PCK Tools

Food, Food Chains, and Food Webs: Student Misconceptions and Strategies for Teaching

What Are Food, Food Chains, and Food Webs?

The scientific definition of *food* is often confused with its common usage. In everyday usage, "food is whatever nutrients plants and animals must take in if they are to grow and survive. … [I]n scientific usage, food refers only to those substances, such as carbohydrates, proteins, and fats, from which organisms derive the energy they need to grow and operate and the material of which they are made" (American Association for the Advancement of Science, 1993). Food is defined as those substances that provide energy and/or building materials for organisms

A *food chain* is defined as "the transfer of energy from primary producers (e.g. plants) through a series of organisms that eat and are eaten" (Allaby, 1994). A *food web* depicts "the feeding relationships between organisms in an ecosystem….[I]t consists of a series of interconnected food chains" (Allaby, 1994).

Below are a few critical features to bear in mind about food chains and food webs:

- **Autotrophic organisms start off food chains.** Regardless of whether they are terrestrial or aquatic systems, the first organism in a food chain is an autotroph that is able to create organic compounds using simple non-organic molecules (e.g. carbon dioxide) using energy (i.e. light or chemical reactions). The most common type of autotrophs in an ecosystem are photosynthetic organisms, such as plants, that use sunlight to produce their own food. There are some ecosystems, such as deep sea vents, where bacteria start off the food chain by creating organic compounds through chemical reactions. Autotrophic organisms subsequently become food for other animals to consume, which can become food for other animals in return.

- **Plants produce their own food in the food chain through photosynthesis**. Plants can produce their own food, in the form of sugar, from carbon dioxide in the environment through photosynthesis. During photosynthesis light energy (associated with sunlight) is transformed into chemical energy (associated with sugars). The light energy from the sun is captured by the chlorophyll pigment molecules found in the chloroplast organelles of green plants and transformed into chemical energy. Photosynthesis involves a chemical reaction: the light energy captured by plants during photosynthesis is utilized to facilitate a chemical reaction between carbon dioxide and water to produce sugar and oxygen.

- **Food is used as fuel and building material in all organisms in a food chain**. Both plants and animals use food (e.g. sugar, protein, fat) as a source of energy and building material. Energy is released in another chemical reaction (respiration). In this process that occurs in both plants and animals, sugar molecules react with oxygen molecules to produce water molecules and carbon dioxide molecules. In addition, during respiration chemical energy is released and can then be transformed into other types of energy and used for a variety of functions. For example, the chemical energy can be transformed into mechanical energy to allow an organism to move. If the broken-down food is not used as a source of energy, it can serve as building material for the organism and can be incorporated into the structures of the cells.

- **Matter and energy are conserved in the food chain**. The flow of matter and energy in a food chain obey the laws of physics and chemistry (see PCK tools on Energy and Change and Matter). Whether it be photosynthesis, respiration, or catabolism (e.g. the building of biological molecules within cells), matter and energy are conserved. This applies to all matter and energy transformations within organisms. Thus, during photosynthesis the carbon atoms in carbon dioxide are rearranged to produce sugar molecules, and during respiration the carbon atoms in sugars are rearranged to produce carbon dioxide. No carbon atoms appear or disappear from existence in these processes. Energy is also conserved. Energy can be passed from one organism to another in a food chain or dissipate through heat, but it is never destroyed.

State Standards

On the overall topic of food, food chains, and food webs, **New Jersey Core Curriculum Content Standards** hold the following learning goals for the middle grades:

- Explain how organisms interact with other components of an ecosystem.
- Describe the effect of human activities on various ecosystems.
- Explain how the products of respiration and photosynthesis are recycled.

The Texas Essential Knowledge and Skills (TEKS) standards set these learning goals for the middle grades:

- Identify that radiant energy from the Sun is transferred into chemical energy through the process of photosynthesis.
- Describe interactions within ecosystems.

- **Not all energy and matter are <u>utilized</u> in the food chain**: Even though all energy is <u>conserved</u> in the food chain, not <u>all</u> energy is <u>utilized</u>. During the process of energy transformation some energy is released out of the system (e.g., does not pass from one organism to the next in the food chain) in the form of heat (thermal energy). Hence, much of the energy from the sun is not utilized by the photosynthetic organism to do any work (see Energy PCK tool). Likewise, when an animal eats a plant or another animal for food, much of the chemical energy in the food is not utilized. A very clear example of this is when a person exercises: during vigorous activity, a lot of chemical energy in food is transformed into mechanical energy in order to move the body, but during this process a lot of heat is released from the body and this heat is not utilized by the body to do any work. Similar to energy, not all the matter in food is utilized when it is transformed from one form to another. For example, when an animal such as a human eats a carrot, not all the carbon atoms are necessarily transformed to other substances inside the animal; some of the matter exits the animal as undigested waste.

- **Changing the abundance of one organism in a food web can often have direct and indirect affects on many other organisms in a food web.** This point is nicely illustrated by the aquatic ecosystem in Lake Victoria. Humans introduced a nonnative perch to this African lake, and as a result of the increase in population of perch, a lot of smaller fish declined (Hazen & Trefil, 1990). Since these smaller fish feed on algae, algae growth went up sharply. The increase in algae lead to more algae dying and falling to lower levels in the lake. Once fallen, the algae decomposed. The dramatic increase in decomposing algae lead to depleted oxygen levels at lower levels and forced fish that lived at that level to move to higher levels, but those fish were soon impacted by the perch also. Thus, organisms far removed from the perch in the food web—the algae and fish at low levels in the lake—were dramatically affected. This example illustrates how all organisms in a food web are connected through a variety of different direct and indirect relationships.

What Common Misconceptions Do Students Have Around Food?

All children have eaten food. Many parents have told their children to eat something because it is "nutritious." However, these experiences do not translate easily to the scientific notion of food as a source of energy and cellular building material for all living organisms, including humans. Food for plants as defined in this manner, along with the process of photosynthesis, are considered some of the "most difficult [concepts] for students" (Stavy, Eisen, & Yaakobi, 1987). The scientific concept of the food chain also connects plants and people together and helps us to understand how everyone and everything impacts our larger world.

"There is little and contradictory research about how biological knowledge is structured by children," writes Teixeira (2000). While some researchers contend that children come to certain biological understandings from daily life experiences with food (Hatano & Inagaki, 1997), others have argued that young children have no knowledge of biology and must be taught with these understanding as the context (Carey, 1985). However, there are some things we do understand that may be helpful in addressing student misconceptions.

Children think of food as “anything taken into an organism’s body, including water, minerals, and, in the case of plants, carbon dioxide or even sunlight” (Driver, et al., 1994). While they understand it to be necessary to keep people and plants alive, they do not talk about the role of food in metabolism. These notions do not always improve after instruction.

In addition, many students seem to have a limited understanding of the role of food for organisms. Eisen and Stavy (1988) found that among high school and university students, only 14% related food materials for building the body and only 11% related food to both energy and materials for building the body. Thus, this study suggests that many students did not fully comprehend the roles of food because they failed to realize that it has dual roles: providing energy for the organism and providing building material for the organism.

From an early age, children have vague ideas that link eating with several consequences: growth, health, strength, and energy. Carey (1985) argues that eating has such strong psychological and social significance that children understand food only in such vague ideas rather than in biological terms. Gellert (1962) found that by age 11, many children have some basic understanding that food is broken down, that acid breaks down the food, and that some kind of “goodness is somehow extracted.” However, the process of this “extraction” is unclear to students. Furthermore, our goal is to help students to understand the biological role of food, not to simply think of it as “goodness.”

Students think that digestion is the process that releases energy from food. Only 3 of the 34 children between ages 9 and 11 knew that food is broken down in the stomach and that it provides what the body needs after being broken down into other substances and carried to tissues throughout the body (Gellert, 1962). Simpson (1984) found that a common misconception for students is to think that digestion is the process that releases energy from food, because they correctly understand that energy comes from food and that digestion is the process of breaking down food.

Students do not understand the chemical process of acquiring energy from food. According to Rowlands (2004), children at age 10 take a “mechanical” approach to understanding what happens to food after swallowing. They see it as “being contained inside a sack or tube in the body” and then as a “process of separation of useful parts of the food from non-useful parts, with the former being retained and the latter got rid of as feces.” Teixeira (2000) says that students at that same age understand the function of the organs and have a “biological basis” for understanding the digestive system. However, in both cases, students show no sign of understanding these changes as chemical processes in which matter is transformed from one type of substance to another during digestion. Similarly, Stavy and colleagues (1987) report that when students are asked about the “chemical elements” upon which the body is built, students were surprised by the question and list parts of the body instead of substances such as carbohydrates and protein. Students have little understanding of the chemical energy in food being *transformed* into other types of energy and the matter in food constituting an organism's body, especially their own.

What Common Misconceptions Do Students Have Around Photosynthesis?

A number of researchers have described photosynthesis as one of the most difficult topics for students to learn. Barker and Carr describe photosynthesis as "counterintuitive" and similar to "the makings of a fairy story" (1989). Why is this subject so difficult for students?

Students do not have the chemistry knowledge required. Many pupils do not have the "prerequisite concepts of living things" such as gas, food, and energy required to understand photosynthesis (Driver, et al., 1994). Arnold and Simpson (1980) point out that students need to understand that

> an element, carbon (which is solid in pure form), is present in carbon dioxide (which is a colorless gas in the air) and that this gas is converted by a green plant into sugar (a solid, but in solution) when hydrogen (a gas) from water (a liquid) is added using light energy which is consequently converted to chemical energy.

Stavy, et al., (1987) found that 8^{th}-grade students in Israel, despite previous teaching in chemistry, "had serious gaps in ... knowledge of chemical notions required for an understanding of the basic processes of photosynthesis." Students do not understand the essential elements in living things, such as oxygen, hydrogen, and carbon, and in many cases can be confused by simple terms such as "element" and "compound." Further, they are not comfortable with the understanding that a gaseous element is a real substance with mass and weight, an essential notion in understanding how plants use carbon dioxide.

Students think that plants get their food from the soil. This is a very common misconception found by multiple researchers and summarized by Bell (1985). It is simply easier for students to believe that roots are used for feeding instead of coming to understand that photosynthesis is the process by which plants can produce their own food. Further, students understand that plants absorb water from the soil and think that this is the main process for growth (Barker & Carr, 1989). This stands to reason, as we talk about fertilizer for the soil as "plant food" and ask children to water plants. Commercial products that are labeled as "plant food" that students may have seen their parent's purchase or have seen advertised are also misleading (these often contain important elements or minerals that plants need, but do not actually provide *food* as defined by biologists).

Students do not understand photosynthesis as the process of transforming light energy to chemical energy and stored in chemical compounds. In a report by the project Children's Learning in Science (1987), it was found that students believe that photosynthesis is a substance instead of a process. Tamir (1989) found students describing it as a kind of "plant respiration." There is little understanding of food providing energy for the plant's life processes or energy transfers in plant metabolism. Barker (1985) found that only 3% of students described photosynthesis in terms of a process that leads to the storage of energy in food.

Students do not understand the role of chlorophyll. Children think of chlorophyll as one of the following, according to a number of researchers (Driver, et al., 1994):

- a food substance
- something that provides protection
- a storage product
- a vital substance like blood
- something that makes plants strong
- something that breaks down starch
- something that attracts sunlight or absorbs carbon dioxide
- something that makes leaves green and attractive

In many cases the role of chlorophyll is still unclear after teaching. Simpson and Arnold (1982) found that only 29% of 12- to 13-year-olds and 46% of 14- to 16-year-olds correctly understood the role of absorbing light energy and helping to convert it to chemical energy.

Students do not understand the role of the sun in photosynthesis. Despite experiments in which students see germinating seeds and mature plants kept in the dark, this idea seems to hold (Roth, Smith, & Anderson, 1983). Nearly 80% of 13-year-olds thought that plants use heat (instead of light energy) from the sun as the energy for photosynthesis. In addition, most pupils considered that the sun is one among many sources of energy for plants, also including soil, minerals, water, air, and wind. Thus, many students equate sunlight to substances like water or minerals. As a result of such naïve conceptions, many students fail to recognize the essential role of sunlight in photosynthesis.

Students do not understand the gas exchange of carbon dioxide and oxygen in plants. Often children have a "plant breathing–animal breathing" model: Animals breathe in oxygen and breathe out carbon dioxide, and plants breathe in carbon dioxide and breathe out oxygen. They think of photosynthesis as a type of respiration. The terms *breathing* and *respiration* were often used interchangeably, and *oxygen* is equated with *air*. They also believe that plants exchange gases primarily for the benefit of people. Students need to understand that oxygen is simply a waste product of the process (Driver, et al., 1994).

Students tend to hold onto beliefs historically held by scientists of the past. Wandersee (1985) found that three patterns of beliefs often held by students similar to historical viewpoints:

1. Younger students (elementary and junior high) are more likely to hold concepts of photosynthesis once accepted by scientists but now discarded or greatly modified.

2. Societal practices (such as those about raising plants) tend to encourage students to hold on to these outdated concepts of photosynthesis.

3. Students at all grade levels studied may hold misconceptions about photosynthesis that are similar to those that occurred and are documented in the history of science.

What Common Misconceptions Do Students Have Around Food Chains and Food Webs in Ecosystems?

The following section addresses some naïve conceptions about food chains and food webs; however, there is more on naïve conceptions concerning the related ecological concepts of predator-prey relationships, interpreting food webs, and feeding relationships that can be found in the Population and Community tool.

While most students understand that people and animals could not exist without plants, a study of students aged 13 to the college level found that some thought that "carnivores could exist if their prey reproduced plentifully" (Stavy, et al., 1987). The students did not understand the indirect relationship between carnivores and plants. Food chains are often thought of in terms of the food being eaten and not in the larger context of our interdependency upon other organisms. In addition, we also have a tendency to underemphasize the importance of the conservation of matter and energy when covering food chains and food webs in school; and unfortunately, a failure to understand such conservation principles may underlie some of the problems in this area (Driver, et al., 1994).

Students interpret food webs in a limited way. Griffiths and Grant (1985) and Barman, et al., (1995) along with Hogan (2000), found the following misconceptions to be common at the high school level: "1) students tend to interpret food webs in terms of individual rather than interconnected food chains, and 2) students focus on direct rather than indirect effects of perturbations, which limits the number of steps they trace within food webs." They focus on linear food chains in an isolated way, specifically the predator-prey relationship and fail to recognize the cyclical flow of matter and the interdependent relationship of organisms within an ecosystem.

Students (as well as adults) are egocentric and anthropocentric. Children can be self-centered by nature, especially at very early ages, so it should not be a surprise that children see the food chain as "all about us." The species that are lower on the food chain are simply seen as existing to feed the next level up. Using what is termed *teleological reasoning*, students think that there are lots of rabbits simply so the foxes that eat them will not get hungry (see Population and Communities tool for more on teleological reasoning). Similarly, as discussed earlier, students think that plants undergo the process of photosynthesis just so we humans can breathe.

Students see the food chain simply as a series of feeding relations and do not consider the purpose of the food. Many see the study of ecology as simply the "hierarchical chain of eating events" (Eilam, 2002). Despite study of the world's constant flow of matter and energy cycles, students in a study by Reiner and Eilam (2001) continued to focus on feeding over the chemical aspects of "supplying cells with matter and energy" to support life (Eilam, 2002). Their original beliefs remained and made it difficult to develop a full meaning of ecology, including topics such as energy transfer and conservation, as well as matter transfer and transformation.

Students appear to have deficits in understanding feeding relationships.
Eilam (2002) analyzed student perceptions of feeding relations after specialized instruction to find deficits in each of four “dimensions of understanding”:

1. *Macro-level dimension of feeding relations* (e.g., specific roles and order in the chain). Students continued to perceive

- the abiotic (a nonliving component of an ecosystem such as sunlight) phase as part of a food chain,
- a cyclic rather than web configuration, and
- the decomposers as feeding only on the last element of the chain. (pg.664)

2. *Micro-level dimension of feeding relations* (e.g., the principle that molecules travel in and through the organisms as part of the world’s matter cycle; transfer of matter and energy in ecosystems in general and food chains in particular). Students’ difficulties in this dimension related to the understanding of

- the formation and transformation of sugars and other organic and inorganic compounds in certain cells and
- the constant change in molecular structure and amount, and in the energy tied into the molecules’ chemical bonds, while they flow inside a whole organism or through several organisms. (pg. 664)

Deficits were evident in simultaneously accepting both above phenomena and the fact that these flows of compounds continue to conform to the laws of matter conservation.

3. *Spatial dimension of feeding relations* (e.g., a dynamic view of the simultaneous occurrence of many activities in space and of organisms’ capacity to hold several roles at any point in time). Three main difficulties characterized students’ perspectives regarding this dimension:

- the inability to grasp multiple occurrences as simultaneous (expressed in their responses to the extinct links in chains),
- a difficulty in considering each element in the chain as occupying more than one role (expressed in their responses to the bacteria case and their discussions of the carnivore plant), and
- a unidirectional perception of feeding relations (expressed in viewing an organism as feeding on several others but not as being food for several others). (pg. 665)

These difficulties constrained students’ understanding of the web configuration.

4. *Time dimension of feeding relations* (e.g., evolutionary forces that select webs rather than chains; an organism’s inability to feed on just any other organism due to its biological structure as selected in the course of evolution). Deficits emerged in students’ understanding of the long-term effects rendered by evolutionary processes on organisms’

structures and functions and the influence those have, in turn, on the final structures of feeding webs in ecosystems. (pg. 665)

Key Points on Student Misconceptions: Food, Food Chains, and Food Webs

- Everyday language and experiences with food poses problems for understanding the scientific understanding of food and its role for organisms.
- Many students assume anything put into the organism is food, including water, vitamins and minerals.
- Many students are unaware that plants make their own food—often thinking instead that it is taken up through the roots in the soil.
- Many students do not apply principles of conservation of energy and matter to the flow of matter and energy through food webs and ecosystems.
- Students fail to develop the idea that matter from the carbon dioxide in the air is incorporated into the structure of a plant as it grows. Students fail to develop the idea that matter from food is incorporated into the body structures of animals.
- Students fail to realize that the processes by which plants make sugar (photosynthesis) and by which we obtain energy from food (respiration) are chemical reactions in which matter and energy are conserved and rearranged to form new molecules.
- Students tend to focus on direct interactions and affects, and often fail to account for more removed and indirect affects on other organisms in the food web.
- Students fail to realize that just one change in a particular population of organisms can affect all the other populations of organisms in the ecosystem.

Strategies to Address Student Misconceptions About Human Food Chains and Food Webs

These are all difficult topics, and taken together provide a much broader view of the world than many students are used to. Listed below are some suggestions from the research on how to reach students and help them to understand these ideas about food, food chains, and food webs.

Understand and Address Student Misconceptions

As in other areas of science, teachers need to understand what their students believe and address their nonscientific viewpoints. Teachers must create “a sense of ‘dissatisfaction’ with existing explanations” by providing other explanations that are more powerful than the misconceptions (Mintzes, 1984). This can be done through classroom experiences and experimentation, (e.g., germinating seeds and growing mature plants kept in the dark) along with discussion and debate about the differing notions. Such debates must take place in a “non-judgmental atmosphere so that students feel comfortable asking questions and expressing their confusion so that they can come to understand the scientific viewpoint” (Mintzes, 1984).

Review and Stress Chemical and Biological Knowledge

Students must have a clear understanding of basic chemistry and about the ways in which living things are made up of chemical elements to understand both photosynthesis and the ways in which humans and animals use food. They must realize that food has certain chemical elements that people need and that plants also use chemical elements in the process of photosynthesis. Further, the basic biological concepts outlined previously must be clear in order for students to have a full understanding of food chains and our larger ecosystem.

Use Analogies to Explain the Way the Human Body Uses Food

Analogies in science teaching are useful in many contexts, and the kinds of comparisons between the body and familiar everyday processes (e.g., a car getting gasoline) could be a way of helping children to make the distinctions involved. Rowlands (2004) argues that “merely supplying more factual knowledge about the body without there being such basic understanding may not be helpful or may even be confusing and counterproductive.”

Use Science History to Bring Students to the Modern View

If students are made aware that their misconceptions were also held by the scientists of the past, they may see that their ideas are not just wrong but instead the first step toward learning what modern scientists have come to understand today. Expose students to the misconceptions of the past so that they can find their own ideas among them. If a teacher compares and contrasts the historic and modern views, students may be convinced to revise their ideas (Wandersee, 1985). After all, kids always want the latest thing.

Use Concept Mapping as a Way to Connect Topics and Determine Student Understanding

With topics that are so interconnected and also so confusing for students, the use of concept mapping seems especially appropriate, as exemplified by the work of Lin and Hu (2003). Students are able to map their understanding of the topics, and teachers can get a clearer picture of how students are thinking. Children might be given relevant words (e.g., respiration, photosynthesis, energy, food, producers, consumers, oxygen, carbon dioxide, water, etc.). Each word is written on a small square of paper, and then students have to construct a diagram where related terms are placed close to each other. Relationships are shown by linking terms with lines, and sentences are added to the lines to show what the relationship is. If the mapping activity is done by groups of students, they are forced to justify their choice of arrangement of the terms, and articulate their own understanding.

Focus on Causality to Address Misconceptions in Ecology

Some researchers contend that the root of many misconceptions about systems in ecology and other scientific disciplines stem from a limited understanding of the nature of causality. Use activities and/or discussions that make different forms of relational causality (e.g., extended linear, two-way, and cyclic relations) explicit for the students (Hogan, 2000).

Require Students to Apply Knowledge in the Study of Ecosystems

According to Eilam (2002), “students must personally and actively use and apply knowledge in order to (a) make sense of ecology theories studied in the classroom, (b) construct their own relevant, interrelated bodies of knowledge about ecology, and (c) bring about a gradual conceptual change of ecological processes.” Students should be able to alter their mechanical representations of food relation concepts in order to develop “a deeper understanding of complex, dynamic, energy-and-matter-based concepts,” thereby integrating knowledge of ecology and physics.

Getting Tangled in the Food Web: Closing Thoughts

Research on student learning indicates that even after relevant instruction, students have difficulties understanding ideas about food, plant, and animal nutrition, and the release of energy from food. Photosynthesis is “so complex and completely different from the nutrition of animals” that we should not be surprised that these concepts should be confusing for students (Wandersee, 1985). Students are influenced by many experiences that do not support the scientific viewpoint, such as watering plants and talking about fertilizer as “plant food.” Further, humans see themselves as the highest form of life on the planet, so remembering our larger role in the food chain and the importance of plants in our everyday lives can be a challenge for students.

Part of the problem may be the need for a more interconnected understanding of an essential topic: energy. Students encounter this topic in four biological contexts that are essential to understanding feeding relations: photosynthesis, respiration, nutrition, and the interdependency of organisms. However, this version of energy is very different from the one used in physics classes. Indeed, although all of the phenomena we experience in the world are connected in the world of science, we break them up into individual topics: biology, chemistry, and physics (Eilam, 2002). Klein (1990) asserts that the subjects comprising ecology “cannot be contained within a single disciplinary framework.” Concepts in ecology interact with concepts in physics such as equilibrium. As mentioned previously, students must have a firm basis in chemistry to understand photosynthesis, a concept generally covered in biology. Just as plants, animals, humans, and even the sun interact with regard to nutrition, so too do the differing branches of scientific study when we cover this broad set of topics.

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