important to the things you circled.

<table>
<tr><td colspan="4">Assessment Aim: This question assesses the connectedness that students see in the food web. It considers whether they detect the domino causality involved and if they see direct and indirect connections.</td></tr>
<tr><td colspan="4">Content Understanding Goal: Detecting Connectedness in Ecosystems</td></tr>
<tr><td colspan="4">Causal Understanding Goal: Domino Causality, Indirect Causality</td></tr>
<tr><td>Level 1</td><td>Level 2</td><td>Level 3</td><td>Level 4</td></tr>
<tr><td>No connections given: Says that the green plants are important but does not elaborate on the principles behind the statement.<br><br>Examples:<br>“The green plants are important.”</td><td>Describes a one step linear or branching, one-way connection: Producers are important only to primary consumers or sees the importance to secondary consumers as having to do with contributions other than energy transfer.<br><br>Examples:<br>“The green plants are important to the insects because they give the insects energy.”<br>“The green plants matter only to the things that eat them, like the insects and the mice.”<br>“The green plants only matter to insects for getting food but they help the rest of the things to breathe.”</td><td>Describes two step, linear connections with indirect components: Producers are important to the primary consumers because they eat them and to the secondary consumers because they eat the primary consumers.<br><br>Examples:<br>“The insects eat the green plants and the toads eat the insects.”</td><td>Describes multi-step linear connections of three or more steps with indirect components:<br><br>Examples:<br>“The insects eat the green plants and the toads eat the insects and the skunks eat the toads.”<br>“The green plants are important to everything because they make the energy from the sun into food and everything else uses that energy.”</td></tr>
<tr><td colspan="4">**Unscoreable responses include: no response; “I don’t know”; drawing pictures of different animals; not a food chain or food web</td></tr>
</table>

**Question 1c:** Are owls important to mice? Yes or no? Why or why not? Are mice important to owls? Yes or no? Why or why not?

<table>
<tr><td colspan="4">Assessment Aim: This question considers whether students detect the mutual aspects of feeding relationships in the food web. Individual organisms benefit in terms of gaining energy and populations of animals are kept in balance by the activities of the predators. Because these benefits construe to the population rather than the individual, many students have difficulty recognizing them.</td></tr>
<tr><td colspan="4">Content Understanding Goal: Detecting Connectedness and Balance in Ecosystems</td></tr>
<tr><td colspan="4">Causal Understanding Goal: Mutual Causality, Population Reasoning</td></tr>
<tr><td>Level 1</td><td>Level 2</td><td>Level 3</td><td>Level 4</td></tr>
<tr><td>Makes a one-way connection: Gives a predator-prey relationship that is described only from the perspective of the predator.<br><br>Examples:<br>“The mice are important to the owls because they are food for them. Owls aren’t important to mice.”</td><td>Makes a two way connection but at the level of individuals: Both owls and mice are impacted but not at the level of population effects.<br><br>Examples:<br>“The owl gets food but the mouse dies.”<br>“Mice help owls but owls kill mice.”</td><td>Makes a two way connection focused on the individual benefits to predators and population effects to prey OR a one way connection focused only on the population effect to the prey: Mice are impacted at the population level and owls gain energy.<br>Example:<br>“If there are too many mice, there won’t be enough food for them, so the owls keep the numbers of mice to a good size.””</td><td>Makes a two way connection where predator and prey are impacted at the level of population effects: Mice and owls are both impacted at the population level.<br><br>Example:<br>“The owls get food (or energy from the mice) and the mouse population stays a good size (or in balance).”</td></tr>
<tr><td colspan="4">**Unscoreable responses include: no response; “I don’t know”; drawing pictures of different animals; not a food chain or food web</td></tr>
</table>

**Question 2:** What happens to a tree in the forest when it dies? What would happen to the tree after a few years?

| | | | |
|---|---|---|---|
| **Assessment Aim:** This question has multiple parts. It considers whether students understand that organism decompose and are broken down into reusable matter as part of the matter cycle. | | | |
| **Content Understanding Goal:** Change Over Time and Matter Recycling | | | |
| **Causal Understanding Goal:** Predicted Change | | | |
| Level 1 | Level 2 | Level 3 | Level 4 |
| *Does not expect a change:* Nothing would happen to the tree.<br><br>Example:<br>"The tree is dead." | *Expects changes **not** related to the decomposition of the dead tree or focuses on near term changes:* Focuses on the tree as a habitat, that it would no longer have leaves, gets knocked over. Also includes Uncertain changes-"If the tree decayed"<br><br>Example:<br>"Animals live in the dead tree."<br>"The tree falls over." | *Expects changes over time that relate to the tree breaking down or falling apart.* Focuses on it breaking up.<br><br>Examples:<br>"After a while, it would fall apart."<br>"Bugs would live in the tree and the tree gets broken down." | *Expects changes over time and focuses on longer term changes that relate to the tree becoming part of the soil.* Focuses on it becoming soil.<br><br>Example:<br>"After a while, the actual tree goes away—it becomes a part of the soil." |
| | | | |
| Content Understanding Goal: Matter Recycling | | | |
| Causal Understanding Goal: Cyclic Causality | | | |
| Level 1 | Level 2 | Level 3 | Level 4 |
| *Focuses on location of the tree or ability to find the tree after a few years:* Describes how its location might change because it had been moved by water, wind, animal, etc.<br><br>Examples:<br>"An animal might move it."<br>"It would be gone; maybe water took it away."<br>"It would blow away." | *Focuses on appearance of the tree after a few years:* Describes how the tree would appear on a superficial level.<br>.<br><br>Examples:<br>"It turns brown."<br>"It looks bad."<br>"It wouldn't have lots of branches."<br>"It falls over"<br>"Branches fall off." | *Focuses on a weakening of tree's structure in some way that distinguishes from simple change in appearance:* Explains how the tree can no longer be recognized as it once was, but does not talk about recycling of matter.<br><br>Examples:<br>"It is falling apart."<br>"It disappears."<br>"It gets eaten by bugs."<br>"It shrinks until you can't see it."<br>"It disintegrates."<br>"It will decompose" "It will rot." | *Focuses on structural change at the micro-level:* Explicitly recognizes the recycling of matter.<br><br>Examples:<br>"It turns into rich soil."<br>"It gets broken down into soil" |
| **Unscoreable responses include: no response; "I don't know" | | | |

**Question 3:** What causes this to happen?

| **Assessment Aim:** This question has multiple parts. It considers whether students understand that organisms decompose, that there are obvious and non-obvious causes for decomposition, and that decomposition depends upon reliable, on-going causes. | | | |
|---|---|---|---|
| **Content Understanding Goal:** Role of Decomposers | | | |
| **Causal Understanding Goal:** Existence of Causal Mechanism | | | |
| Level 1 | Level 2 | Level 3 | Level 4 |
| *Does not expect a change:* Nothing would happen to the tree.<br><br>Example:<br>"The tree is dead." | *Acknowledges that change happens, but does not attribute the changes to a causal mechanism:* Says that it just happens but doesn't give a cause.<br><br>Example:<br>"It just breaks down." | *Attributes the changes to the lack of a cause actively keeping it together:* Says that things just get old and fall apart after a while. *Uses uncertain causes* "maybe something makes it happen" Or attributes it to the lack of something, "Without water, it falls apart"<br><br>Example:<br>"Once the tree dies, it loses its strength and eventually, it just falls apart." | *Attributes the changes to a causal mechanism:* Something makes the changes happen.<br><br>Example:<br>"It breaks down because bugs are eating it." |
| | | | |
| Content Understanding Goal: Role of Decomposers and Matter Recycling | | | |
| Causal Understanding Goal: Obvious and Non-Obvious Causes | | | |
| Level 1 | Level 2 | Level 3 | Level 4 |
| *Does not describe any causes*: Does not mention decomposers, thinks nothing will happen or does not account for changes.<br><br>Example:<br>"It gets brown and mushy."<br>"Nothing happens."<br>"People take it." | *Describes only obvious causes of decomposition:* Attributes changes to causes that one can see such as earthworms and sow bugs.; *Use of the word "decomposers" only*. *Includes processes;* weather; no longer strong enough. *Incorrect or vague responses* "chemicals in the tree"<br>Examples:<br>"Earthworms break down the dead matter."<br>"Bugs eating garbage and dead leaves." | *Describes only non-obvious causes of decomposition:* Attributes changes to microbes as the primary decomposers.<br><br>Example:<br>"Bacteria breaks down dead matter by digesting it." | *Describes obvious and non-obvious causes of decomposition.* Attributes changes to observable (such as earthworms) and non-observable causes (such as microbes.) Include "little organisms" (but they have to say "little" or equivalent.<br><br>Example:<br>"Decomposers like earthworms and microbes break down dead matter by digesting it." |
| | | | |
| **Content Understanding Goal:** The Nature of Decomposers | | | |
| **Causal Understanding Goal:** Characterization of the Causal Mechanism | | | |
| Level 1 | Level 2 | Level 3 | Level 4 |
| *Does not describe any causes*: Does not mention decomposers, thinks nothing will happen, or does not | *Describes unreliable causes*: Attributes changes to things that may or may not happen. | *Describes processes or conditions as the cause:* Attributes changes to background conditions (heat, wetness, aging, rain) that may or may not affect rate of decay | Describes on-going, reliable micro causes: Talks about the role of micro- (molds, bacteria) or macro- (worms, sow bugs) decomposers |

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| account for changes. Doesn't mention a cause at all.<br><br>Examples:<br>"It turns brown."<br>"Nothing happens." | Examples:<br>"Animals happen to sit on it."<br>"A thunderstorm could do it." | Example:<br>"The sun or wind dries it out." | Example:<br>"Bacteria feed on and break down dead matter."<br>"Worms digest it and it is broken up into the soil." |
| **Unscoreable responses include: no response; "I don't know" | | | |

**Question 4:** Is what happens to the tree important to the plants in the forest? If so, how? If not, why not? Is what happens to the tree important to the animals in the forest? If so, how? If not, why not?

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| **Assessment Aim:** This question is scored twice. It considers whether students see decomposition as part of the larger phenomenon of matter recycling. It also assesses whether students grasp the cyclic nature of the process and the conservation of matter that it entails. | | | |
| **Content Understanding Goal:** Matter Recycling | | | |
| **Causal Understanding Goal:** Cyclic Causality | | | |
| Level 1 | Level 2 | Level 3 | Level 4 |
| *Does not mention a cycle:* Gives responses that do not recognize the cyclic pattern.<br><br>Examples:<br>"It's important because it is part of life."<br>"It's what happens next after the tree dies." | *Mentions cycles or circles without explanation:* Says it's like a cycle but doesn't connect it to matter recycling.<br><br>Examples:<br>"It's like a cycle."<br>"It's like the circle of life." | *Mentions decay as part of recycling:* Says that decay turns dead matter <u>back</u> into soil or stuff in the soil.<br><br>Examples:<br>"It turns back into dirt."<br>"The tree grows using the soil and then becomes soil again." | *Mentions decay as part of recycling AND discusses it as a circle or recycling:* Says that dead matter turns back into soil <u>and</u> this is like a circle or recycling.<br><br>Example:<br>"It turns back into soil. This is part of a big cycle that creates rich soil which helps the plants to grow and then they die and create more soil." |
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| **Content Understanding Goal:** Matter Recycling | | | |
| **Causal Understanding Goal:** Conservation of Matter, Cyclic Causality | | | |
| Level 1 | Level 2 | Level 3 | Level 4 |
| *Does not view decay as important or does not address decay:*<br><br>Examples:<br>"It's what happens, but if it didn't, it wouldn't be such a big deal."<br>"Dead things might smell, but that's all." | *Does not recognize the finite nature of matter, but considers decay essential, otherwise dead matter would accumulate or focuses just on the good of having rich soil, not the conservation of matter aspects* (to make food for the earth; to make use if it for the earth)..<br><br>Examples: | *Does not mention the finite nature of matter, but believes that decay is essential for having good soil.*<br><br>Example:<br>"If nothing decayed, there wouldn't be good rich dirt to grow plants in." | *Recognizes that matter is finite and is recycled:* Recognizes that if dead matter was not recycled, that the building blocks for new life would not exist. *Discussion of conservation of matter.*<br><br>Examples:<br>"The particles go back into the soil to become a part of new things."<br>"The matter in the tree will become the matter in something else someday." |

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| | "If nothing decayed, there'd be tons of dead matter everywhere until there would be no room for anything else."<br>"It's like the circle of life." | | |
| **Unscoreable responses include: no response; "I don't know" | | | |

**Question 5a:** What is balance in an ecosystem and what makes it happen?

| **Assessment Aim:** This question considers whether students have a concept of balance at the population level, whether they view balance as playing a role in ecosystem stability, and if they have a sense of factors that lead to balance. | | | |
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| **Content Understanding Goal:** Understanding Balance in Ecosystems | | | |
| **Causal Understanding Goal:** Mutual Causality**,** Population Reasoning, Cyclic Causality | | | |
| Level 1 | Level 2 | Level 3 | Level 4 |
| *Has a concept of balance, but not as it pertains to the abstract concepts in an ecosystem*: Describes balance in terms of a seesaw, a balance scale, not tipping over, etc.<br><br>Example:<br>"If something is in balance, like a seesaw, then the two sides even out." | *Views balance in terms of individual organisms and mutual causality:* Animals have to eat certain amounts or they will deplete their diet sources.<br><br>Example:<br>"If a snake eats too many mice, then it will run out of mice to eat." | *Views balance as a population effect:* In order for an ecosystem to be in balance, the sizes of the populations of organisms has to be just right for the populations of the things that they need to eat.<br><br>Example:<br>"The numbers of each animal has to be in the right balance with the numbers of the animals that it feeds upon for there to be balance." | *Views balance as what creates stability at the level of populations, Might understand factors that give rise to it:* When things are in balance, organisms have what they need to survive. Might describe measures of redundancy (multiple acceptable food sources or habitats) and adaptability (switch food sources or habitats) that provide balance .<br><br>Example:<br>"Balance means that all the animals have what they need and the ecosystem stays pretty much the same. If it is out of balance, things will die out and things can crash quickly." |
| **Unscoreable responses include: no response; "I don't know" | | | |

**Question 5b:** A student said, "It is good for ecosystems to always be in balance." Do you agree or disagree? Why or why not?"

| **Assessment Aim:** This question considers whether students understand that both balance and flux play important roles in ecosystems. Often students believe that only balance is good and all flux is bad. | | | |
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| **Content Understanding Goal:** Balance and Flux in Ecosystems | | | |
| **Causal Understanding Goal:** Mutual Causality**,** Population Reasoning, Cyclic Causality | | | |
| Level 1 | Level 2 | Level 3 | Level 4 |
| *Views only the negative aspects of flux*: States that it is bad for an ecosystem to be in flux because it is unstable. | *Views balance as essential:* Stresses that ecosystems should always be in balance or that balance is the best or "natural" state. | *Suggests that constant balance might be limiting:* States that it is bad for ecosystems to always be in balance because it limits changes and that may be unhealthy in the long term. | *Sees the value of balance and flux:* Considers balance and flux to play important role in ecosystems.<br><br>Example:<br>"Balance and flux both have roles in |

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| Example:<br>"If ecosystems are in flux, species can die out." | Example:<br>"It is important for ecosystems to remain in balance. For example if skunks can't find mice to eat they can eat snakes or green plants." | Example:<br>"If ecosystems are always in balance, how would new species become established?" | ecosystems. More mice than predators can keep in check might result in an unbalanced population until an event like a dry spell causes large numbers of mice to die off." |
| **Unscoreable responses include: no response; "I don't know" | | | |