FEATURE ARTICLE

Food Webs: Implications for Instruction

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Abstract

The interdependency of relationships and energy flow in ecosystems are crucial biological concepts that students frequently find hard to understand. They are one of the foundations to the survival of living things and the complex processes that balance life on Earth. The ability to interpret food chains and food webs is fundamental in the communication and understanding of relationships between organisms in the domain of biology. I examine the ways elementary-level students read a simple food web diagram and the effect this has on their understanding of the encapsulated biology concepts. Diagram reading approaches are described along with analysis of how meaning making is influenced by students' preconceived ideas. The results indicate the students experienced a range of difficulties in reading the food web diagram. I conclude that food web instruction must address prior knowledge, challenge preconceptions, and involve deep diagram processing. The research provides insights into the difficulties high school students have in comprehending food webs and understanding relationships in ecosystems.

Key Words: *food webs; ecosystems; diagrams; arrows; elementary students.*

○ Introduction

Progressing Learning about Food Webs

Food webs are a specific type of diagram used in biology to represent energy flow in ecosystems. The ways elementary-age students approached and explained food web diagrams is the focus of research discussed in this article. The study aimed to capture the extent to which pre-high school students could make sense of a food web diagram. The explanations developed were analyzed to determine how the diagram helped them understand the embedded ecology concepts. Food webs are designed to convey the overarching concept of unidirectional energy flow from autotrophs to different levels of consumers (herbivores, carnivores) and ultimately to decomposers. Students frequently misunderstand this concept as they "incorrectly identify the direction of energy flow and fail to precisely differentiate the concepts of food chains and food webs" (Grumbine, 2012). Students also lack knowledge about the role decomposers play in food webs or energy pyramids. Even after instruction students may retain the view that decomposers are simply waste removers that keep the "environment clean by eating dead animals and plants" (Ozkan et al., 2004, p. 103). Insight into why such misunderstandings prevail can be gained from considering the knowledge and understanding, including the preconceived ideas, students bring with them to high school biology. Research in the learning sciences area indicates that lessons on new concepts in a particular domain should be "designed to activate and build on their existing knowledge" (Moreno et al., 2011, p. 33). Findings from my research can assist high school teachers to challenge and extend their students' understanding of the ecology concepts conveyed by food web diagrams. In the Next Generation Science Standards (NGSS, 2013) food webs are encompassed by two disciplinary core ideas: in LS2.A *Interdependent relationships in ecosystems*, food webs occur in the year 3-5 grade-band, and LS2. B *Cycles of matter and energy transfer in ecosystems* specifies food webs in both the year 6-8 and 9-12 grade-bands.

Food webs are a specific type of diagram used in biology to represent energy flow in ecosystems.

Research Relating to Diagrams and Food Webs

Teacher awareness of students' previous ideas related to food webs and how they make sense of these visual representations is essential for guiding deeper conceptual understanding. Diagrams are perhaps the most frequent type of representation, forming concrete models to support students' learning of abstract processes (Lankford & Friedrichsen, 2012). Biology concepts are frequently represented visually through different types of diagrams

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(Cheng & Gilbert, 2015). Diagram comprehension has been described as "a key competence for students in mastering many of the biological theories" (Kragten et al., 2013, p. 1786).

Food webs are typical of science diagrams because they require strategies, knowledge, and skills specific to the biology science domain (Lowe, 2000; Cheng et al., 2001). We can expect that school students inexperienced in reading science diagrams will view them differently from their teachers. Questions about students' interpretive approaches to food web diagrams bear thinking about. Do students pay more attention to different parts of food webs? Do they mentally represent food webs at a number of levels? Do they mentally separate food webs into smaller components, enabling conceptual chunking to accommodate the complex concepts involved? A problematic aspect of science diagrams for inexperienced learners is the use of graphical conventions that differ depending on diagram type and science domain. Especially confusing is the use of arrows, because they can convey a variety of meanings in science diagrams, some simultaneously (Heiser & Tversky, 2006). Arrows are a common convention in biology diagrams (Cheng & Gilbert, 2015).

An earlier, but pertinent study investigated how the presence of arrows influenced secondary students' interpretation of science diagrams (Schollum, 1983). Students were shown paired diagrams, with and without arrows, and asked to explain what each meant to them. Some pupils gave different meanings to arrows than those intended to be conveyed. For example, students could explain clearly what food chain diagrams showed without arrows, providing responses such as "the bugs eat the bush, the birds eat the bugs." The diagrams including arrows resulted in a wider range of views that were expressed less confidently. Half the students were puzzled, as indicated by replies such as "This looks like the cabbage is going to eat the caterpillar" and "Those arrows are around the wrong way" (ibid., p. 47).

In a larger study involving elementary and high school students, 5- to 16-year-olds were shown a food web diagram to probe the reasoning they used to think about populations of organisms (Leach et al., 1995). Although the aim was not to find out whether students could interpret the diagrams, some of the findings are relevant to the current study. Five- to 11-year-olds tended to "talk about organisms in the singular, suggesting a relationship between one predator and prey organism as opposed to relationships between populations" (Leach et al., 1996, p. 136). Students also had difficulty interpreting food chains in which the energy exchange relationship is depicted by arrows. The authors noted that use of food web models by students differed from their intended use: students applied linear causal reasoning and tended to frame their explanations in terms of individual organisms rather than populations (ibid., p. 140). In another study grade 6–8 students reportedly had difficulty reading food webs when symbols (e.g., A and B) were used instead of names of familiar organisms. Students interpreted arrows as pointing from predator to prey, suggesting unfamiliarity with the conventional meaning of arrows in food webs (Lennon & DeBoer, 2008). Food webs are difficult to understand fully at the elementary level due to the biological conceptions of the complex ecological systems involved. Such meaning is not embedded in the diagram, but must be actively created in the mind of the reader (Cheng & Gilbert, 2015, p. 144). The current study explores elementary level students' interpretation of food web diagrams.

○ Methods

Overview of Research Methods

The present study conducted in Australia adopted a qualitative approach (Johnson & Christensen, 2004; Maxwell, 2005). Participants were Year 3 (8–9 years old, $n = 10$) and Year 5 (10–11 years, $n = 11$) students from a suburban, government school. Males and females were selected by their class teachers to include low-, medium-, and high-ability students. Individual students were involved in semi-structured, task-based interviews. Separate teacher interviews and examination of students' notebooks confirmed that science was given low priority in the school. Students were not formally taught about food webs prior to or during the study.

The data were collected in three steps. First, each participant was shown the toy objects in Figure 1 and asked if they could answer the question, "What eats what out of these things?" This was designed to elicit prior knowledge and help students feel at ease in expressing their ideas by having tangible objects to focus on.

Second, a typical, simple food web diagram intended for assessment of Year 4 primary students was used. The visual-only food web diagram (modified to remove labels) in Figure 2 was shown, and the student was encouraged to talk freely (out loud) about the image to tell the researcher (author), "What do you think this picture is telling you?" The "think aloud" method allowed me to understand what the student was thinking as they interacted with the diagram. This visual-only version also tested whether text was essential to diagram reading.

Third, if students struggled to make sense of the diagram, they were shown the labelled food web in Figure 3. This version included text naming the organisms and was modified to include arrow meaning based on another question from the same source. This modification was made because "the function of an arrow in a process diagram is usually conveyed by a label" (Kragten et al., 2013, p. 1788). This version tested whether this information helped or hindered the students. The entire interview was repeated after one month to test for long-term learning effects. No direct instruction about food webs had occurred during this time period.

Figure 1. Bird, snail, frog, and artificial plant.

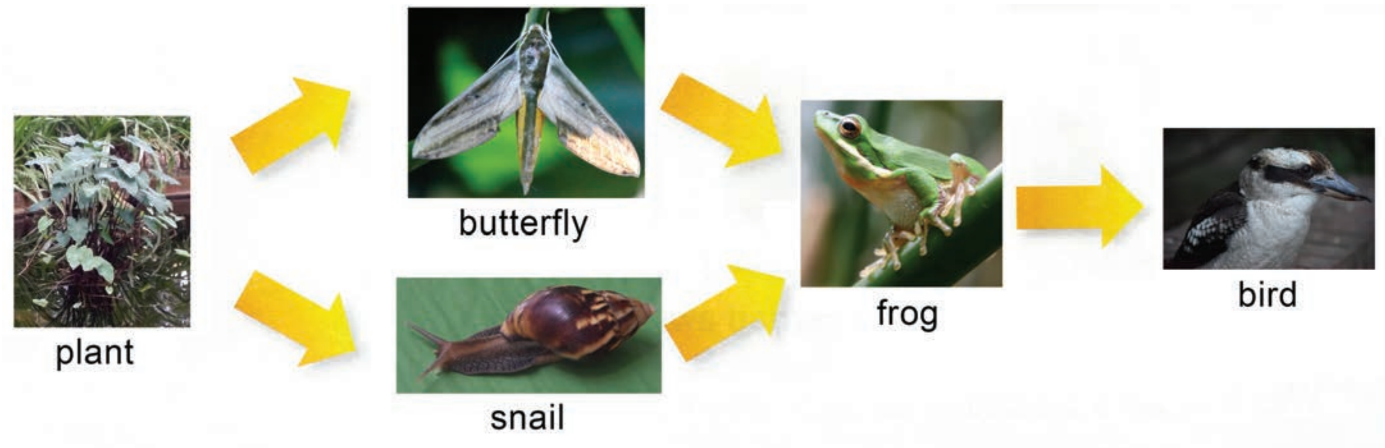

Figure 2. Visual diagram replica.

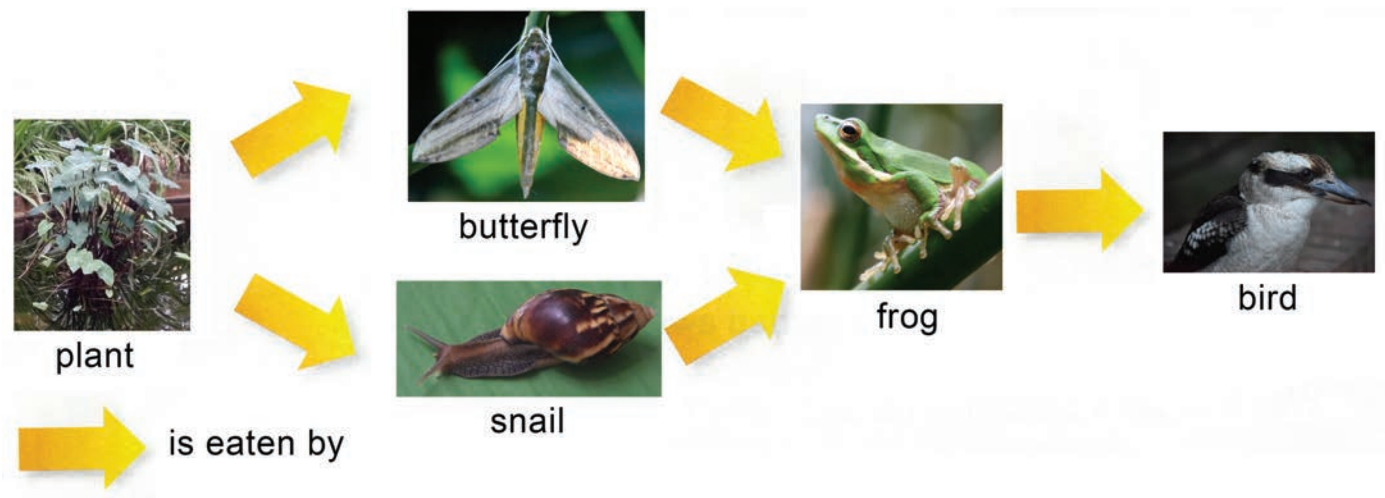

Figure 3. Labeled diagram replica.

The data were analyzed on three levels. First, the recorded interview parts were content-analyzed line-by-line. This categorized student's ideas as scientific or nonscientific. Second, these key ideas were translated into conceptual models. These snapshots of thinking across interview parts revealed changes over time. Third, a two-dimensional classification scheme was applied to the conceptual models. One dimension recorded understanding as nonscientific, mixed, or scientific. The other dimension recorded scientific thinking level as low, medium, high, or advanced. This allowed me to identify and record changes in students' scientific thinking about food webs within and between the interviews influenced by the diagram. Pooling the data allowed trends in students' thinking about food weds to be determined.

Elementary-Level Students' Reading of a Simple Food Web Diagram

Excerpts from the interviews are presented using example students (names are pseudonyms) to show the typical approaches they used to make sense of the food web diagram. Each example is discussed briefly to highlight the issues revealed about the diagram and/or the elements of the students' thinking that influenced their understanding of concepts.

Example 1: Arrow Direction

RESEARCHER: *What's happening in this picture?*

NORMA: *The plant, no the slug, eats, ah [thinking] the slug eats the, and it's going [confused expression] because the arrows are pointing that way it means they have the plants eating the slug.*

RESEARCHER: *So you think the arrow means, "this is eating that"? Ignore the arrows and tell me what eats what.*

NORMA: *The snail eats the crops and stuff, the frog eats the snail, and the kingfisher eats it.*

Starting reading from the plant, Norma faltered as she tried to make sense of the arrows. Norma thought the arrows showed that the plant "is eating" the slug (snail). That she thought the arrow should point away from, not toward the slug indicates her lack of knowledge of conventional arrow meaning in food webs (energy transfer between organisms). Children's life experiences of learning about what different living things "eat" creates a common perception of eating as an active process (this eats that). This view confounds their reading of the diagram because the arrows have a different (conventional) meaning than their expectations.

Example 2: Arrow Meaning

RESEARCHER: *Have a look at this diagram for me. What do you think is happening here?*

MICK: *Well, ah, so the bird is eating the frog, the frog is eating the snail and the butterfly, and the snail and butterfly is eating the plant.*

RESEARCHER: *Okay, and what do the arrows mean?*

MICK: *Well when you, what it eats is that.*

In direct contrast to Norma, Mick started reading from the opposite end of the diagram, at the bird. The presence and direction of the arrows did not affect his reading approach. Mick invented his own definition of arrow meaning, "what it eats is that," to compensate for the arrows facing the opposite direction. An underlying intuition that "the biggest animal is most important" likely influenced Mick's choice of starting point in reading the diagram.

Example 3: Reading Pathway

RESEARCHER: *Can you tell me what is happening in this diagram please?*

ELAINE: *The pot plant [pause] the snail, the pot plant. The snail would come to the pot plant. The butterfly would come to the pot plant. The snail will eat a bit of the pot plant and the butterfly will eat a bit of the pot plant. Then the frog will eat the butterfly and the snail, and the kookaburra will eat the frog.*

RESEARCHER: *What do you the arrows mean in this diagram?*

ELAINE: *Going on.*

RESEARCHER: *Anything else?*

ELAINE: *[Shakes head]*

Elaine was unsure whether to start reading from the plant or the snail. It took her a while to figure out that the diagram was concerned with feeding relationships. Her convoluted reading approach is shown in Figure 4.

Elaine made sense of the diagram by choosing a nonstandard starting point and adopting a unique, backward-looping strategy to read the arrows from right to left rather than left to right. When asked directly about arrows, her generic meaning "going on" indicated lack of knowledge of specific scientific meaning. In the study students were re-interviewed after a one-month period to determine any lasting effects of diagram interaction. Elaine's reading approach the second time is shown in Figure 5.

This time Elaine's diagram reading was more succinct, aided by a direct approach that was more ordered. She commenced with the herbivores and again mentally reversed the arrows, but maintained a consistent approach to the diagram. This highlights the value of repeated exposure with biology diagrams to hone students' reading skills. As students become more comfortable with the visual representations and rethink their meaning, the messages they are designed to convey become clearer.

Example 4: Accumulation Effect

RESEARCHER: *What's happening in this picture?*

MITCHELL: *The kookaburra eats a frog and it eats butterfly, whatever, or moth and snails eats plants, and butterflies eat plants, and frogs eats snails, and the kookaburra eats all of them.*

RESEARCHER: *Good, and what does the arrow mean?*

MITCHELL: *Means eats.*

RESEARCHER: *So the plant eats the snail?*

MITCHELL: *No, the snail eats the plant.*

Mitchell started reading the food web at the bird. Like others he overcame the problem of arrow meaning by reading the diagram in the reverse direction. He read toward the left, correctly identifying what each animal "eats" before incorrectly stating that the kookaburra "eats all of them," suggesting they were all consumed by the bird. Mitchell appears to have an intuitive view that "large animals eat everything else," which influenced this interpretation of the food web. This example highlights that the arrows have multiple functions

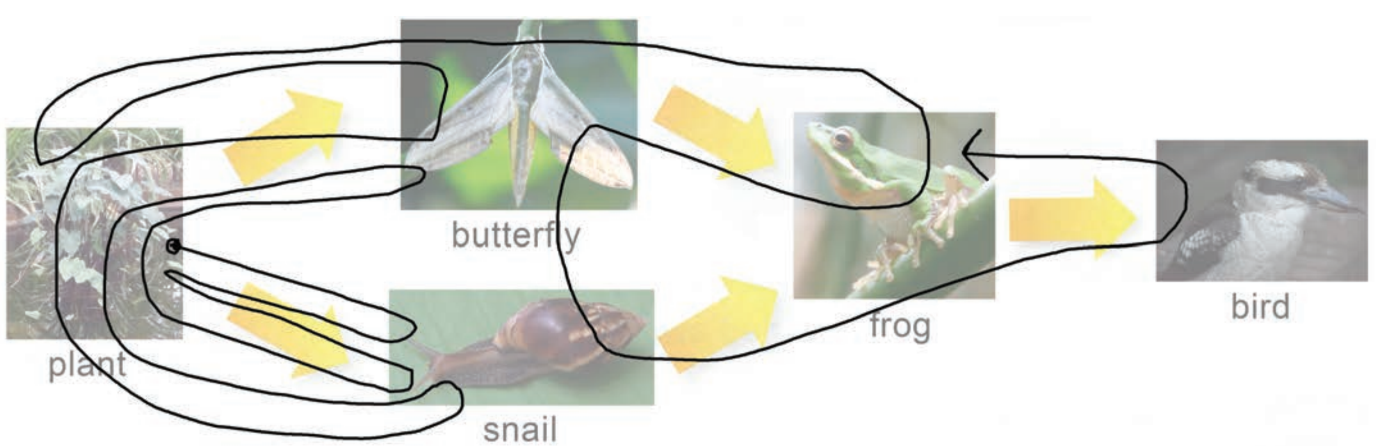

Figure 4. Elaine's diagram reading path.

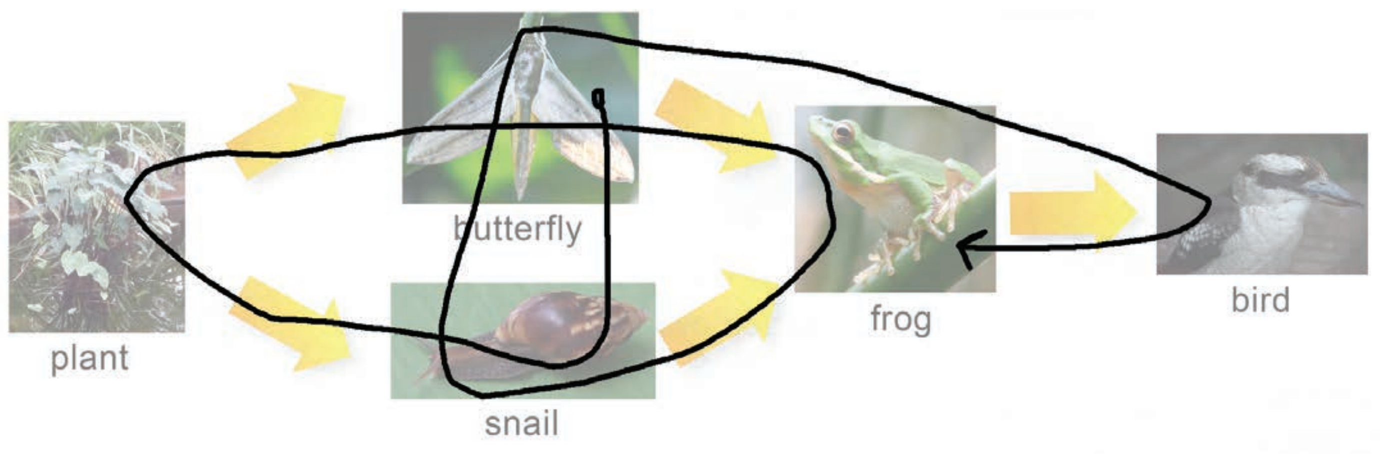

Figure 5. Elaine's new reading path.

in food web diagrams that are not intuitive for nonexpert readers. As discussed later, the arrows indicate a direct relationship between adjacent organisms. They do not mean (as Mitchell thought) that all the food accumulates with the animal at the end.

Example 5: Apparently Correct Interpretation

RESEARCHER: *Can you tell me what's happening in this diagram, please?*

JOHN: *It show plants get eaten by butterflies and snails, which get eaten by frogs, which get eaten by birds.*

RESEARCHER: *Excellent, and what do the arrows mean?*

JOHN: *It means that that's showing what that particular thing, it gets eaten by*

John started at the plant (left-hand side), reading confidently and fluently from beginning to end. He interpreted the arrows by using the meaning "is eaten by," which suggested possible prior learning. John had no difficulty interpreting the diagram and read it succinctly. He correctly interpreted arrow meaning and consistently read the diagram in the desired direction. Despite this John's diagram reading did not help him to construct a complete, scientifically accurate explanation. John (like others) read the diagram on a superficial level, focusing on food acquisition and overlooking the critical purpose of energy transfer. He also failed to distinguish the two food chains making up the food web. Only one student in the study considered the interlinked food chains separately.

○ Results

Classroom Implications

The analysis of the example students' interview dialogues provides evidence that elementary-level students experienced a range of difficulties in reading the food web diagram. In general their sense-making comprised surface-level understanding of the underlying ecological concepts. Findings from this study provide vital background for secondary teachers commencing teaching about these ideas.

Five trends in students' sense-making from food webs worthy of consideration by secondary teachers are starting point, reading pathway, arrow meaning, repeat exposure, and depth of diagram processing. Each has relevance for biology teachers in devising instructional strategies to challenge existing preconceptions, to guide students in deeper processing of food web diagrams, and to extend student's understanding of ecological concepts.

Where to Start Reading

Three starting points, the bird (right), the butterfly / snail (second left) and the plant (left) were recorded in my study indicating students were unclear about where to commence reading the food web diagram. Teachers should not assume students will automatically read left-right following normal conventions for text. Food webs are designed to be read with a predetermined start, at the producer. Secondary students may require specific instruction on this non-arbitrary starting point. Students need to learn food webs always start with the producer(s) regardless of position on the page. (Food webs are traditionally drawn with producers at the bottom and consumers in order of trophic level above).

Prior knowledge (what animals eat) and subconscious intuitions (for example, largest animal is most important) can affect where student attention is initially directed on the diagram. In a classroom asking students where they think a food web starts and discussing differing ideas would be a useful instructional strategy. Identifying the plant as the initiator of a food web is critical for students to appreciate its role as a producer. The unique ability of producers to assimilate Sun's energy means animals ultimately depend on them for energy. This knowledge helps students understand the purposes of food webs as a model to think about habitats by showing *possible* feeding relationships and an ecological tool (Kitchen, 2008, p. 32) to map energy (and matter) flow in ecosystems.

Reading Pathway Through the Diagram

Students used a variety of reading pathways to navigate their way through the diagram. Three trends in reading direction were observed: right to left, left to right, and convoluted, back and forth in different directions. Food webs are designed to be read in a particular sequence, usually left to right for linear presentations or bottom up for standard, hierarchical presentations. After establishing that food webs commence with producers, students could be asked to number the organisms in order of reading and explain their reasoning. Students need to learn that the order of the organisms signifies more than "who eats who." Encouraging students to use scientific vocabulary such as "producer," "consumer," "herbivore," and "carnivore" would assist in developing a deeper understanding of food web organization. The reading pathway was influenced by both the chosen starting point and a means by which to make sense of arrow meaning (discussed next).

Understanding Arrow Meaning

Students in the study found arrows confusing; some even suggested they were drawn the "wrong way around" in the diagram. The arrows in the food web were a characteristic feature that clearly constrained students' diagram reading. Many students thought arrows meant direction only, not discerning the deeper meaning of energy (and matter) transfer essential to survival. This corresponds with previous findings that children misinterpret arrows in science diagrams, resulting in invalid conclusions (McTigue & Flowers, 2011). It also highlights the problem that arrows can have specific, embedded meaning that differs across science domains (and between diagrams within the same domain).

Arrow interpretation in food webs is influenced by students' prior knowledge about animal eating habits. In a child's mind birds *eat* frogs; they don't tend to think that frogs "*give energy*" to the bird when they are *eaten*. Use of the popularized phrase "is eaten by" (adopted by some teachers and text authors) attempts to solve this problem but reduces scientific accuracy. Mishra (1999) reports that such morphing of science diagrams misleads students. This definition of arrow meaning can also be counter-intuitive to elementary students' sense-making. Of the few students in my study who needed to be shown the labelled version of the diagram, one adopted this arrow meaning, another continued to apply their own meaning, and yet another simply ignored the arrows.

Secondary teachers should encourage students to express and discuss their ideas about arrow meaning before being taught the accepted meaning. Purposeful questioning can usefully guide students to think more about arrow meaning. For example: Arrows not only show direction in science diagrams: "What else could the arrows mean?" Arrows may differ in meaning: "Do all the arrows have the same meaning?" Multiple arrows can be used in science diagrams: "Why does a second arrow point to the snail?" Animals gain energy from eating: "How does the bird benefit from eating the frog?" Arrows are used purposefully: "Why has the author used arrows instead of words?" These questions help students understand the communication mechanisms and think beyond the pictures and symbols used. Even John's correct interpretation of arrow meaning and consistent reading of the food web in the desired direction did not help him to gain deep understanding of concepts. The major message the arrows were designed to convey, "energy and matter go from this organism to that one," must be reinforced by the teacher.

Repeat Exposure

My research also provided evidence that students' reading of the food web improved with diagram re-exposure in follow-up interviews. Elaine's example demonstrated this and showed that teachers should not expect students to automatically convey sophisticated scientific explanations on first reading of a food web. Students require repeated learning experiences with diagrams (especially those that look deceptively simple), allowing time for consolidation of ideas. This parallels findings that elementary students benefit from the repeat exploration of model texts with good visuals in science read-alouds (Coleman et al., 2012). Repeat reading tasks with food webs is a worthwhile instructional strategy for secondary teachers to facilitate students' diagrammatic fluency and understanding of science concepts.

Depth of Diagram Processing

In analyzing the effect of diagram interaction on students' understanding, success was measured by the construction of coherent, scientific explanations about food webs. Students like John read the diagram correctly, demonstrating accurate scientific understanding about the feeding relationships. From a secondary biology perspective his diagram reading would be classed as superficial. John read the food web as a single food chain by grouping the butterflies and snails together. He oversimplified the diagram, not treating it as a food web comprised of two separate food chains linked by shared organisms. He explained what was depicted in the diagram, without offering reasoning for why this would occur, nor elaborating on the consequences (benefit / detriment) for the organisms involved.

John's example shows that students' explanations were descriptive rather than causal; the depth suffered from reading the diagram on a superficial level. At best students in my study were able to explain *what* ate what but not *why* this occurred. Causal reasoning—for example, the snail ate the plant *because*: it was hungry, it is an herbivore, or it needed food to gain energy—was lacking from students' explanations. This means that the significant message embedded in the food web, energy transfer essential for survival of organisms in one type of ecosystem, was not gained by any of the elementary-age students in my study.

Focusing on the feeding interactions between the individual organisms depicted without considering their arrangement, relative to each other in the food web, also stifled deeper learning. To explain this trend it is apparent that students overlooked the additional structural purpose of arrows in food webs. An arrow, firstly, conveys which organisms have a direct relationship, that is, one can be affected by the other. A second function is to separate organisms by trophic level (producer, first-order consumer, second-order consumer, to top consumer) and feeding type (producer, herbivore, omnivore, carnivore). Function three is to delineate component food chains as discrete *examples* of feeding relationships in food webs. In this case, each food chain could be considered separately as two *possible* pathways of energy transfer in the ecosystem. No student in my study interpreted the diagram in this way, indicating a lack of deep knowledge about food webs.

This highlights the fact that arrows have multiple functions in food web diagrams that are not immediately obvious to the student (Heiser & Tversky, 2006). These functions are not explicit in food webs (especially simplified forms) and frequently not mentioned in associated text because it is assumed (discipline-specific) knowledge.

It also illustrates that the apparently simple appearance of this food web diagram disguises a high degree of abstraction of relatively sophisticated concepts.

Superficial reading of the diagram contributed to the similarity with previous findings that elementary-level students applied linear reasoning (Leach et al., 1996, p. 137), which differs from the way food webs are designed to be read. As secondary students continue to see food web relationships as linear rather than systematic (Silva & Maskiewicz, 2016), this remains a current problem for biology teachers.

A useful strategy for teachers is to have students compare food webs from different habitats and identify the organisms that occupy equivalent places (niches). This signifies equivalent roles and ways organisms gain energy for survival. It would lead students to see patterns across ecosystems and help view food webs as models of the bigger picture of ecosystems as functioning biological systems.

○ Discussion

Summary of Implications

Analysis of results provides insights into students' sense-making from food webs that have implications for teachers developing diagram-reading instruction. Due to the limited sample size, the results can only be viewed as preliminary findings and further research is obviously needed. This apparently simple food web contains layers of conceptual information with meaning conveyed in its structural arrangements and purposeful use of arrows. Although the food web diagram discussed here might look simple, it is not necessarily straightforward for elementary students to read. To understand food webs fully requires looking beyond the macro-level elements to the functional (life-preserving) processes happening at the population level in ecosystems. The diagram can be read superficially without the deeper processing required for comprehending the science concepts contained. The view that what an animals "eats" was more salient to elementary-level students than what might get energy from "eating it" was apparent from my study.

Continuing the Learning

To interpret and understand food webs, at the level of sophistication this specialized diagram was designed for, requires looking beyond the surface-level elements depicted. Students must consider the functional (biochemical) processes happening at the individual organism level as well as extrapolating to the broader-scale, ecological processes at population level. Consequently, the food web is a science diagram that requires the development of special skills specific to the biology domain (Lowe, 2000; Cheng et al., 2001). The biological concepts encapsulated in food webs as models of ecosystems are complex.

Some of the difficulties secondary students face in understanding ecological relationships was manifest in my research with elementary-level students. This suggests that preconceived ideas counter-intuitive to biological conventions in food web diagrams are engrained well before students enter high school. This signals a need for biology teachers to address this problem through targeted instruction. One of the reasons for the lack of an advancing learning continuum of important biology concepts is because students cannot automatically generate the meaning in food web diagrams. This means secondary teachers need to ensure that their instructional strategies involving food webs are effective. Teaching strategies should elicit and build on students' prior knowledge, challenge preconceived ideas, and encourage deep rather than superficial diagram processing.

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