Causal Patterns in Science
a professional development resource

Understandings of Consequence Project
Teacher Overview

Understanding Ecosystems

What are ecosystems, and why are they difficult to understand? This overview outlines concepts in the Ecosystems curriculum and explains difficulties that students have when learning the concepts. It illustrates how understanding the underlying causality is important in developing a deep understanding of ecosystems.

Section 1 explains the scientific concepts. Section 2 reviews how students' ideas typically progress and what problems they encounter when learning the material. Section 3 illustrates how causal restructuring is important in gaining a deep understanding of the subject. Section 4 outlines typical student misconceptions about ecosystems and is divided into two types: those misconceptions that require learning a new causal structure and those that do not.

What are the Scientific Concepts?

Ecosystems are amazingly complex systems involving individual organisms, their physical surroundings, and interactions between the organisms and between the organisms and their surroundings. Individual organisms of the same species living in the same place at the same time that interbreed are called *populations*. A *community* is a group of interacting populations of different species. The organisms, the interactions between populations in a community, and the community's non-living physical surroundings make up an *ecosystem*. Organisms both cooperate and compete in an ecosystem; the interrelationships and interdependencies of these individual organisms may generate ecosystems that are stable for hundreds or even thousands of years.

The science of studying ecology and ecosystems has many aspects. In the Ecosystems curriculum, the main concepts are energy transfer, matter recycling, the causes of decomposition, symbiotic and mutual relationships, and issues of balance and flux in ecosystems.

In order to live, all organisms (plants and animals) need nutrients and energy. The energy needed by organisms is released from matter and nutrients through the process of *respiration*. All organisms (plants and animals) must carry out respiration. In its scientific meaning, the process of respiration means that food molecules are broken down to release energy; this energy is the energy needed by an organism to carry out the processes of life. Note that *respiration* is different from *gas exchange*, which for humans means inhaling oxygen and exhaling carbon dioxide.

The process of respiration can occur with or without oxygen. For many plants and animals, respiration occurs with oxygen. This is called *aerobic respiration*. However, sometimes respiration occurs without oxygen, even in humans. This is called *anaerobic respiration*.

Organisms called *autotrophs* or *producers* – plants, blue-green algae, and photosynthetic bacteria – make their own food by carrying out the process of photosynthesis. Photosynthesis is a chemical reaction which takes carbon dioxide, water, and energy from sunlight to produce certain food molecules. These certain food molecules are then broken down through respiration, as described above, releasing the energy producers can use. In other words, energy from sunlight is converted by producers into energy that can be used to carry out life processes.

All other organisms, called *heterotrophs* or *consumers*, depend on producers for nutrients and energy. *Herbivores* are consumers which eat only plants. *Carnivores* are consumers which eat other animals. *Omnivores* are consumers which eat both plants and animals. *Scavengers* feed on dead organisms, plant or animal. *Decomposers* break down the complex compounds of dead plants and animals into more simple molecules that they can absorb. Consumers which eat only plants are called *primary consumers*. *Secondary consumers* eat primary consumers. *Tertiary consumers* eat secondary consumers. Tertiary consumers can also eat primary consumers.

A typical way to think of how organisms in an ecosystem get nutrients and energy is to break the food web down into food chains. For example, one long food chain might run like this. Green plants get energy from sunlight, and matter and nutrients from the air (carbon dioxide) and soil (nitrogen, water). These plants carry out photosynthesis which processes the sunlight energy and the matter and nutrients to create their food, and then the plants carry out respiration to release needed energy from their food. A primary consumer, perhaps a rabbit, eats a green plant; nutrients and energy from the plant are then passed to the rabbit. The rabbit carries out respiration, breaking down some of the nutrients to release the energy needed by the rabbit. A secondary consumer, perhaps a bobcat, eats the rabbit; nutrients and energy are thereby passed from the rabbit to the bobcat, and the bobcat carries out respiration. A tertiary consumer, perhaps a mountain lion, eats the bobcat; nutrients and energy from the bobcat are passed to the mountain lion, and the mountain lion carries out respiration. The mountain lion dies and scavengers, perhaps turkey vultures, feed on the dead mountain lion; nutrients and energy from the body of the mountain lion are passed to the turkey vultures and they carry out respiration. Decomposers, such as microbes and fungi, feed on what remains of the mountain lion, breaking down the complex compounds of the lion's body into more simple molecules and elements. These molecules and elements can then be used again by plants. This long food chain of nutrients and energy passing from one organism to another started with the sun and ended with the decomposers, and the decomposers returned material back to the physical surroundings to be used in a new chain. Like threads in a luxurious tapestry, combinations of food chains like the one described here, as well as shorter and longer food chains, weave together to form a food web.

The transfer of energy is a sort of one-way street. A great deal of the energy traveling through a food web in an ecosystem is lost along the way; decomposers pass only matter, not energy, back to the physical surroundings. Much of the energy consumed is dissipated as heat through the process of respiration. Plants can only convert a small amount of sunlight (approx. 1% to 3%) to a useable form of energy through photosynthesis. Only a small amount (approx. 10%) of the stored energy in plants is available to the herbivores that eat the plants and only a small amount of that energy (approx. 10% of the initial 10%) is available to secondary consumers. Because so much energy is lost along the way, there needs to be a constant source of energy available. That constant source is in the form of sunlight, which plants convert to useable energy first through photosynthesis then respiration.

Matter, unlike energy, follows a sort of cyclic process: matter is conserved in an ecosystem, and is constantly cycled throughout the ecosystem. Matter is taken in by producers from their physical surroundings. The matter is passed along to other organisms. When organisms – plant and animal – die, decomposers break down the matter into its basic elements, returning the elements to the physical surroundings to be used again.

Through decomposition, the elements are made available for new use. Some decomposers are obvious, such as earthworms, sow bugs, and mites. Most decomposers, however, are microscopic – tiny organisms such as fungi and bacteria that we call microbes. These microscopic microbes are responsible for most of the matter recycling in ecosystems.

There are many interdependencies in ecosystems. *Symbiosis* refers to the interaction of two species that live together in more or less direct contact. There are different ways such interactions can affect species. In the case of *mutualism*, both organisms benefit from their interaction. In the case of *parasitism*, one organism benefits at the expense of the other: the parasite benefits by living off the other organism, but the other organism usually suffers as a result of this interaction. There are other forms of symbiosis as well, such as *commensalism* and *competition*.

The states of balance and flux are important in ecosystems. At the level of populations (instead of individuals), predators help to keep the populations of prey in balance. This balance is important for the prey population: it helps the prey population live within the limits of resources available to them in the ecosystem. When reasoning about balance, it is easy to get caught up in the idea that only balance is good. Certainly, balance is what enables stability. However, flux also plays a natural and important role in ecosystems. Flux creates new opportunities within an ecosystem and enables new species to become established.

Balance in ecosystems can be hard to observe when a system is actually in balance. It is when that balance is disturbed (sometimes by human impacts) that the complex sets of interactions that result in balance become obvious. Because ecosystems often entail a fair amount of flexibility, initial impacts may not appear to affect the system until it is far too late to undo the disruption.

How Do Students' Ideas Typically Progress?

In general, 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.

Children's earliest thinking about ecosystems is typically self-oriented and human-oriented[1]; this type of thinking stems from children reasoning from their own experiences. For example, children focus on how animals impact people. It is also common for children to think that animals have human wants and desires.

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. However, they may not recognize extended effects such as the effects on secondary and tertiary consumers if there were no green plants.

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. 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[2]. It is also common for young children to assume that events or situations have been planned in advance in order to fulfill a need, as in *'there are a lot of rabbits so that foxes will not get hungry'*[3]. The concept of populations of organisms in the wild is established in children older than age 13, but 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'*[4] 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.

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. 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 starting over again[5]. 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.

Students also tend to focus on simple, one-way patterns when thinking about two-way processes. For example, when bees pollinate flowers, both the bees and flower benefit. However, students often focus on the “active” role, so they see a bee as benefiting from a flower but don’t realize that the flower also benefits. Also, students may realize that an owl population benefits from eating mice, but may not realize that the mouse population benefits from having their numbers kept in check.

What does causality have to do with it?

Students typically use a simple linear causality in their learning of any science concept. They reason that one thing directly makes another thing happen. They also tend to focus on obvious variables – ones they can perceive directly. Yet ecosystems are amazingly complex systems which are greatly affected by non-obvious as well as obvious variables.

Helping students move beyond their simple linear thinking towards more complex notions of how ecosystems work involves helping them understand the causal dynamics involved, especially with regards to the concepts of energy transfer, matter recycling, the causes of decomposition, symbiotic relationships, and issues of balance and flux. This includes understanding the patterns of domino, cyclic, and mutual causality; 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.

In the pattern 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. The typical concepts of food chains are easy to learn and study. Unfortunately, food chains are generally oversimplified; they also tend to suggest that the food chain is about the obvious act of eating rather than the non-obvious, passive flow of energy. Food webs, which attempt to capture all of the possible energy transfer relationships in an ecosystem, can also be misinterpreted as being about the act of eating.

In the pattern of *cyclic causality*, the pattern of cause and effect progresses in a circular fashion. Matter is constantly cycled throughout an ecosystem, and follows a cyclic pattern of use and reuse as it moves between the living and non-living worlds. Through decomposition, elements are made available for new use.

Mutual, or *two-way causality* is a pattern of cause and effect where each component acts as both cause and effect. Symbiotic relationships are an example of two-way causality: what happens to each organism in the relationship has an automatic effect on the other organism. Another form of mutual causality has to do with balance and flux in ecosystems: at the level of populations, predators help keep prey populations in balance, and the prey help the predators survive by provided nutrients and energy to the predator.

Understanding issues related to the causal patterns can help students develop a deeper understanding of ecosystems. For example, non-obvious causes are easy to ignore, yet the organisms responsible for most of decomposition and matter recycling are non-obvious, microscopic microbes. Similarly, indirect effects are easy to overlook, such as extended relationships in food chains and food webs. It is easy to miss 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 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 in 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.

What are typical misconceptions or difficulties in students' understanding of ecosystems that relate to causal structure?

- Students typically focus on direct, one-step connections and overlook indirect, extended effects or connections.[6]

- Most students interpret food webs in a limited way, focusing on isolated food chains[7] [8] [9]

- Students confuse the domino transfer of energy with the cyclic pattern of matter recycling. They end up thinking that energy is recycled and that once there is enough energy, animals only need the sun for warmth, but not food.[10]

- Students typically focus on effects at the individual level, not the population level. This leads them, for example, to feel sorry for the prey that is eaten by predators. This makes it difficult to reason about checks and balance in ecosystems.[11]

- Students draw food web relationships with the arrows going from the predator to the prey to show who eats whom, rather than showing the flow of energy.[12]

- It is common to hear students at all grade levels state that plants use soil and water as food, yet also state that *'plants make their own food'*[13] .

- Students typically reason using linear cause and effect, often thinking about cyclic patterns by breaking the circles into lines; this makes it harder to completely understand what is happening.

- The cycle of decay is crucial to the rest of the food web and the ecosystem as a whole. However, students typically do not describe decay at the level of matter recycling. There are cycles of decay happening all the time (simultaneously) so while each thing rots "in order," there will always be decayed matter available in the ecosystem.

- Students typically do not understand the nature of decay and the role of microbes as decomposers and recyclers of carbon, nitrogen, and minerals.

- The further the effect is removed in time and space from its cause, the harder it is for students to notice the effect and to realize it is connected to the precipitating event.

- Students tend to think of "the balance in nature" and miss the importance of change, or flux, in ecosystems. Students typically reason that flux or change is bad, which makes it difficult to detect the role of flux in positive outcomes.

- Students may be confused about where to apply particular patterns. It is common for students to confuse the process of energy transfer with the process of matter recycling and to think that energy transfer is cyclic.

- Students have problems understanding that animals could not exist in a plant free world.[14]

- After teaching, 65% of 15- to 16-year-olds used the words 'bacteria' and 'fungi' or 'decomposers' but were not sure of role.

- Students realize that dead things disappear over time, but attribute this to causes they can see, such as rain, trampling, or large scavenger animals.

- Students don't know about decomposers and often list unreliable causes for the decomposition of matter. Sixth graders' comments on decay have included such things as[15]; *'Dead branches fall off the trees and you step on' em and they break up." When it's been dead a long time and gets real old it breaks up and disappears. 'The dirt breaks it down. It's something I can't explain in words, but I know about it.' 'When the rain and wind come the dead plant spreads out into the dirt.'*

- Some students describe food chains as *'a big thing eats a smaller thing, and that thing eats something smaller, and it keeps on going like that'*[16].

Young children think that…

- things just disappear when they die (no idea about conservation of matter). Most students are not aware that material from dead organisms becomes part of the nonliving environment or that microbes initiate the process of decay[17,18,19] Following instruction, only 4% of students studied understood that matter is converted back and forth between organisms' bodies and substances in the environment[20]

Students think that…

- energy adds up through an ecosystem so that the top predator would have all the energy from the producers and consumers in the chain.[21]

- rotted material 'enriches' or 'fertilizes' the soil but do not identify it as part of the soil[22]

- energy is recycled, confusing it with matter recycling.

What are other (non-causality-related) typical misconceptions or difficulties in students' understanding of ecosystems?

- Students recognize need for soil, water and sunlight but air, oxygen or carbon dioxide was identified by only a small number of students.[23]

- The youngest students are unable to think of organisms and their environments without human involvement[24] and think that all organisms are fed by people.[25]

- Students could not distinguish between the term 'population' and 'community.'[26]

- Students had problems relating 'plant' and 'animal' to 'producer' and 'consumer.'[27]

- Students think that plants get their food from soil.[28]

- Younger students think that plants make food for the benefit of animals and people rather than for the plants themselves[29] perhaps in response to instruction that stresses how helpful plants are.

- Respiration and breathing are thought to be the same.[30]

- Most students have a limited idea as to what happens to inhaled air, especially relating the need for oxygen with the use of food.[31]
- Some students thought that plants do not respire or only do so in the dark[32]

- Students may confuse food chains with nutrition. They have described food chains as *'like what's written on the label -- sodium, nutrition, fat, cholesterol, all that stuff'*, or *'it's like placing the foods in sections, like the steaks and pork chops are in the meat family'.*[33]

- Some students think that larger animals always eat smaller ones. (For instance, elephants are large so they must eat other animals.)

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