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Instructional Framing and Student Learning of Community Interactions

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INSTRUCTIONAL FRAMING AND
STUDENT LEARNING OF COMMUNITY INTERACTIONS

by

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A THESIS

Presented to the Faculty of
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INSTRUCTIONAL FRAMING AND STUDENT LEARNING OF COMMUNITY INTERACTIONS

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University of Nebraska, 2016

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Ecology is a broad field of science that encompasses many disciplines with large impacts in our society (AAAS, 2011; NRC, 2009). To understand the complex systems and concepts of this discipline requires a foundation of knowledge that students often gain in the classroom (Bransford, Brown, & Cocking, 2000). Helping students develop this foundation of knowledge requires an understanding of how they use surface and deep reasoning skills to understand and learn new material. In addition, using methods to teach students to transfer these skills between multiple contexts is key to expanding their ability to broadly apply knowledge. The purpose of this research was twofold. First, I wanted to understand the differences between students who used surface reasoning skills and students who used deep reasoning skills. Second, I wanted to understand the effects of two types of instructional framing that may improve students' ability to apply knowledge between multiple contexts.

In the first study, undergraduate introductory biology students were given during-instruction and post-instruction assessments that tested their ability to explain the effects of disturbances within a food web. Responses were coded to assess students' surface and deep reasoning skills. Results showed a wide variation in student responses. Findings from this study suggest that when learning a new subject, students may use a combination

of surface and deep reasoning to solve problems. Additionally, surface reasoning students have the potential to meet or exceed the same standards as deep reasoning students. In the second study, students were split into two instructional framing groups: bounded and expansive. Expansive framing is an instructional method designed to help students understand that the concepts and skills taught in a single context are applicable in multiple scenarios (Engle, Ngyuen, & Mendelson, 2011). Bounded framing involves presenting learning events as segmented ideas, separate from each other. The instructor focuses on developing the students' understanding in a single context. Students were taught food web concepts and reasoning skills using either bounded framing or expansive framing methods. In a follow-up session, students were asked questions about the knowledge gained from the prior session and asked to reason about the effects of food web perturbations. Findings from the second study suggest that compared to bounded framing, expansive framing does not significantly affect the transfer of reasoning skills between contexts. In addition, regardless of prior knowledge about the subject, students were able to transfer reasoning skills and knowledge learned in the first session to the follow-up session.

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CHAPTER 1

INTRODUCTION

In a time when the global environment is consistently the focus of political debates, it is important for our society to be able to understand the complex nature of ecology (Sadler, 2004; Driver, Newtown, & Osborne, 2000). Understanding the science behind these issues requires knowledge of systems, quantitative reasoning, and modeling. In 2011, the American Association for the Advancement of Science (AAAS) published *Vision and Change in Undergraduate Biology Education: A Call to Change*, a comprehensive report that represented the culmination of three years of nationwide discussions and conferences convened to help improve the future of undergraduate biology education (AAAS, 2011). The report recommended specific actions aimed towards improving our country's undergraduate biology education programs which included reconceptualizing teaching to focus on core concepts and competencies.

One of these core competencies is modeling and simulation. This requires students to understand and interpret mathematical models (Schwarz *et al.*, 2009). Another core competency is quantitative reasoning. The ability to apply quantitative approaches is becoming increasingly important when describing biological systems (Brewer & Gross, 2003). According to the National Research Council (NRC), modeling and simulation are integral to systems biology, a core subject of biology literacy (AAAS, 2011; NRC, 2009). As a part of biology, educators have used modeling, simulation, and quantitative reasoning to teach ecology and related concepts.

According to Schwarz *et al.* (2009), a model is an “abstract, simplified, representation of a system of phenomena that makes its central features explicit and visible and can be used to generate explanations and predictions.” Research has shown that involving learners in the practice of creating and explaining models can improve their understanding of the concepts in that particular area of science (Lehrer & Schauble, 2006; Schwarz & White, 2005). Schwarz and White (2005) created and integrated a curriculum in which students learned about scientific models and practiced the process of scientific modeling. Their research suggests that this instructional approach significantly improved students’ understanding of modeling and the purpose and usefulness of models in science. Implementing the use of ecology models such as food chains and food webs in this study can help students develop their understanding of the interactions in these models and how the models can be used to make scientific predictions. Beyond the classroom, modeling is important for fields such as conservation biology and population dynamics since the model predictions can help professionals such as wildlife managers make decisions about ecosystem management.

Study Rationale

Numerous studies have been done assessing students’ ecological conceptions (Barman, Griffiths, & Okebukola, 1995; Hogan & Fisherkeller, 1996; Grotzer & Basca, 2003), system reasoning abilities (Chandler & Boutilier, 1992), and causal cognition (Grotzer & Perkins, 2000; Green, 1997; White, 1997). According to their study, Grotzer and Basca (2003) suggest that ecosystem facts and concepts cannot simply be relayed to students because they believe the knowledge will fit simple linear models of cause-and-

effect. This occurs because students lack a fundamental understanding of the underlying ecosystem processes and the nature of relationships between organisms in a food web.

The relative inexperience students have with ecology results in an incomplete understanding of concepts such as food webs (Jordan *et al.*, 2013). Students often show minimal understanding of the core concepts necessary to effectively reason about disturbances within such a complex system. Research suggests students may develop a better understanding of the concepts if they learn about and analyze systems with multiple interconnected structures (Hmelo-Silver *et al.*, 2007; Hogan, 2000).

The research in this thesis represents my work in addressing concerns brought by previous studies in the literature about developing student understanding of ecological frameworks, specifically the underlying processes involved in complex systems such as food webs. Students may hold incorrect beliefs about ecology that affects their ability to process and learn new information about this discipline. These are misconceptions that can diminish even the most effective educator's impact on student learning and result in a fundamental misunderstanding of the natural world. My research will address how students learn food web concepts and the strategies that have been suggested as effective methods of helping students develop a deep understanding of ecological concepts.

Literature Review

Food Webs

Food webs are a compilation of feeding relationships within a community of organisms (Stiling, 2012; Molles, 2010). A community is comprised of multiple populations of different species that are usually represented by pictures or images of the

species connected to their predator or prey by an arrow that represents consumption. The complexity of natural systems such as food webs can be attributed to the numerous species (Winemiller, 1990). Beneath these representations are the deeper characteristics comprised of underlying connections between species which can be direct or indirect (Paine, 1966). Direct effects occur when a population affects another population through either consumption or predation. Indirect effects occur when one species affects another species through a third species (Begon, 2014). For example, in Figure 1.1 the predators are depicted as indirectly affecting plants through the herbivores. The predators reduce the herbivore population or prevent the herbivores from consuming plants resulting in the growth of more plants relative to plant population size. This indirect effect is an example of a trophic cascade which involves a predator affecting the abundance or behavior of prey and other organisms in the food web (Begon, 2014; Stiling, 2012).

The characteristics of food web dynamics can be separated into four categories: Population Size, Food Chains/Webs, Competition, and Stability. These four represent independent but connected themes in the ecosystem curriculum that are important for undergraduate students to learn. To understand the complex dynamics of food webs requires a strong foundational knowledge of these concepts. I chose to study these four categories for that reason. It should be noted that resilience, or the ability for populations to recover after a large disturbance (Holling, 1973), is not covered.

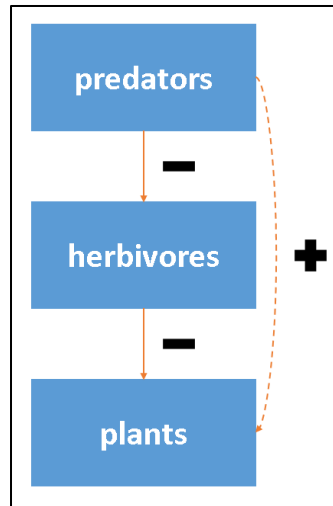


Figure 1.1. A general food chain model. Includes direct (solid arrows) and indirect (dotted arrows) indicators and their effect (positive or negative) on each organism.

Population Size

Population size refers to the number of same-species organisms that are able to mate and produce offspring. Like any population in nature, its size will vary depending on a number of factors including available resources and predator behavior (Werner & Peacor, 2003; Lima, 1998). This can have numerous effects on the organisms. For example, as a result of a smaller prey population, there are fewer resources for a predator population which means that the predator population will eventually shrink in size (Klemola, Koivula, Korpimäki, & Norrdahl, 2000). Population growth is also determined by variables such as climate, habitat space, competition, disease, and natural disasters (Molles, 2010). The sizes of populations in a food web impact the survivability of other populations (through available resources) and can help predict how a food web will

respond to disturbances. This is why it is important to understand the role population size plays in nature.

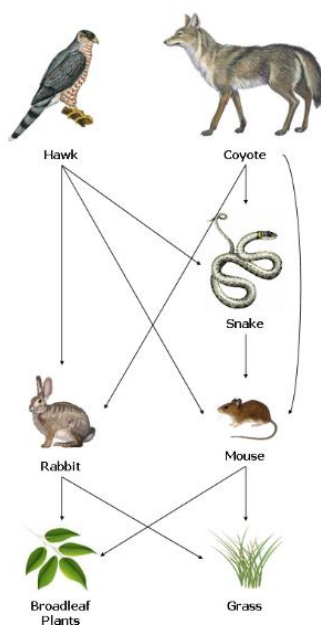


Figure 1.2. Food web model of a prairie community. This model shows the feeding interactions between organisms at different trophic levels. In this model, arrows representing consumption, e.g., hawks in a hawk population consume rabbits from the rabbit population.

Food Chain

A food chain is a sequential relationship of three or more species that are connected through consumption (Hastings & Powell, 1991). The organisms in a food web represent organisms from different trophic levels, which are classifications used to sort organisms in a community based on their feeding relationships (Stiling, 2012). Figure 1.1

is an example of a food chain. Unlike a food web, a food chain only has one organism at each trophic level and each organism has at most one prey and one predator (Power, 1992). It is simple to depict food chains but they are not accurate representations of communities. Food chains imply that organisms are complete specialists that only consume one prey and have a single predator. Frequently, a single organism may be a generalist and have multiple predators and multiple prey.

Competition

When two species use the same resources such as food, water, habitat space, the two species are in competition (Stiling, 2012). Competition affects both species negatively and are mainly categorized as intraspecific between individuals of the same species, or interspecific between individuals of different species (Molles, 2010). For example, the threespot damselfish is an organism that lives and defends reef territory just off the north coast of Jamaica. This habitat contains resources, such as shelter and food, which are necessary for the species to survive. Due to the territorial nature of this organism, damselfish will aggressively defend territory against any intruder that threatens their offspring and resources, an example of interspecific competition. The damselfish also displays intraspecific competition since they will even attack members of their own species if they are from different subterritories along the reef. Damselfish are also a good example of another type of competition known as interference competition which occurs when individuals interact with each other directly through aggression (Stiling, 2012; Molles, 2010). If a group of damselfish is removed from the reef, this opens up room for other members to swoop in and expand their territory. The fish will fight over the space,

going as far as biting and slapping each other with fins. This is also a type of resource competition since there is limited space for the fish to live on.

Competition is an important aspect of food web dynamics and is considered an indirect effect. Food webs generally do not represent competition, and the nature of it as well as its effects must often be inferred. One major effect of competition is the impact it has on competing organisms. For example, when organisms are competing for resources, neither population can grow because their resource access is limited. Unless more resources are added or one population gains an advantage over the other, the environment cannot support any more of either species. Oftentimes, when organisms are competing, they indirectly affect their predators and prey. For example, in Figure 1.2 the Mouse and Rabbit populations are competing for Broadleaf Plants and Grass. Since the environment cannot support any more mice and rabbits, this limits the populations of their predators.

Stability

Within ecology, there are several definitions of stability (Molles, 2010; Ives & Carpenter, 2007). For the purposes of this research, stability is defined as the ability of populations within a food web to resist changes in size in response to a large disturbance (McCann, 2000; McArthur, 1955). For example, assume that the mice population in Figure 1.2 was drastically reduced. Its predators would lose a prey resource. If there were no other prey options, then the predator population would plummet. In this case however, the predators have access to other prey and their population size may or may not be affected. Similarly, the broadleaf plants and grasses would have one less predator and would greatly increase in population size under these conditions if the other predators

also decreased. A number of factors contribute to the stability of a food web such as the number of connections between organisms (Dunne, Williams, & Martinez, 2002; Neutel, Heesterbeek, & Ruiter, 2002), strength of connections (McCann, 2000; May, 1972), and species diversity (Hooper *et al.*, 2016; Tilman, 1996; Frank & McNaughton, 1991).

Species diversity is defined based on how many different species are in the community and the population size of each species (Molles, 2010). As species loss decreases, species diversity increases and food webs with lower diversity may not have the ability to recover from a large loss of species as the remaining populations may not be able to compensate for the changes (Thébault, Huber, & Loreau, 2007; Tilman *et al.*, 2001; Hector *et al.*, 1999). In larger communities, there are many other species to fill those functional roles. This is an important learning outcome for teaching food web dynamics. A student who understands the concept of stability understands the dynamics behind food webs.

How Students Learn

Studying and improving students' ecological reasoning requires knowledge of how students learn new content and how they transfer knowledge to new contexts. In *How People Learn* (Bransford, Brown, & Cocking, 2000), the authors reported three key findings about learners: (1) students hold preconceptions about natural phenomena which must be addressed otherwise they may not understand the new information or they may revert back to their preconceptions after learning the information; (2) to develop proficiency in a subject, students must have good foundational knowledge, understand concepts and how they are applicable in the appropriate contexts, and organize

knowledge so that it can be remembered and applied efficiently; and (3) using a metacognitive approach to teaching can help students become more autonomous during the learning process.

Other studies have also discovered that the organization of knowledge develops based on an individual's experience, type of knowledge, and how that knowledge fits into his/her life (Ambrose, Bridges, DiPietro, Lovett, & Norman, 2010). Ifenthaler (2010) argued that a person will process new information through assimilation and accommodation. Assimilation involves the activation and adjustment of previously learned knowledge organization strategies. Accommodation occurs only when adjusting learning strategies is not successful or if no learning strategy is available. In that case, Ifenthaler (2010) argued that the learner will reorganize the information and create a mental model that explains the information in a manner that the learner understands. Ambrose *et al.* (2010) suggest that educators should be cognizant of the learning experiences students are engaging in and determine how it might influence the development of their knowledge organizations. Developing an understanding of the impact teaching has on the students will help educators decide what knowledge organizations would be most useful to students during the learning process.

These suggestions are exactly the direction the contributors to *Vision and Change* (AAAS, 2011) encouraged. By adapting the curriculum to support student development of knowledge organization, lessons focus more on helping students learn the core competencies and concepts. Experiences in the classroom become more student-centered

as opposed to teacher-centered and modeling, simulation, and quantitative reasoning skills can be taught and fostered within this productive environment.

Novice and Expert Learners

A person can organize knowledge in many ways and there is no one method that is necessarily better than the rest. There are however, distinct differences between how novices and experts structure the information (Ambrose *et al.*, 2010). When novices learn new information, they organize it as superficial structures that are comprised of the visible features such as names, images, or direct interactions (Mintzes, Trowbridge, Arnaudin, & Wandersee, 1991; Chi, Feltovich, & Glaser, 1981; Gellert, 1962). Novices develop these structures because they have little to no background experience with the content. Organizing the information in this manner hinders the learner's ability to remember and use what they learn (Chi & VanLehn, 1991; Ross, 1989). Chi and VanLehn (1991) found that students who were more successful at using technical procedures to solve problems were also better at solving problems which tested their ability to answer conceptual physics questions. These students had a better understanding of the knowledge and underlying strategies and were able to employ them in the right contexts.

Experts have already built strong and meaningful structures based on previously learned information (Chi, Feltovich, & Glaser, 1981). When presented with "new" but related information, experts can build new connections with established structures and use their experience and previously developed learning strategies to understand and

comprehend the new information (Dauer, Momsen, Speth, Makohon-Moore, & Long, 2013; Ifenthaler, 2010; Wenk, 1997; Dufresne, Gerace, Hardiman, & Mestre 1992).

In their study, Chi and colleagues (1981) found that novices and experts also connect knowledge structures differently. They presented physics novices and experts with a number of physics problems and asked them to group them into categories. The novices grouped problems according to surface characteristics such as whether the problem described a pulley or a ramp. The experts, organized the problems based on deeper and more meaningful features such as the second law of thermodynamics, momentum principles, and kinematics. Experts also discussed the strategies they would use to arrive at each solution. The results of this study indicate that novices tend to focus on the surface features when presented with new information while experts will recognize the deeper, more meaningful aspects.

Surface and Deep Features

In addition to knowledge organization, novices and experts also tend to recognize very different features of problems. Novices recognize only surface features, which are the obvious characteristics and includes the terms, configuration, and figures associated with the problem. Deep features, recognized more by experts, are defined as the underlying concepts and strategies applicable to solving the problem (Chi, Feltovich, & Glaser, 1981).

Food webs contain different features that can be categorized as surface or deep. Examples of surface features include the types of organisms involved (producers, primary consumers, secondary consumers), the prey items for these organisms, and the number of

organisms at each trophic level. According to Jacobson (2001), linear reasoning may also be a type of surface feature (i.e., Organism A eats Organism B thereby reducing the population size of Organism B). In the study, novice students and expert scientists and graduate students were asked questions about complex systems such as: “How do ants find and collect their food?” and “How did cheetahs evolve to run so fast?” (Jacobson, 2001, p. 42). As they answered each questions, the novices talked out loud about all the ideas that they were considering. The study found that experts used deeper concepts to solve the problems compared to the novices.

In the context of food webs, take for example Figure 1.2. The coyote preys on three different organisms as depicted by the arrows: snakes, rabbits, and mice. From the diagram, a novice will likely notice several features such as the arrows between organisms and the names of each species (Jacobson, 2001). They may also note how many of each organism (predator/prey/plant) is in this food web, a characteristic of population size. An expert however, may recognize deep features such as how changes to one population might affect not only its predators and prey, but also their predators and prey. They may also recognize that if the predator is competing with another predator for the same prey resource, a reduction in the prey population means that there is less food for the other predator thereby reducing its population size. In this scenario, an expert will recognize that the population size of prey is a limiting factor to the population size of the organisms that are competing for the prey. A novice, who reasons sequentially about organism interactions, may not notice this dynamic aspect of the food web. These differences separates novices from experts and are the basis of my coding framework.

Transfer of Knowledge

Transfer is a topic that has been researched for decades as an important aspect of learning (Barnett & Ceci, 2002; Gick & Holyoak, 1983). It occurs when there are shared similarities between the original learning and transfer contexts which results in the transfer of information to the next context (Lobato, 2006; Holyoak & Koh, 1987). There are many types of transfer including near and far (Barnett & Ceci, 2002; Renkl, Stark, Gruber, & Mandl, 1998), high and low road (Salomon & Perkins, 1989), and analogical (Gick & Holyoak, 1983, 1980). For my research, I observed analogical transfer which involves recognizing that a problem solving strategy from a learning context is applicable in a novel context and then applying the strategy to the novel context.

Past research suggests that when contexts are dissimilar based on surface characteristics, spontaneity of transfer is low compared to contexts that are more similar to each other (Vendetti, Wu, & Holyoak, 2014; Detterman, 1993; Gick & Holyoak, 1983, 1980). In addition, the ideas students have about concepts are often connected to the contexts and experiences they originated from which may cause cognitive conflict when reasoning (Linn & Hsi, 2000). Despite this, transfer of knowledge is possible between the learning context and novel context even if the presentation of the novel context is delayed by several days (Holyoak & Koh, 1987). For this to occur, the researchers found that the two contexts must have at least one similar important surface feature. This suggests that when designing transfer questions about ecology, the questions should contain similar surface features between the two contexts to increase the possibility of transfer.

To facilitate transfer, Goldstone and Wilensky (2008) suggest that pedagogical methods may be useful, specifically in promoting transfer of complex system principles. They recommend instructors have students actively interpret scenarios that exemplify a principle by pointing out relevant characteristics and interactions. This directly addresses the concept of modeling and may lead into simulation, one of the core concepts of *Vision and Change* (AAAS, 2011).

Studies suggest that an instructional strategy known as ‘expansive framing’ can improve students’ ability to transfer knowledge between similar and applicable contexts (Jordan, Gray, Brooks, Honwad, & Hmelo-Silver, 2013; Engle *et al.*, 2012). This model requires the teacher to incorporate examples of the discussion topic and help students make generalizations about the information so they are able to apply it in multiple situations. For example, when undergraduate biology students are learning about the nitrogen cycle in a terrestrial ecosystem, the teacher can frame the knowledge expansively by explaining that other ecosystems have similar nitrogen cycles and pointing out the similarities and differences between systems (Jordan *et al.*, 2013). The students would have experience with identifying similarities and differences between ecosystems and then be able to generalize the information. In comparison, a teacher using a bounded framing approach would focus on teaching the concepts as they apply to one ecosystem. The instructor would focus on helping students develop a strong understanding of the concepts in that context. This method of instruction may benefit students by providing more experience within that specific domain of knowledge which can be helpful when thinking about other ecosystems (Greeno, 1983). Expansive framing

however, in addition to this, also focuses on teaching the concepts so that they are viewed as relatable to other ideas (Engle, Nguyen, & Mendelson, 2011).

Student Misconceptions

Students hold numerous conceptions about science that are incorrect (Tanner & Allen, 2005; Wandersee, Mintzes, & Novak, 1994) and yet prevalent amongst novice learners (Maskiewicz & Lineback, 2013). The term misconception was used to describe these types of beliefs. Research in this field originally began gaining momentum after Driver (1985) published a book revealing student conceptions about a range of phenomena that occur in nature. The findings were based on the results of a series of interviews Driver and her colleagues conducted in which they asked students questions about concepts such as energy. Students had personal and incoherent beliefs about these concepts that were difficult to correct even with the proper resources (Driver, 1985).

Since then, hundreds of studies about student misconceptions have been published and an extensive collection of these references can be found in the Students' and Teachers' Conceptions and Science Education (STCSE) database (Duit, 2009). Among those references exists studies about how students think about complex ecological systems such as food webs. This research has revealed that students hold numerous misconceptions about the dynamics and functions of natural systems (Barman, Griffiths, & Okebukola, 1995; Hogan & Fisherkeller, 1996; Grotzer & Basca, 2003). For example, Hogan (2000) found that sixth-grade students believed that food webs followed a sequential pattern of cause and effect. However, any disturbances within the food web create effects that do not follow a pattern and are dependent on variables such as

population size, the number of predators and prey for each population, and how many different competitors exist at each trophic level.

Another misconception students have is the idea that a food web will eventually “balance out” or return to its original state because it is more stable than a food chain. In a series of interviews focused on ecosystems and food web dynamics, Sander, Jelemnska, and Kattmann (2006) found that students often introduced the concept of balance without prompt or mention by the interviewer. Subjects in the interviews explained that any changes within the ecosystem are essentially negligible which will eventually lead the system to balance itself out over time. In reality, views from modern ecology state that the system is always changing and balance is an idea taken from classical ecology principles (Sander, Jelemnska, & Kattmann, 2006). A student with these misunderstandings may have difficulty reasoning about the effects of food web disturbances (Reiner & Eilam, 2001, Jordan *et al.*, 2009). For example, Sander *et al.*, (2006) found students believed that if a forest came into a state of imbalance, such as in the case of removing a population of one species, then the ecosystem would collapse causing the forest to be destroyed, endangering all of the animals. Forests however, are complex systems that have multiple organisms representing each trophic level. If one population were to be removed, another species may be able to fill its niche and become predator to its original prey and prey to its original predators (Thébault, Huber, & Loreau, 2007; Tilman *et al.*, 2001). In that example, the forest ecosystem is less likely to collapse and endanger its animals due to the stability of the food web.

Overview

In 2011, *Vision and Change* listed two core competencies which I address in my studies: 1) modelling and simulation and 2) quantitative reasoning. These two concepts are important for undergraduate students to know, especially when learning about complex systems such as food webs. Students generally lack the knowledge and experience to understand food webs. Without this experience, students will have difficulty understanding food web concepts because they will attempt to fit them into pre-established patterns of cause-and-effect relationships and other superficial notions of food web dynamics. As a result, students will not be able to appropriately generalize the knowledge about food webs and apply them to similar contexts.

The research suggests that students who use deeper reasoning to solve food web-related problems understand the underlying concepts and applicable strategies better than students who use superficial and surface characteristics in their reasoning. To observe these differences, I assessed how students performed when answering questions related to four important concepts of food web dynamics: Population Size, Food Webs, Competition, and Stability. Based on the literature about deep and surface reasoning, I wanted to know:

1. How do students who use deep reasoning when solving problems differ in their responses compared to students who use superficial reasoning?
2. How do surface reasoning students and deep reasoning students change their responses from during-instruction assessment to post-instruction assessment?

To understand and reason about how populations change within food webs, students must be able to use strategies and apply concepts that are beneath the surface features of the system. To do this, they must be able to recognize how the knowledge gained in a similar, learning situation is applicable in the transfer or problem-solving scenario. Research suggests that the instructional method of expansive framing may help students learn the appropriate strategies and information, generalize it, and then apply what they learned to a novel context. Based on this, I wanted to know:

1. How does expansive framing in a learning context about food webs affect student ability to transfer knowledge to a novel context?
2. Does expansive framing encourage students to generalize knowledge about food web dynamics?

These questions are pertinent to addressing how undergraduates and novice learners are processing information taught in the ecology section of biology classes and applying what they learn to other scenarios. The findings provide insight into what strategies are working and what need to be improved as educators and researchers continue to look for ways to enhance the quality of education at the undergraduate collegiate level.

CHAPTER 2

RECOGNITION OF SURFACE AND DEEP FEATURES OF A FOOD WEB BY UNDERGRADUATES IN INTRODUCTORY BIOLOGY

There are many interactions that impact the populations within a community such as predation, commensalism, competition, pollination, and parasitism. Food webs depict the predation interactions and are based on the feeding relationships of multiple populations of different species (Molles, 2010). This community of organisms is usually represented by images or words connecting predators and prey by an arrow representing consumption. These relationships are known as direct effects. Indirect effects occur when a direct effect between two organisms affects a third organism (Begon, 2014). A good example of indirect effects is competition in which two organisms share one resource. Understanding direct and indirect effects are important for food web reasoning. These effects can be used to predict the effects of a disturbance within the food web and explain how this may affect all of the associated populations.

For this study, I chose to rate students based on their understanding of four categories: Population Size, Food Chains/Webs, Competition, and Stability. These are four representative themes found in the ecology section of many introductory biology textbooks and in undergraduate biology and ecology classrooms. Determining how students reason in these four categories will inform our understanding of what instructional approaches will be useful for fostering student learning.

Literature Review

Community Interactions

Population Size. Population size refers to the number of same-species organisms that are able to mate and produce offspring. The size of a population varies depending on factors such as the number of available resources and behavior of predators (Werner & Peacor, 2003; Lima, 1998). The population size of one species can directly and indirectly affect the population sizes of other species in the food web. For example, if the population of prey were to decrease, there would be fewer resources for their predators which may decrease the predator population if no other food resources are available (Klemola, Koivula, Korpimäki, & Norrdahl, 2000). Population size is also important because students often reason about an individual rather than the population (Wilensky & Resnick, 1999).

Food Chains and Food Webs. Food chains represent sequential relationships of three or more populations of species at different trophic levels (Hastings & Powell, 1991). Trophic levels are classifications of an organism based on their feeding relationship within the community (Stiling, 2012). These classifications can include producers (grass, algae, and other autotrophic organisms), primary consumers (e.g., herbivores such as rabbits and mice), secondary consumers (herbivore predators such as snakes), and tertiary consumers (predators that eat predators and maybe herbivores) (Figure 2.1).

Food webs are similar to food chains in that they represent organisms at different trophic levels and show predation/consumption of prey by predators. However, webs

have multiple organisms at each trophic level and each species may have multiple predators and prey (Polis & Strong, 1996; Power, 1992). While direct effects (consumption) represent feeding relationships in food webs (Figure 2.1), indirect effects are more complicated. Indirect effects can be described as the secondary effects consumption has on other organisms. For example, in Figure 2.1 the hawk consuming the rabbit is an example of a direct effect. In addition to the hawk affecting the rabbit population, decreasing the population of rabbits also affects other organisms in the food web. Fewer rabbits means less consumption of grass which increases the food available for mice. The population of mice will increase in size with the additional nutrition and provide more food for hawks, coyotes, and snakes. In a food chain, there are fewer indirect effects because each trophic level contains one population of organisms and any disturbances result in linear sequential effects. In a food web, there are multiple populations at each trophic level and any disturbances are felt within trophic levels and throughout the web.

Competition. Competition is the result of two organisms in a community sharing the same resources (Stiling, 2012). Resources may include food, water, and habitat space. Competition can shape the structure of a food web by forcing organisms to partition resources (Pianka, 1981). This reduces the amount of competition between different species (known as interspecific competition) which is important because it relieves unnecessary pressure on the populations. If organisms were continuously fighting for resources, a lot of energy would be wasted. Instead the energy is better suited for other activities such as reproduction. There are different types of competition. For my study I

tested student reasoning about interspecific competition, which is between individuals of different species (Molles, 2010).

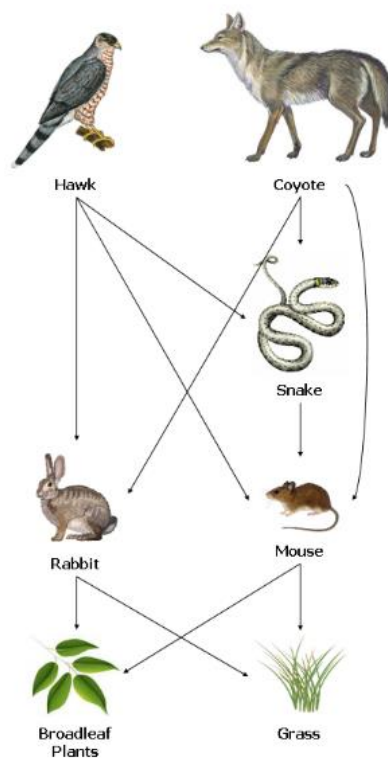


Figure 2.1. Food web model of a prairie community. This model shows the feeding interactions between organisms at different trophic levels. In this model, arrows representing consumption, e.g., hawks in a hawk population consume rabbits from the rabbit population.

Competition is usually not indicated in a representation of food webs and must be inferred. For example, in Figure 2.1 the Mouse and Rabbit populations are competing for Broadleaf Plants and Grass. Since the environmental conditions, the population size of

broadleaf plants and grasses, cannot support more mice and rabbits, the populations of their predators will be limited. If more broadleaf plants and grasses become available, more mice and rabbits could be supported (due to the additional nutrients) which may increase the populations of their predators.

Stability. Stability refers to the ability of populations within a food web to resist changes in size in response to a disturbance (McArthur, 1955; McCann, 2000). For example, assume that the mice population in Figure 2.1 has drastically decreased from a disease. Mice's predators (snakes, hawks, and coyotes) lose a prey item. If there were no other prey options (e.g., for snakes), then the snake population would decrease because it has no alternative source of food. If the predators have access to other prey (e.g. for hawks and coyotes) the predator populations may experience small population fluctuations because there are less resources to feed the predators. Similarly, the broadleaf plants and grasses have one less predator and may increase in population size because they are able to survive and reproduce.

As the diversity of species in a food web increases, the effects of losing species is decreased (Thébaud, Huber, & Loreau, 2007; Tilman *et al.*, 2001; Hector *et al.*, 1999). Species diversity refers to how many different species exist (species richness) at each trophic level within the community and their population size (abundance). Food webs with a lower diversity of organisms at each trophic level have a reduced ability to recover from species loss because the remaining species may be unable to compensate. In the event of species loss, a food web has more than one population at each trophic level that can take advantage of the additional resources and increase in population size as a result.

Novice and Expert Learners

The way an individual organizes their learned knowledge varies from person to person and there are distinct differences in the organization depending on the level of experience with a particular subject (Ambrose *et al.*, 2010). A novice learner is someone who has little background knowledge of the subject and organizes knowledge based on superficial characteristics such as the name of a concept or what it looks like (Gellert, 1962; Chi, Feltovich, & Glaser, 1981; Mintzes, Trowbridge, Arnaudin, & Wandersee, 1991). For example, when asked to organize physics problems, novices organized the problems based on features such as whether a pulley or ramp was involved (Chi, Feltovich, & Glaser, 1981). Expert learners have experience with the subject matter and organize information as strong, meaningful structures that are based on previously gained knowledge. Experts build connections between old and new information and use their experiences to comprehend and learn the new information (Dauer, Momsen, Speth, Makohon-Moore, & Long, 2013; Ifenthaler, 2010; Wenk, 1997; Dufresne, Gerace, Hardiman, & Mestre 1992). Additionally, experts organize their knowledge based on their understanding of deep principles such as the behaviors and functions systems, which improves their ability to understand and recall knowledge (Hmelo-Silver, Marathe, & Liu, 2007; Hmelo-Silver & Pfeffer, 2004).

Surface features are the characteristics of a problem which includes things such as terms, configurations, and figures. Deep features are the concepts and strategies necessary for solving the problem (Chi & VanLehn, 2012; Goldstone & Day, 2012; Chi, Feltovich, & Glaser, 1981). Food webs contain a variety of different features that can be

categorized as surface or deep. Examples of surface features include the trophic levels of organisms involved (producers, primary consumers, secondary consumers), the prey items for these populations, and the population size of each species. Deep features include how the size of a population affects resource availability, how competition between two organisms affects other organisms, and a food web's stability.

Transfer

Transfer is the application of prior knowledge to a new or similar context (Bransford & Schwartz, 2009; Engle Mendelson, & Nguyen, 2011). It occurs when there are shared similarities between the original learning and transfer contexts which results in the transfer of knowledge and reasoning to the next context (Lobato, 2006; Holyoak & Koh, 1987). The better and stronger the learner's prior knowledge, the higher the chance information will transfer. Jordan *et al.* (2013) found that when students had a strong foundational knowledge they were able to generalize the information and processes of one ecosystem and apply those ideas to another. Research suggests that contexts that are too dissimilar have a lower chance of transfer compared to contexts that are more similar to each other (Vendetti, Wu, & Holyoak, 2014; Detterman, 1993; Gick & Holyoak, 1980, 1983). This suggest that novice learners are more likely to transfer information if there are many similarities between contexts.

In addition, the ideas students have about concepts are often connected to the contexts and experiences they originated from which may cause cognitive conflict when reasoning (Linn & Hsi, 2000). Transfer of knowledge is possible between the learning context and novel context even if the presentation of the novel context is delayed by

several days (Holyoak & Koh, 1987). The researchers found that the two contexts must have at least one similar important surface feature. This suggests that when designing transfer questions about ecology, the questions should contain similar surface features between the two contexts to increase the possibility of transfer. In this study, contexts had several similarities which include type of questions asked and community structure (food webs). In particular, students were asked to reason about disturbances in a food web and how competition affects interactions between organisms.

Research Questions

Understanding how students learn and apply food web concepts is important for improving the quality of undergraduate biology courses and addressing the national call of *Vision and Change* (AAAS, 2011). Educators can use this knowledge of how students learn to help them develop and improve courses to help students better understand principles of food web dynamics. To address this, I sought to answer the following research questions:

1. What are characteristics of surface vs deep reasoning students when describing food web dynamics?
2. How does reasoning about food web dynamics change in each of the four categories?

These questions are pertinent to addressing how undergraduates and novice learners are processing information taught in the ecology section of biology classes and applying what they learn to other scenarios. The findings will provide insight into how students are

learning the information and how surface and deep reasoning students differ in food web reasoning.

Methods

Course Design

The research was conducted during an introductory biology course where the content focused on: genetic basis of evolution, macroevolutionary patterns and biodiversity, comparative form and function, and ecology. Students had permanent small groups that they frequently interacted with during class periods. Active learning techniques were implemented throughout the entire course. Students were asked to create concept maps, create and interpret graphs, answer clicker questions individually and as a group, and write narrative responses to questions posed during class. Additionally, assignments were given weekly to assess the learning of content. Exams were a mix of multiple-choice and open-response questions.

Participants

The students in this study were enrolled in an introductory biology course taught at a large Midwestern university. Students in the class were asked to sign a research participation consent form. 84 students gave consent to participate in my study. Of those students, 60 were included in the final analysis, excluding students who did not complete the during-instruction-assessment data or post-assessment data or a combination of both. This study was conducted with permission of the Institutional Review Board (IRB #20140514466).

Data Collection

Students were able to discuss questions in groups and data was collected from individual student answers. Prior to the questions, students were assigned homework that introduced the concept of food webs. Before the during-instruction assessment, the instructor reviewed the homework assignment with students and answered questions and clarified answers.

During-instruction Assessment. The during-instruction assessment occurred during the ecology section of the course, specifically while students were learning about food webs and food web interactions. Students were given two in-class activities that asked questions about food webs based on concepts learned in class.

In the first activity, food webs were given to students, one per students. Students drew a diagram of one and answered questions about the food web including:

1. Which organism would disproportionately affect your food web if they were to significantly decrease in population size, i.e., which organism is most important to your food web? Why?
2. Describe a trophic cascade in your food web. How does a change in population size for the organism have a cascading effect on other organisms?

The second activity was conducted during the next class session. Between the first and second activity, students had time to review the food web concepts taught in class.

During the second activity students were asked:

3. How does having competitors at multiple trophic levels affect the population size of organisms at each trophic level compared to a food chain?

Post-Instruction Assessment. The post-assessment was given during the final exam and used Figure 2.1. Students were asked the following:

1. Consider a third population of herbivore, a grasshopper that consumes only grass and is consumed by snakes. Grasshoppers increased in population size this year. Explain the effect this has on rabbits and broadleaf plants and explain your reasoning.
2. Compared to a food chain, how does increasing the number of competitors at each trophic level (primary producer, herbivore, primary carnivore, etc.) affect the populations in the food web?

Rubric

To assess the quality of student answers, a coding rubric was developed based on four categories: Population Size, Food Chains/Webs, Competition, and Stability. The rubric is provided in Appendix A. Each category was given a code from 0 to 3 except Competition which had a code from 0 to 2. The higher the number, the more deep features students included in their reasoning. Responses rated as 0 did not include any information relevant to the question.

Population Size. The assessments required students to explain how population sizes would change in response to disturbances in the community. The more changes to population sizes students described (increase or decrease), the better score the student was given. A score of 1 required the student to describe a change in population size of

one population as a result of consumption. A score of 2 required that student described a change in two to three populations as a result of consumption and a score of 3 required that a student describe change in four or more populations.

Food Webs. Students were asked to describe differences between a food web and a food chain. If a student described only a food chain or attempted but did not correctly describe a food web, they were given a lower score. If the student described multiple organisms within at least one trophic level, they were given a higher score.

Competition. Within each question was the possibility for a student to describe how competition would affect the organisms in the community. If the student discussed the negative effects created by competition then the student received a higher score. For example, to score a 1 a student would have to attempt to describe the concept but not explain that competition affects interacting species negatively. A score of 1 indicated that the student attempted to describe competition or its effects but did not do it correctly. To a score a 2, the student would have to describe competition and explain the negative effects created by it.

Stability. Students were asked a question related to the ability of populations in a food web to resist changes to size. Responses were rated higher if an explanation of how species richness affected the species' ability to resist changes to their population size. For example, to score a 1 a student attempted to explain the concept of stability but was not clear in the response. A score of 2 is explains that populations in a food web are more resistant to changes in population size because there are multiple organisms at each trophic level. A score of 3 includes the same criteria as a score of 2 and in addition the

student explains that multiple organisms at each trophic level supports and limits population sizes through competition.

Co-coding

Two individuals coded a sample set of twelve student responses that included their during-instruction and post-instruction responses. The first percent agreement was 59%. The coding rubric was then modified by reducing competition to its current number of levels, clarifying the levels on population size, and agreeing on codes for stability. A second sample of ten student responses were coded with a percent agreement of 71%. After discussion and further clarification of Stability and Food Webs, the two coders reached 100% agreement. I then coded all student responses using the final coding rubric.

Analysis

I performed quantitative and qualitative analysis of students' in-class and exam data related to community and food web dynamics. Students responses to questions asked in the assessments were coded based on students' answers in four categories: Population Size, Food Webs, Competition, and Stability. Overall scores in each category were totaled for during-instruction and post-instruction data. The total scores of each student were summed and sorted into two categories: surface and deep reasoning students. Surface reasoning students met the following requirements in their during-instruction-assessment: a) total score of 5 or below and; b) score of no higher than 2 in any category. Students were determined to be deep reasoning students if they had: a) total score of 8 or higher; b) score of 3 in at least one category and; c) no 0 scores.

I fit an additive and interactive effects model of Assessment timing (During-instruction vs Post-instruction scores) and Category for all students and for surface and deep reasoning students using ordinal logistical regression analysis with repeated measures. The interactive model fit the data significantly better than the additive model (log-likelihood comparison, $p < 0.001$).

Results

Total scores from the during-instruction assessment showed a wide range, from 2 to 10, with a total possible score of 11 (Figure 2.2). Students were categorized into surface and deep reasoning students based on their total scores. Surface reasoning students had total scores of 5 or below. Deep reasoning students had total scores of 9 or greater. There were a total of 21 surface reasoning students and 17 deep reasoning students from the sample. Students' post-instruction total scores were distributed higher than the during-instruction scores (Figure 2.3).

The mean and median increased for surface reasoning students from during-instruction to post-instruction (Table 2.1). Surface reasoning students total scores increased from a mean of 4.5 to 7.3, an increase of 63% while the median increased from 5 to 8. Deep reasoning students total scores decreased from a mean of 8.6 to 7.9, a decrease of 9% while the median decreased from 8.5 to 8. In comparison, deep reasoning students decreased in mean and median scores between assessments. All but one student of the 17 surface reasoning students improved in their total score while only 4 deep reasoning students of 21 showed improvement. A total of 11 deep reasoning students scored lower between assessments in their total score compared to only one surface

reasoner who also had a lower total score from during-instruction to post-instruction assessment.

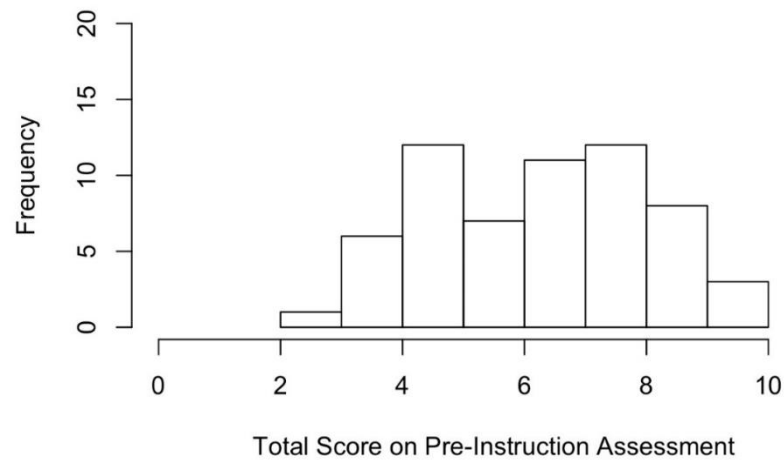


Figure 2.2. Histogram of total during-instruction assessment scores.

Quartiles: 2 (0%), 5 (25%), 7 (50%), 8 (75%), 10 (100%).

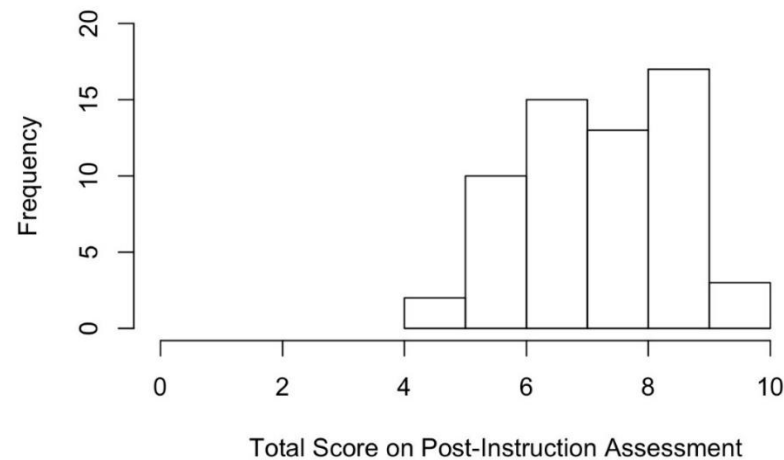


Figure 2.3. Histogram of total post-instruction assessment scores.

Quartiles: 2 (0%), 5 (25%), 7 (50%), 8 (75%), 10 (100%).

In the during-instruction assessment, there were differences between mean and median scores for surface and deep reasoning students (Table 2.1). In every category except Population Size, the deep reasoning students had a higher median score than the surface reasoning students, especially in Stability where the median score for the surface reasoning students was 0 but for the deep reasoning students it was 2. Similarly, the deep reasoning students had higher mean scores in each category than the surface reasoning students.

Type	During-Instruction		Post-Instruction	
	Mean	Median	Mean	Median
Surface	4.5	5.0	7.3 (+63%)	8.0
Deep	8.6	8.5	7.9 (-9%)	8.0

Table 2.1. Overall mean and median scores of surface and deep reasoning students from during-instruction and post-instruction assessments. Results are based on total scores of each student. Percent changes were based on the difference between assessment mean scores.

In post-instruction, surface reasoning students had the same median scores as deep reasoning students for all categories except Stability where median scores were 1.0 (surface) to 1.5 (deep). The surface and deep reasoning students differed largely in the difference between mean scores from during-instruction to post-instruction assessment. The largest increase for both groups was in food webs with an increase of 125% (surface) and 22% (deep) in mean scores. The smallest increase in mean score for surface

reasoning students was 20% in population size. The largest decrease in mean score for deep reasoning students was 52% in stability.

Category	Type	During-Instruction			Post-Instruction		
		Mean	SD	Median	Mean	SD	Median
Population Size	Surface	1.8	0.44	2.0	2.1 (+20%)	0.49	2.0
	Deep	2.4	0.50	2.0	2.1 (-15%)	0.21	2.0
Food Webs	Surface	1.2	0.39	1.0	2.7 (+125%)	0.49	3.0
	Deep	2.3	0.46	2.0	2.8 (+22%)	0.43	3.0
Competition	Surface	1.1	0.6	1.0	1.8 (+64%)	0.56	2.0
	Deep	1.7	0.48	2.0	1.9 (+12%)	0.29	2.0
Stability	Surface	0.4	0.62	0	0.8 (+100%)	0.75	1.0
	Deep	2.3	0.64	2.0	1.1 (-52%)	1.03	1.5

Table 2.2. Mean and median scores of surface and deep reasoning students from during-instruction and post-instruction assessments.

Population Size

Surface reasoning students significantly improved in their description of population size ($Z=2.14$, $p<0.04$). Every student in the sample was able to describe at least one change in population size as a result of consumption. Twelve surface reasoning students scored the same in both during-instruction and post assessment with eleven scoring a 2 and one scoring a 1. The other five improved their scores by at least a code of 1. Deep reasoning students did not improve between assessments ($Z=2.54$, $p=0.011$). Twenty-one deep reasoning students scoring between a 2 and 3 from during-instruction to post assessment. No deep reasoner scored below a 2 in either assessment for this category.

Student 49 is an example of a surface reasoning student that improved from a 1 in the during-instruction assessment to a 3 in the post-instruction assessment for this category. In the during-instruction assessment, the student mentioned that the vegetation would be most important to the food web because “many consumers only rely on it for food.” The student does not quantitatively describe how the vegetation will impact the other organisms in the food web. In the post assessment however, the student describes how an increase in the population size of one herbivore will quantitatively affect other organisms because,

“more grasshoppers means there will be a competition between mice and [grasshoppers] for grasses but mice will resort to eating a majority of broadleaf plants since grasshoppers only consume grasses and will deplete the grasses as a food source.”

Food Webs

Surface reasoning students showed the most improvement in their use of deep features to describe food webs ($Z=-5.57$, $p<0.001$). Six surface reasoning students scored a 1 in the during-instruction assessment while all deep reasoning students scored a 2 or higher. No surface reasoner scored below a 1 or above a 2. All seventeen surface reasoning students improved in the post-instruction assessment by at least one level with eight students improving from a 1 to a 3. Deep reasoning students generally improved their use of deep features in this category ($Z=-3.12$, $p=0.0018$). Only one deep reasoner did worse in the post while nine stayed at either a 2 or a 3 and twelve improved from a 2 to a 3. In the post-instruction assessment, neither type of reasoner scored below a 2 in this

category. This category was the “best” in terms of post assessment performance for both surface and deep reasoning students because it had the highest number of 3 codes (surface: 11, deep: 17).

Student 27 was a deep reasoner that initially scored a 2 in the during-instruction assessment and then improved to a 3 in the post. When asked about the effects on organisms in a food web compared to a food chain, student 27 stated that in a food web,

“predators may have multiple prey so when a certain prey’s population size gets low they will switch prey. But in a food chain they will continue driving that prey’s population down.”

While the student does not provide much information about a food chain, there is a description of one trophic level (predator’s prey) in the food web that has multiple organisms which qualifies the student for a score of 2 in this category. In the post assessment, student 27 described organisms at multiple trophic levels:

“[Broadleaf plants] would decrease because with the grass population decreasing due to the grasshoppers both mice and rabbits would be forced to eat more broadleaf plants.”

Organisms at the herbivore level include mice and rabbits while organisms at the plant level include grass and broadleaf plants. The student describes these organisms as connected through consumption. The student also states: “in a food web predators may have multiple prey,” which suggests that the student understands a predator may have a single or multiple prey species. These factors qualified the student for a score of 3 in the post assessment.

Competition

Surface reasoning students also did well in this category ($Z=-3.18$, $p=0.0015$). Ten surface reasoning students improved with eight improving from a 1 in the during-instruction assessment to a 2 in the post. The other two improved from 0 to a score of 2. Four surface reasoning students retained a score of 2 between assessments. Deep reasoning students also improved in this category but the results were not significant ($Z=-1.54$, $p=0.12$). Five deep reasoning students improved from a 1 to a 2 between assessments while 15 stayed at a score of 2. The other two students stayed at a score of 1. Student 50 (surface reasoner, post-instruction) stated:

“If you increase the # of competitors at each level, the populations of the trophic levels below will decrease.”

This student did attempt to explain the effects of adding competitors but did not provide a reason why increasing the number of competitors would affect lower trophic levels which qualified this response as a 1. Student 20 explained competition through a different means by stating:

“Grasshoppers would have a potentially negative effect on broadleaf plants by consuming more grass and forcing rabbits & mice to focus more on broadleaf plants.”

So the student describes how adding the grasshopper as a competitor would negatively affect other herbivores as well as plants that are not a part of its diet. Student 4 provided a similar response stating:

“Rabbit population size will decrease because they are competing with grasshoppers for grass, so as grasshoppers go up, they have to go down.”

These description qualified the responses as a 2 for competition.

Stability

In stability, surface reasoning students also improved in the use of deep features to explain answers but the difference was not statistically significant ($Z=-1.66$, $p=0.096$). Seven surface reasoning students improved between assessments while seven stayed at a score of 0 or 1. The remaining three students did worse from during-instruction to post assessment. Deep reasoning students did have significant results, however their use of deep features in their explanations was significantly lower in the post-instruction compared to the during-instruction assessment ($Z=5.26$, $p<0.001$). In the during-instruction assessment, all deep reasoning students scored at least a 1 while eight scored a 0 in the post. Only two students in this group improved their scores. No surface reasoner scored higher than a 2 in either assessment for this category. Student 51 stated that:

“Competitors at multiple levels makes changes in a population less dramatic over time because there are multiple variables that have to be taken into account to change populations.”

This student attempted to describe the effects of stability but did not clearly explain that this occurs because there are multiple organisms at each trophic level which is why this response qualified as a 1. Student 5 explained:

“Increasing the number of competitors in a food web allows for more stable population sizes. With a chain, a change in one population can

dramatically affect the other, but with a web there are more organisms to fill in the gap.”

This student attempted to describe stability and that it is caused by multiple organisms. However, the student did not describe how multiple organisms at each trophic level would affect the other populations in the food web which qualified this response as a 2.

Student 45 is the only student to maintain a score of 3 in the stability category between assessments. In the during-instruction, student 45 stated,

“there would be less huge changes in population of the organisms because if one dies out there are multiple other predators or prey to fill the opening. They balance each other out so there will be much smaller fluctuations than in a simple food chain.”

In the quote, the student describes this “balance” as occurring because there are multiple organisms at each trophic level to fill the role of another organism if it were to die out. The student also states that having multiple organisms at each trophic level limits the growth in population size and reduces the fluctuations in a food web. In the post assessment, the student essentially responds with the same answer, stating:

“[Increasing competitors at each trophic level] affects food webs less because there are more interactions and diversity. There are more organisms that can fill in the open niches and resist disturbances/fluctuations.”

Both responses explain that the competition is what helps food webs resist large changes to population size and are why the student scored a three in both assessments for this category.

Overall, the surface reasoning students used significantly more deep features in their reasoning from during-instruction to post assessment in Population Size, Food Webs, and Competition. These students also used more deep features to explain the concept of Stability but the results were not statistically significant. Deep reasoning students used significantly more deep features when explaining the concept of Food Webs and significantly less deep features when explaining Population Size and Stability. These students also performed better in Competition, but these results were not statistically significant.

Discussion

There were two questions I wanted to answer with this study. First, I wanted to determine what characteristics were unique to surface and deep reasoning students when describing food web dynamics. Second, I wanted to determine how reasoning about food web dynamics changed as students became familiar with the concepts.

Similar to past studies, I found that surface reasoning students were individuals who focused more on the obvious features present in a food web (Hmelo-Silver *et al.*, 2007). According to the rubric, many of these students attempted to apply concepts to support their reasoning about how disturbances in a food web affected other populations but were unable to explain how the concept applied in that scenario. Some students were able to score a 3 in one or two categories but no student was able to provide enough

details in their explanations to qualify for a 3 in stability. Overall, surface reasoning students included less deep features in their reasoning about Competition and Stability than deep reasoning students. After spending some time learning the information however, surface reasoning students did improve their reasoning of food web dynamics and included more deep features in their explanations.

Deep reasoning students were initially individuals who better understood how concepts were applicable in a scenario and were able to use deep features to explain how a food web was affected by perturbations. Deep reasoning students included more deep features in their reasoning than surface reasoning students during the during-instruction assessment. In the post-instruction assessment, deep reasoning students used less deep features in their reasoning about Population Size and Stability compared to their responses in the during-instruction assessment. Past studies have found the transfer of knowledge to be more successful if there is a strong foundation of knowledge and the contexts are similar (Bransford & Schwarz, 2009; Lobato 2006). This suggests that the contexts may have not been similar enough to facilitate transfer.

Population Size

Population size affects how populations in a food web affect each other (Klemola, Koivula, Korpimäki, & Norrdahl, 2000). Every student was able to describe how at least one population would respond to consumption suggesting that students understand this concept. In this category, the deep reasoning students used more deep features in their explanations than the surface reasoning students. This implies that deep reasoning students have a better understanding of the concept and how it affects multiple

organisms. The ability to reason about how populations change is necessary to understand concepts such as competition and stability. The level of understanding deep reasoning students have about this concept may explain why the deep reasoning students included more deep features than the surface reasoning students when explaining competition and stability. Changing the population size of one species may impact its prey and predators and have effects that reach organisms throughout the community that are not directly connected to the species. Surface reasoning students do not likely possess this level of understanding which may explain why surface reasoning students struggled with the concepts of competition and stability. It is also possible that population size is not as strongly connected to stability principles which are about diversity and not applicable to stability.

Food Webs

In this category, deep reasoning students scored at least a 2 in the during-instruction assessment while surface reasoning students scored at least a 1. Deep reasoning students were able to describe a food web as having multiple organisms at least at one trophic level that were connected in some way through consumption. This suggests deep reasoning students have a better understanding of this concept than surface reasoning students and see the food web as many components interconnected through multiple organisms instead of linear chain-like connections. In the post-instruction assessment, all but one student scored a 3 in the food webs category. To qualify for this score, a student had to describe a food web with multiple organisms on at least two trophic levels. A significant number of the deep reasoning students were able to

accomplish this which suggests that their understanding of food webs was more complete. Most surface reasoning students scored a 3 in the post-instruction assessment and all of these students improved which suggests their knowledge of the concept was also more complete, compared to their understanding in the during-instruction assessment.

Statistically, this category was where students performed the best in the post-instruction assessment which suggests that the concept of a food web was taught very well or an easy concept to learn. To reason about food webs requires students to move beyond simple unidirectional reasoning and to consider the effects of disturbances in multiple directions on numerous organisms (Polis & Strong, 1996). Hogan (2000) showed the elementary school students had difficulty with two-way reasoning and would only assess changes to the food web based on a unidirectional cause-and-effect relationship. Since the undergraduate students in my study had encountered many food webs throughout their education, they likely had more knowledge and a better understanding about how the relationships affect organisms between trophic levels and within the same level (i.e., competition).

Competition

Surface reasoning students performed worse than deep reasoning students in competition in both during-instruction that deep reasoning students initially have a better understanding of the concept. Surface reasoners did improve between assessments and performed similar to deep reasoners in the post-instruction assessment. Competition was still difficult for some students to understand even in the post-instruction assessment.

Since it is an indirect effect, it is a deep feature of food webs and requires a student to think more critically about how it impacts the populations. Due to this fact, it is not surprising that some students from both groups struggled with the concept in both assessments.

Stability

Stability requires an understanding of population size, food chains, and competition. For example, competition affects organisms at each trophic level and a change in a population's size can affect its predators and prey. Surface reasoning students improved in their use of deep features when explaining stability. However, no surface reasoning student scored a 3 in the stability category from during-instruction to post-instruction assessment. Deep reasoning students did worse between during-instruction and post-instruction assessments. For deep reasoning students, this suggests that they were able to reason about stability initially, but were not able to apply the same reasoning in the post-instruction assessment. If their knowledge of stability was learned, they would be able to transfer their reasoning to a new scenario which they struggled with in the post-assessment. It is also possible that there were not enough similarities between the learning and transfer sessions (Lobato, 2006). For surface reasoning students, the concept of stability was problematic in both assessments. These findings suggest that stability was the most difficult concept for students to reason about among the four categories possibly because it was not adequately learned.

Reasoning Ability

Variation in Reasoning. The total scores from the during-instruction assessment represents a range of students with different background experience and knowledge. The variation was reduced in the post-instruction where the range of scores became smaller. This probably occurred because of a “ceiling effect.” The students could not score any higher than a 3 so there was no way to improve if they already scored a 3 in the during-instruction assessment. This is not unusual since students were purposefully preparing themselves to take an exam in which the post-assessment questions were based. This could explain why so many students showed improvement between assessments. It could also suggest that students are recalling deeper features of food web dynamics and applying them to their reasoning when answer the questions.

For the during-instruction assessment, deep reasoning students included more deep features in their explanations than surface reasoning students. In the post however, the average scores from both groups were very similar and in the case of Population Size, differed by less than a tenth of a point. Firstly, lower performing students have the greatest potential to improve throughout the course. Surface reasoning students represent the lowest scoring students in the class for this section and therefore have the most room to improve. By the end of the assessment, students in this group had improved significantly, matching and sometimes exceeding the scores of their deep reasoning counterparts. In the case of Food Webs surface reasoning students more than doubled their mean score.

These findings also suggest that the deep reasoning students may include less deep features in their reasoning, especially if the information is not fully understood. Due to the way the during-instruction assessment was delivered to students, the overall scores for deep reasoning students suggest these students were able to interpret and learn concepts faster and more efficiently than surface reasoning students. I expected the deep reasoning students to maintain a similar level of scores between assessments due to their scores in the during-instruction assessment. That was not the case. Instead, the deep reasoning students did significantly worse in Population Size and Stability while doing significantly better in Food Webs and improving in Competition. A decrease in scores may happen because the students forget the information or because they believe they understand it well enough to simply skim over it while studying. The former is unlikely because the students were preparing to take a final exam so the information would have been recently reviewed. The latter suggests that students may be overconfident in their abilities and generalize the knowledge for the exam.

If students had learned the concepts, they would be able to transfer the knowledge to a similar scenario such as the post-instruction assessment. This does not mean that all the knowledge was lost. Deep reasoning students did perform better in some categories which suggests that some transfer occurred. Those concepts of food webs and competition were likely learned better than population size and stability. It is also possible that there were not enough similarities between the learning and exam contexts. Research suggests that the success of transfer improves when there are multiple

similarities between contexts (Vendetti, Wu, & Holyoak, 2014). Presenting the post-instruction assessment outside of the exam may improve the transfer of knowledge.

Motivation. Research on motivation is diverse with numerous theories and explanations for the reasons behind student learning. Schultheiss (2001) suggested that when the goals of the classroom and personal motives of the student are in line, the individuals are more motivated and perform better. Elliot and Church (1997) have shown that motives influence individual behavior which also affects student learning and performance. In the classroom, students who do not improve their reasoning abilities may be affected by their own personal motives. This suggests that instructor influence in the form of teaching is not the only factor that affects student learning. If the student does not possess the motive to learn or improve, no amount of teaching will significantly impact a student's ability to process and understand new knowledge.

Future Directions

Active Learning. Studies on active learning suggest that these techniques make students more skilled learners and decrease the gap between low-performing and high-performing students (Freeman, Haak, & Wenderoth, 2011; Haak, HilleRisLambers, Pitre, & Freeman, 2011; Linton, Pangle, Wyatt, Powell, & Shepard, 2014). In addition, the use of active learning instruction has been shown to improve the performance of students and success rates in the classroom (Freeman *et al.*, 2014). In this study, students were taught food webs concepts using an active learning format of teaching. Between assessments, students improved their ability to reason about food web disturbances. These results are

in line with the results found in previous studies on active learning (Freeman *et al.*, 2011).

Further research on active learning should focus on the impact of active learning on surface and deep reasoning students in the context of food webs. Researchers should focus on how active learning affects these groups of students as well as students that do not fall in either category. Understanding how different groups of students respond to active learning techniques may show which techniques are suited for each group and separately and all together.

Impact for Instructors. Instructors have a limited amount of time during the course to teach students the course content and spending more time on helping students understand a specific concept or its value may not be possible. Since students appear to have a strong understanding of population size, instructors should focus on food webs and competition. To teach these subjects, instructors should consistently implement active-learning instruction in the classroom. These sessions should highlight the deep features necessary to understand food web interactions and competition effects. This will provide students with consistent practice with the concepts and allow the instructor to address misconceptions at the same time (Hartley, Wilke, Schramm, D'Avanzo, & Anderson, 2011). Instructors can select a wide variety of active-learning activities such as group problem-solving, peer instruction, or personal response systems (Freeman *et al.*, 2014). Once a good foundation of knowledge about food webs and competition has been built, instructors can focus on teaching stability.

Since students struggle with stability, it may not be necessary for students to learn the concept of stability in an introductory biology course. The concept of stability can be taught in upper level biology courses where instructors have students who are already knowledgeable about the basics of biology. Students at the introductory level should focus on developing a strong foundation of the basics. Once a strong understanding of population size, food webs, and competition is established, instructors can connect the concepts together and use student knowledge of those concepts to teach stability.

At the beginning of the course, students who use more surface features in their reasoning have the potential to improve. While they may be a surface reasoner initially, over time their understanding of the course material will improve and they will include more deep features in their reasoning. Similarly, while a student may be a deep reasoner initially, they may include less deep features in their explanations at the end of the course. To help surface reasoning students improve their understanding of the course concepts and to help deep reasoning students retain their understanding, instructors should challenge students throughout the course by including assignments and discussions that draw on previously learned knowledge. In addition to providing students with practice with concepts, instructors will be helping students develop a strong foundation of knowledge that can be built on in future courses. Students learning a new subject require a lot of time to process and learn information which is necessary for the mastery of the knowledge (Chi & VanLehn, 1991). Repeated practice can help students develop mastery of the concepts.

One way instructors can challenge students with previously learned concepts is to provide multiple opportunities to apply the concepts they learn in familiar and unfamiliar food webs. The more experience the students have, the better their mastery of the concepts. Recent studies suggest that an instructional method known as ‘expansive framing’ may help students learn concepts and apply them across multiple, similar contexts (Jordan, Gray, Brooks, Honwad, & Hmelo-Silver, 2013; Engle, Nguyen, & Mendelson, 2011). It involves presenting how concepts are applicable in multiple situations and providing the experience students need to understand how the concepts apply. Expansive framing differs from the traditional method, also known as bounded framing, in which instructors do not explicitly describe concepts as applicable across multiple contexts. Instructors may use expansive framing to help teach students the concepts of population size, food webs, and competition. Once the students have a strong understanding of the concepts, it will be easier for the instructor to teach the concept of stability.

CHAPTER 3

IMPACT OF INSTRUCTIONAL FRAMING ON FOOD WEB REASONING

In 2011, the American Association for the Advancement of Science (AAAS, 2011) published *Vision and Change in Undergraduate Biology Education: A Call to Action*, a comprehensive report that represented the culmination of nationwide discussions and conferences that focused on the future of undergraduate biology education (AAAS, 2011). One of the major goals outlined by this document, was improving the quality of undergraduate learning in biology courses. These courses introduce students to a variety of important topics from the scientific method to the ecology of food webs.

Literature Review

Reasoning about Complex Systems

The complexity of natural systems such as food webs can be attributed to their numerous structures (Winemiller, 1990). Understanding the complex dynamics of this system can be difficult because it requires learning about several different but related components (Hmelo-Silver, Marathe, & Liu, 2007; Jordan, Gray, Demeter, Liu, & Hmelo-Silver, 2009). This includes multiple interconnected levels and the interactions between each component (Duncan & Reiser, 2005; Hmelo-Silver & Azevedo, 2006; Wilensky & Resnick, 1999). Food webs are comprised of multiple feeding relationships representative of different trophic levels. Trophic levels are classifications used to sort organisms in a community based on their feeding relationships (Stiling, 2012) and

include producers (plants, algae, and other autotrophic organisms), primary consumers (herbivores), secondary consumers (predators), tertiary consumers (predators that eat predators), and beyond.

Food webs are a representation of the feeding relationships between organisms (intraspecific and interspecific) living in a community of organisms (Molles, 2010; Stiling, 2012). A community is comprised of populations of different species living in the same habitat. Organisms within food webs are usually represented by words or images of the species connected to their predator or prey by an arrow that represents consumption (Figure 3.1). These connections represent direct effects in the food web (Paine, 1966). Direct effects occur when a population affects another population through consumption. For example, if species A eats species B, increasing the population size of species A may decrease the population size of species B because there are more of A eating B. Previous studies suggest that students understand these direct effects (Mintzes, Trowbridge, Arnaudin, & Wandersee, 1991).

Indirect effects are also a part of food webs. One species affects another species through a third species, however this interaction is not always shown (Begon, 2014). For example, in Figure 1 the predators are depicted as indirectly affecting plants through their effect on the herbivores. This indirect effect occurs because the predators reduce the herbivore population or prevents the herbivores from over-consuming plants resulting in the growth of more plants. Without the pressure of consumption from the herbivores, the plants have more “room to grow.” When a predator negatively affects the abundance of herbivores and the effects on the herbivore positively affects the plants, this is an

example of a trophic cascade (Begon, 2014; Stiling, 2012). As an indirect effect, trophic cascades are generally not indicated in food webs and their effects must be inferred.

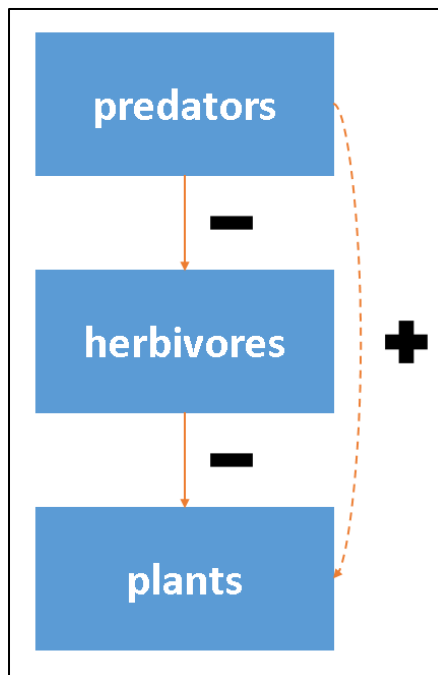


Figure 3.1. A general food chain model. Includes direct (solid arrows) and indirect (dotted arrows) indicators and their effect (positive or negative)) on each organism.

Competition is another example of a food web concept that creates indirect effects. Competition occurs when two or more species use the same resources such as food, water, or habitat space, they are in competition (Stiling, 2012). It directly affects the organisms involved and indirectly affects the other organisms in the community (Molles, 2010). For example, if another predator was added to the food chain in Figure 3.1 and

this predator consumed the same herbivores as the original predator, the population of herbivores would decrease because of increased predation. In response, the amount of plants would grow due to the population decrease in herbivores.

Transfer of Knowledge

Students are expected to not only learn this knowledge about food webs but also apply it to other, similar contexts. Transfer of knowledge requires students to recognize similarities, such as direct and indirect effects, between contexts and apply previously learned concepts to new scenarios (Chi & VanLehn, 2012; Engle, Ngyuen, & Mendelson, 2011). This can be difficult if students do not expand their ability beyond linear, unidirectional reasoning which involves reasoning only about direct between two organisms (Gotwals & Songer, 2010; Hogan, 2000. For example, in Figure 3.1, increasing the population of predators decreases the population of herbivores. A student that only reasons linearly, may have difficulty understanding how disturbances to populations of organisms affect the entire food web (Gotwals & Songer, 2010). For example, at the elementary school level, Gotwals and Songer (2010) found that some students struggled with reasoning about how a disturbance at one trophic level in a food chain would indirectly affect another trophic level. Students understood that snakes ate mice but were unable to connect an increase in the mice's food to an influence on the snake population.

To correctly transfer knowledge to similar contexts, students must develop a broad understanding of food web dynamics and recognize when and where the appropriate concepts are applicable. One evidence-based instructional approach to

improving transfer employs the strategy of expansive framing (Engle, Lam, Meyer, & Nix, 2012; Jordan, Gray, Brooks, Honwad, & Hmelo-Silver, 2013). This requires the purposeful inclusion of several examples of a concept in multiple contexts and opportunities for students to develop and present their own unique understanding of the information. This approach could help students apply what they learn about one food web to other food webs and improve the success of knowledge transfer.

Expansive Framing

In two recent studies, Engle *et al.* (2011) and Jordan *et al.* (2013) suggest that a model known as ‘expansive framing’ can improve students’ ability to transfer knowledge between similar contexts. This model requires the teacher to incorporate examples of the discussion topic so the students are able to recognize that the knowledge is applicable to multiple situations. For example, when undergraduate biology students are learning about the nitrogen cycle in a terrestrial ecosystem, the teacher can frame the knowledge expansively by explaining that other ecosystems have similar nitrogen cycles and pointing out the similarities and differences between systems (Jordan *et al.*, 2013). In comparison, a teacher using a bounded framing approach would focus on developing student understanding of concepts as they apply to one ecosystem.

By using an expansive framing approach, instructors could abstract ideas from one ecosystem and apply them to another (e.g., the nitrogen cycle in a terrestrial system compared to cycle in a marine system). In this way, instructors are providing students opportunities to view concepts generally and observe context-specific similarities and differences of a cycle. Bounded framing focuses students on learning about concepts in a

specific context and develops a specific foundation of knowledge. Students may, on their own, abstract these ideas to other, similar contexts. This can be beneficial because students gain experience with applying concepts to multiple contexts and may develop their understanding and mastery of the concepts.

Expansive framing may help students recognize that what they are learning is also applicable in other contexts and generalize concepts to transfer the information to new situations. Generalizing concepts helps students understand how an organism in one food web may be similar and different from an organism in another food web (Magntorn & Hellden, 2007). The studies done by Engle *et al.* (2011) found that students were more likely to transfer knowledge when they recognized that information learned in one context is applicable to one or many other contexts. In their study, students participated in two sessions. In the first session, a tutor met with each student individually and instructed students to explain in-depth text about the cardiovascular system and complete a range of activities that involved creating diagrams, answering questions, and describing the relationships between components of the system. At the end of the first session, the tutor confirmed that every student was able to correctly explain the relevance of pressure and surface area to the processes of the cardiovascular system. For the second session, students learned about the respiratory system and were asked to complete three activities. The first activity was to review a text about the respiratory system during which students were asked to convey their thoughts out loud. The other two activities were to explain a lung model and provide an explanation for the amount of alveoli in a normal human lung.

Both explanations are related to the surface area principle discussed during the cardiovascular tutoring session.

The bounded group was told each session would be about the cardiovascular or respiratory systems while the expansive group was instructed that both sessions were about body systems. Framing the sessions in this manner presented the information as separate topics (bounded) or one interconnected topic (expansive). The students that successfully transferred information about the cardiovascular system transferred concepts such as the surface area principle and its relation to both systems and learning strategies such as diagram drawing (Engle *et al.*, 2011).

When instructors framed the information expansively by explaining how the ecosystems were similar (e.g., both have nitrogen systems) to other ecosystems, the students were able to transfer their knowledge about processes and components from one ecosystem to another (Jordan *et al.*, 2013). Their research suggested that students taught using the expansive framing method were more apt at explaining the processes involved within a given ecosystem and were more likely to transfer the knowledge of the processes between ecosystems. If expansive framing was useful in helping students recognize the similarities between contexts and how concepts applicable in one situation can be used in another, it may be useful to apply the method in teaching other aspects of biology such as food webs.

Research Questions

Vision and Change calls on educators to improve the quality of undergraduate biology classes (AAAS, 2011). To do this is no small feat and requires changes to many

aspects including how certain concepts are taught. Research suggests that the instructional method of expansive framing may help students learn the appropriate strategies and information, generalize it, and then apply what they learned to a novel scenario. This method may also help students develop a better understanding of food web dynamics. Based on this, I wanted to know:

1. How does expansive framing in a learning context about food webs affect student ability to transfer knowledge to a novel context?
2. Does expansive framing encourage students to generalize knowledge about food web dynamics?

These questions are pertinent to addressing how undergraduates and novice learners are processing information and transferring information and in understanding how students in introductory biology classes are learning and applying what they learn within the context of food webs. The findings provide insight into the generalizability of expansive framing instructional approaches in undergraduate biology teaching.

Methods

Participants

The students recruited in this study were undergraduate life science majors enrolled in an introductory biology course that at a large Midwestern University. Emails requesting participation were sent out to approximately 120 students. A total of 25 students responded to the request. From those who responded, 20 students (5 males, 15 females) were selected for the study based on their ability to attend two sessions, scheduled exactly one week apart. No other demographic information was collected. All

students signed a consent form at the beginning of the first session. All participants were given monetary compensation after the completion of the second session. Responses from both sessions were recorded and then later transcribed by the author. This study was conducted with the permission of the Institutional Review Board (IRB #20140514466).

Treatment

Students were randomly assigned to the expansive or bounded treatment based on the order in which they responded to the email. Students were asked to attend two sessions: a learning session and a follow-up session. In the first session, both groups were given a lesson about food web dynamics. The lesson specifically focused on food web concepts including food chains, trophic cascades, competition, and the application of these concepts when reasoning about disturbances in a food web. The bounded group was presented with organisms from one food web throughout their lesson (Figure 3.2). The expansive group was presented with organisms from five different food webs, including the one shown to the bounded group, and taught the same concepts. The organisms seen by the expansive group were representative of different natural communities and included marine, grassland, lake, garden, and savannah organisms (Figure 3.3). In the follow-up session, students were asked questions about the concepts learned in the learning session.

Learning Session. In the learning session, students were taught by an instructor (the author) about food web concepts including direct and indirect effects, trophic levels, food chains, trophic cascades, competition, and how these concepts are used in food web reasoning. At the beginning of the lesson, students were read the following learning objectives to preface the information:

By the end of the study, you should be able to,

- Identify relationships between components;
- Use quantitative reasoning to deduce indirect effects; and
- Predict direct and indirect effects on population size

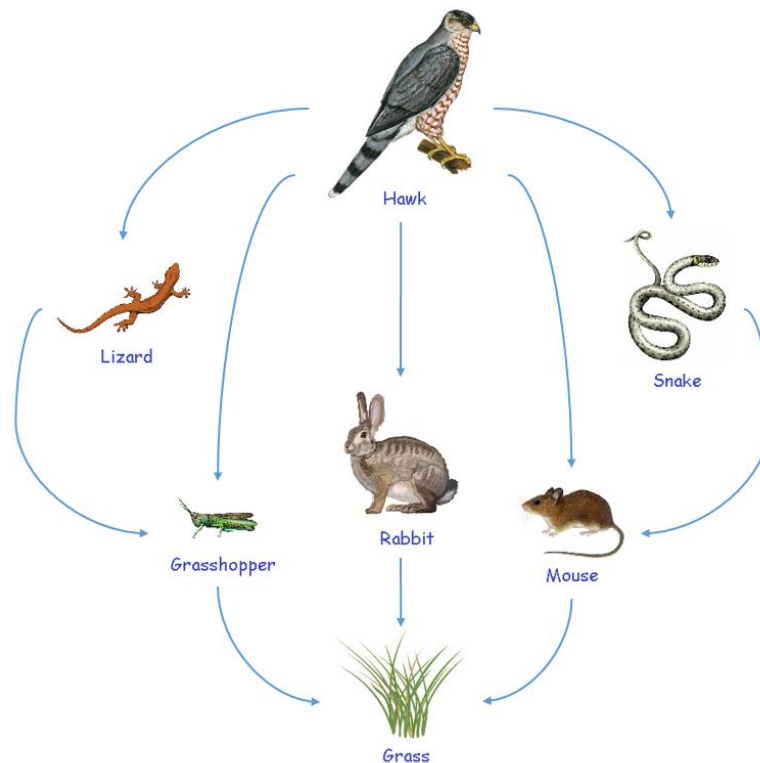


Figure 3.2. Terrestrial food web presented to bounded and expansive groups. Arrows between organisms represent feeding relationships.

Students were introduced to food chains and provided examples of direct (consumption) and indirect (inferred) effects which led into the concept of trophic cascades. After discussing trophic cascades, organisms were added to each trophic level

(producer, herbivore, carnivore) of the food chain and the concept of competition was introduced. Students were asked to explain the effects of adding another organism at the same trophic level which allowed them to practice describing competition.

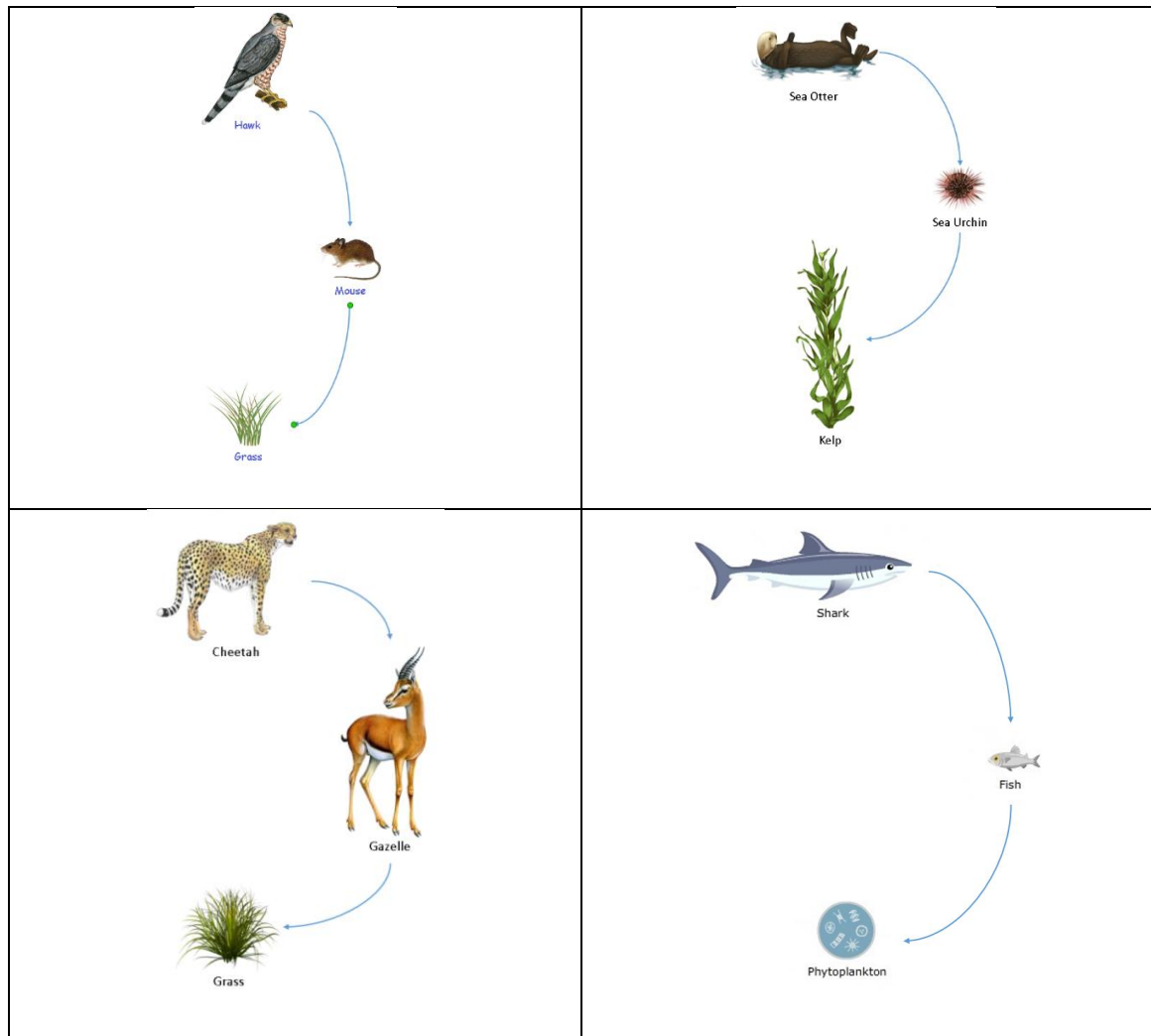


Figure 3.3. Food chains used in expansive treatment lesson. Grassland (top left), kelp forest (top right), savannah (bottom left), and marine (bottom right).

Students were also asked questions during the first session designed for students to practice describing concepts with respect to the presented food web and help them develop their understanding of the information. Students in the bounded treatment were able to practice describing the concept using one food web while students in the expansive treatment practiced with five food webs presented throughout the lesson. Students were also asked to explain the effects of quantitative changes based on factors such as increasing/decreasing the population size of a predator or herbivore. In addition, students were asked to explain how trophic cascades and competition affected the populations of other organisms. Responses included negative effects on competing organisms or positive effects on organisms not directly involved with the trophic cascade. At the end of the lesson, the instructor verbally explained how the concepts of population size, food chains, trophic cascades, competition, and stability were important to consider when reasoning about how disturbances affected the populations in food webs.

Transfer Session. In the transfer session, the same instructor asked students to solve problems that required them to draw on their knowledge of the concepts taught in the first session. Students were first asked to report about anything they learned or saw during the time between sessions that was related to any of the concepts taught. The baseline was important to determine if any bias from previous instruction was present. Students were then introduced to three made-up organisms: the Schiveldens, Ovelzets, and Krewenveds. The Schivelden preyed on the Ovelzet and the Ovelzet preyed on Krewenveds (Figure 3.4). Asking students to reason about made-up organisms requires

the abstraction of their knowledge about food web concepts to a new scenario (Goldstone & Son, 2005).

Organism List

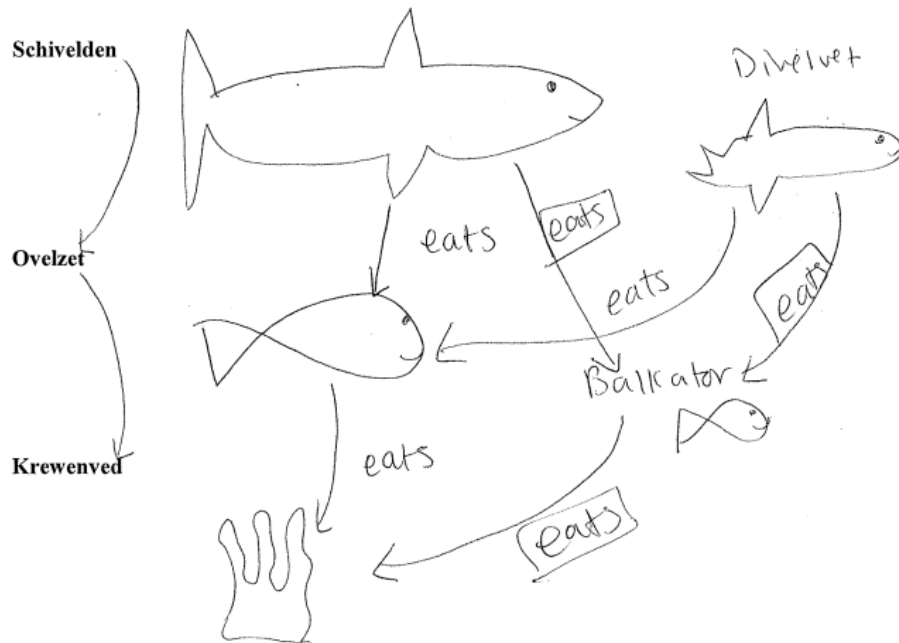


Figure 3.4. Example of made-up food web drawn by student. This student was from the expansive group. The student used an aquatic scenario to depict these organisms.

Students were asked to draw what they believed these made-up organisms looked like. Using what was drawn, students were then asked to describe indirect effects and trophic cascades. Following these descriptions, students were asked a series of quantitative questions to assess their quantitative reasoning. These questions required

students to explain how increasing/decreasing the size of a population would affect the other organisms in the community. Two additional organisms were added at different times during the session. These organisms were the Dibblevik which consumed Ovelzets and the Bokkeltir which consumed Krewenveds and was consumed by Schiveldens and Dibbleviks. Adding the Dibblevik created competition with Schiveldens for Ovelzets and Bokkeltirs. Adding Bokkeltirs created competition with Ovelzets for Krewenveds. Students were also asked to draw these organisms and their relationships to the other species that resulted in a small food web such as the example drawn by a student in Figure 3.4. Similar to the food web(s) in the learning session, the made-up food web in the transfer session had the following:

1. At least three trophic levels;
2. An initial food chain structure;
3. Two organisms at the herbivore level and predator level; and
4. At least two organisms in competition for another organism

After the entire food web was drawn, students were asked questions about how the removal of certain species would impact the other organisms. These questions were identical to those asked in the learning session. This was followed by a hypothetical situation unique to the transfer session in which the Bokkeltirs experienced a massive growth in population size. The student had to come up with at least two different solutions to regulate the growth of this species. Students were instructed that they could not eliminate the Bokkeltirs through hunting or any other means that would involve humans killing them.

This question was of particular importance because it was new to the students and required them draw on all the knowledge they had previously learned and use it to solve a complex problem. In the learning session, students had only been asked to reason about the quantitative changes that would occur in response to changes to population sizes. To answer this question, required consideration of multiple factors to consider such as the number of organisms at each trophic level, the predator and prey relationships, and how any change to the food web would alter the population sizes of the current organisms. Depending on the response and explanation, the student could demonstrate a level of understanding of the concepts necessary to reason about how disturbances would affect organisms in a food web. The most likely solution I expected, was students would be able to solve the problem by adding an organism to the food web that would consume the Bokkeltir to control its population size. However, adding another organism would have other effects such as reducing a food source for Schiveldens and Dibbleviks, reducing a predator of Krewenveds, and reducing the population size of the Ovelzets' competitor. The student would have to consider the implications of adding another organism in their answer. In addition, the students were required to provide two answers and were not allowed to provide an answer similar to their first. So if a student wanted to add an organism in their first answer, they could not in their second which required additional thinking and reasoning.

Assessment

Student responses from the transfer session were compared to those given during the learning session. Questions asked in both sessions were similar and tested students'

understanding of food web concepts such as trophic levels, trophic cascades, competition, and quantitative reasoning. Responses by each treatment groups were compared for including concept comprehension, recall of information, and explanation of quantitative effects were observed and recorded. Any observable differences between treatment groups would indicate if expansive framing had an effect on the students in this study.

Results

Twenty students learned about food webs from a bounded or expansive framing perspective. Their ability to transfer knowledge about food webs was assessed one week later. Generally, there was little treatment effect with students from both treatments similarly applying their knowledge of food webs from the learning session to the transfer session. Student reasoning was largely constrained to thinking about direct effects and they often failed to transfer knowledge of indirect effects such as trophic cascade and competition.

Framing Perspective

Learning Session. Students were asked a series of questions to establish what they knew about food webs and related concepts prior to the study. Every student indicated some prior experience learning about food webs during high school however, recall of information was limited to: predators ate prey (most common), energy was transferred from one organism to another, and competition was between two organisms that shared a resource (least common).

During the lesson, students from both treatments responded similarly to each question. For example, when asked what happens to the organisms in a food chain when

the predator's population was reduced by one, every student replied that the herbivore's population would increase and the plant population would decrease as a result. Similarly, when asked what would happen if the predator's population was reduced by 10, students responded that the herbivore would increase a lot more and the plant population would decrease a lot more compared to if the predator population was only decreased by one.

Framing groups spent a similar amount of time learning the information. The average learning session lasted 21 minutes. In addition, there were no group differences in prior knowledge before the session began.

Transfer Session. Similar to the learning session, in the transfer session students were asked questions about food webs and related concepts. The questions were similar in terms of how they were phrased and the concepts they were addressing. Only three students (1 bounded, 2 expansive) were exposed to information that may have influenced their answers during the second session. When asked to describe concepts such as trophic cascades and competition however, none of these students supplied any explanation that noticeably differed from other students.

All students were able to describe indirect effects using the relationships between the three made-up organisms (Table 3.1). For example, when asked to describe an indirect effect, student 11 replied:

“An indirect effect would be, in this case, since the Schivelden are eating the Ovelzets, the Schivelden are indirectly affecting the Krewenveds-- Krewenveds' population or they're indirectly affected even though they don't directly consume them or anything like that. Because the Schivelden is

eating the Ovelzets. The Krewenved is increasing in population because they no longer, or they have, there's a smaller population of the Ovelzet.”

Students provided similar responses between framing groups. This implies that students understand direct and indirect effects and how organisms indirectly affects other organisms in a 3-trophic level food chain.

Description of criteria	Bounded Framing	Expansive Framing
Accurately described indirect effects	10	10
Accurately described trophic cascades	0	0
Accurately described competition	10	10
Recalled something from previous session without being prompted/asked about it	3	2
Described initial 3 organisms (Schivelden, Ovelzet,& Krewenved) as food chain	0	1
Competition was created when adding Dibblevik (without prompting)	7	6
Competition caused competitors to decrease	6	5
More predators meant prey were consumed faster or had a “larger effect”	10	10
Mentioned predator shifts in prey	1	1

Table 3.1. List of criteria searched for in student responses during the transfer session.

No student was able to sufficiently describe the concept of trophic cascades. Responses were limited to direct effects such as how the population size of the predators would affect the population of herbivores and so on. Students that attempted to recall information about trophic cascades were not able to move beyond this explanation and did not mention that the effects of a trophic cascade affects those organisms and organisms in the food web.

Students were also able to describe that competition was present when two organisms preyed on the same organism. When asked about the effects of increasing the

number of predators by more than 20, every student explained that more predators meant that the prey will be consumed at a faster rate (more organisms consumed in a shorter amount of time). Students were asked this question to assess their understanding of how a trophic cascade would affect other organisms in the food web. Any effects on those populations would affect other organisms in the food web. For example, if the population of an herbivore in the trophic cascade was reduced, its competitors would have less competition for resources and may increase in population size. If the competitors share a predator in addition to resources however, the predator population may also increase as the competing herbivore population increases.

Solution to control population of herbivores	Bounded Framing	Expansive Framing
Increase population size of predators	9	10
Add competitor species for predators	8	8
Decrease population of primary producer	8	7
Add organism that selectively eats increasing herbivore population	7	7
Increase population size of competing herbivore	2	2
Decrease population size of competing herbivore	2	2

Table 3.2. Options suggested by students to control the population of herbivores. Students may have included more than one option in their response to the hypothetical situation.

No difference between treatment groups was observed. There were six total proposed options to control the population of Bokkeltirs (Table 3.2). The most common option to control the growing population of herbivores was to increase the population

sizes of its predators. The students who suggested this as an option explained that this would increase predation on both populations of herbivores (Bokkeltirs and Ovelzets) which (as described by Student 7) result in:

“[Bokkeltir] population would be a little bit more controlled because they have more predators. They would probably, since these two populations, the Schiveldens and Dibbleviks population both increased, the Ovelzet population would probably be more controlled or decreased a little bit.”

The least common options were to decrease or increase the population of competing herbivores. Both options were acceptable if the student could support their reasoning. The students who suggested decreasing the competing herbivore assumed the predators would increase predation on the growing herbivore population since more of that population would be available. For example, student 9 explained:

“if there are less Ovelzets then the Schivelden or the Dibblevik will eat the Bokkeltir. Yeah. Because there are less Ovelzets and it will be harder to get the Ovelzets compared to the Bokkeltir if the Dibblevik and the Schivelden are both competing for Ovelzets.”

Students who suggested increasing the competing herbivore population explained that the plant population would decrease and limit the food available to the herbivores. For example, student 6 mentioned that increasing the population of Ovelzets would: “make it harder for the Bokkeltir to obtain Krewenveds. So there’d be less Krewenved for the Bokkeltir.” Decreasing the food available for Bokkeltirs would decrease the population size of that species.

Discussion

Framing effects

Student responses indicated that there was little to no effect of expansive framing compared to bounded framing in my study. This differs from Engle *et al.* (2011) who found that students in an expansive framing treatment were more likely to transfer knowledge than their bounded framing peers. Variation in responses did differ between students during the transfer session, however no patterns were connected to a specific treatment group. In the Engle *et al.* study, conclusions were based on what content students transferred between a learning session about the cardiovascular system and a transfer session about the respiratory system; the sessions involved two biological processes with similarities and differences. The conclusions of my study were based on the content students transferred about food web dynamics to a new, made-up food web. In addition, Engle and her colleagues used statistics to support their findings while the findings of my study were dependent on emergent patterns within student responses. This may explain why no differences were detected between treatment groups. If my study incorporated statistics, there may have been significant differences between treatment groups.

In my study, no student was able to transfer more complex food web concepts such as trophic cascades and the indirect effects of competition. Jordan *et al.* (2013) found that after several instructional sessions, students in the expansive framing treatment were able to transfer more complex ecosystem concepts such as energy flow and photosynthesis. In addition, the students were able to represent a wider range of concepts

in their ecosystem models compared to students from the bounded framing treatment. This suggests that one 30-minute learning session may not be enough for students to process and learn new this information. Instructors may need a second session to discuss the concepts or send students with homework designed to improve their understanding.

The transfer session required the application of numerous concepts which may be too much for the novice learner. Novice learners require a lot of time to process the information and learn it which is necessary for the mastery of the knowledge (Chi & VanLehn, 1991). They do not necessarily have the skills to organize the information in a useful and efficient manner (Chi & VanLehn, 1991; Ross, 1989). This may explain why there were no pattern differences between the treatment groups, even if a student had more background knowledge about the subject.

Mastery requires long commitments of time (Chase and Simon, 1973). This may be difficult to achieve in a single interview setting and even more difficult in a classroom setting where several concepts may be covered within a matter of minutes. Given more time and practice, students may have increased their knowledge retention and improved the chances for transfer to a novel scenario (Ericsson, Krampe, & Tesch-Romer, 1993; Singley & Anderson, 1989). The instructors in the study conducted by Jordan *et al.* (2013) spent three weeks teaching a lesson to students about ecosystems and ecosystem processes. This does not imply that expansive framing requires more time than bounded framing instruction. Engle *et al.*, (2011) found evidence of expansive framing effects after only two sessions. However, each student in the study had a tutor and the sessions

were longer. This suggests that the effects of expansive framing may be more detectable if the session times were increased.

In addition to adding time, the structure of the lesson could also be redesigned to better encourage students to develop their own correct understanding of the information. This is metacognition and requires students to think about what they are learning and to determine if they really “know” it (Bransford, Brown, & Cocking, 2000). Students can be taught strategies that help them assess their learning and can improve their understanding of the information (Ku & Ho, 2010; Berthold, Nückles, & Renkl, 2007). Hogan and Thomas (2001) suggested that an incomplete understanding of the concepts can make it hard for students to construct representations of a system. Understanding the concepts and deeper underlying processes can be difficult, especially for a novice learner. Grotzer and Basca (2003) found that coupling class discussion with activities designed to reveal the nature of underlying processes and the effects of these processes on the ecosystem can improve student understanding of the connections that exist within ecosystems and processes that affect them. They are designed to engage students in the learning process and can also improve overall performance in the class (Freeman *et al.*, 2014; Haak, HilleRisLambers, Pitre, & Freeman, 2011; Beichner *et al.*, 2007). Example activities include creating diagrams of the concepts (Felder & Brent, 2003), answering clicker questions (Linton *et al.*, 2014), and individually reflecting on the topics covered in class then discussing it with a peer (Smith, Wood, Krauter, & Knight, 2011).

After spending some time with the activity, students can be asked to describe how trophic cascades and competition affects organisms in food webs or to deduce how it may

affect the growth of populations. Instructors can discuss the responses with the students and help them correct or improve it. Students would have multiple opportunities to practice using their knowledge which may improve their ability to recall and apply it in the appropriate contexts.

Quantitative Reasoning

After learning about food web models and using quantities to reason about food web disturbances, students were able to correctly reason about the effects of changes to population sizes. Students answered quantitative questions throughout the learning session and were able to construct a food web based on the feeding relationships of its organisms. Students were also able to reason about changes in population sizes within a made-up food web. This suggests students understood the simplified food web model presented to them in the learning session.

During the second session, one interesting pattern present across all students was that no one asked about the quantitative feeding relationships between organisms. This suggests two possibilities:

- 1) Students may not remember using consumption quantities to describe changes in population size despite having practiced the skill during the first session; or
- 2) Students are generalizing information learned in the first session and applying it to their reasoning in the second session. This means that they do not view the consumption quantities as necessary in their reasoning.

The first implies that a deeper connection has to be made between the knowledge and its application in future contexts. Students need to understand the importance of the

information they are learning. If little value is placed on the information, students may not remember it making it difficult to recall it the next time it is needed. The second implies that students have a great understanding about how direct effects (feeding relationships) impact each organism in the food web (Mintzes, Trowbridge, Arnaudin, & Wandersee, 1991). This may explain why students did not ask about the number of organisms each species consumed. They were able to generalize knowledge about the feeding relationships because they understood the direct effects and how they impact each organism. However, this approach is highly superficial and does not mean a student understands how organisms may indirectly affect other organisms in the web. A student with a good grasp of direct effects but a poor understanding of indirect effects, trophic cascades, and competition will have difficulty reasoning about multi-directional effects throughout a food web.

In addition, my study also revealed that students hold misconceptions about food webs. The most common misconception, was that the predator in a predator-prey relationship is always the larger animal. Gallegos, Jerezano, and Flores (1994) found similar results in their study of elementary school students. Research suggests that students have misconceptions about ecology (Barman, Griffiths, & Okebukola, 1995; Hogan & Fisherkeller, 1996; Grotzer & Basca, 2003) that they learn early and will use to comprehend new information in the classroom (Maskiewicz & Lineback, 2013). If not addressed early in the class, students may have difficulty learning the new concepts and strategies for reasoning about food web-related problems (Reiner & Eilam, 2001; Jordan *et al.*, 2009).

Finding misconceptions in student response suggests that they came into the study with preconceived notions about food webs. This may have affected their ability to reason about the effects of food webs beyond direct effects between organisms. Instructors should address common misconceptions in their classroom before teaching so that students can overcome the difficulties associated with using misconceptions to reason about food web disturbances.

Proportional Reasoning

Reasoning about the effects of a perturbation in a food web requires an understanding of the two-way causality of food web relationships and the knowledge of how bidirectional effects impact populations (Assaraf & Orion, 2005; Hovardas, 2016; Sweeney & Sterman, 2007). This requires non-linear reasoning and is less common in novice learners. Students tend to reason linearly which is known as proportional reasoning (De Bock, van Dooren, & Verschaffel, 2011). For example, when asked what would happen to the organisms in the food web when the population of Dibbleviks was decreased, student 12 replied:

“There [would] be more Ovelzets for either the Schiveldens to eat. And that would decrease the amount of Krewenved because there [would] be more Ovelzets...”

The student makes no mention of any other effects such as how changes to those populations would affect the Dibblevik population. Instead, the student only discusses the occurrence of effects in a linear unidirectional progression.

Food webs involve non-linear interactions between organisms (Hmelo-Silver & Azevedo, 2006; Riess & Mischo, 2010). If a student is only able to reason linearly, this can make it difficult to answer questions about perturbations in a food web. A student may only trace the effects of a perturbation along one route and miss the immediate effects on other organisms. In addition, a student who reasons linearly would only consider effects in one direction and not the reverse. For example, if the population of Dibbleviks is decreased, it follows that there is less predation on its prey which frees up resources for the Schiveldens and decreases the population of Krewenveds, just as student 12 described. These are the effects in one direction. In the reverse, a decrease in the population of Krewenveds will decrease the population of Ovelzets and then decrease the populations of Schiveldens and Dibbleviks.

Other questions that could be asked to ascertain students' reasoning ability may specifically ask how the perturbation will affect the food web over time. For example: "How would the changes you (the student) just described affect organisms in the food web over the course of X amount of time?" Ideally, the student would describe what would eventually happen to the populations of organisms as a result of the perturbation.

Solutions for Bokkeltir regulation

Students provided a variety of creative suggestions to regulate the growing population of Bokkeltirs (Table 3.2). The most common suggestion was to increase the population size of both of the Bokkeltir predators. This would decrease the growing population size of Bokkeltirs and its competitor, the Ovelzets. As a result, Krewenveds would increase due the decrease in predators. This option demonstrates the concept of

top-down control in which populations are controlled by predators (Hunter & Price, 1992). The students who chose this option demonstrated their understanding of how changes at one level can impact multiple organisms below.

Similarly, another population option was to decrease the population size of the Krewenveds (primary producers). Since this is the only food source for the herbivores, students explained that it would negatively impact Bokkeltir population size. In addition, this would decrease the population sizes of the other organisms due to the decrease in resources. This is known as bottom-up control, in which populations are controlled by a limiting resource (Hunter & Price, 1992). Similar to biological control, this idea was not introduced to students during the learning session. By choosing and explaining this option, students show their understanding of the impact a single resource can have on multiple organisms. While there is no evidence to suggest they are reasoning about the effects in multiple directions, it's clear that these students knew how reducing the population of an organism at the bottom of the food web would impact all of the organisms above it.

Another common suggestion was to add an organism that preys on the Bokkeltir, is similar to the concept of biological control which is a concept students were not introduced to in the learning session. Biological control involves the use of live natural predators to reduce the population of pests (Coombs, 2004). The successful introduction of a natural predator (biological control agent) will reduce the population size of the pest (target species) and effectively maintain the target population size while minimizing the risk to other non-target species. Students that mentioned biological control as an option

were considering solutions that ecologists may also consider in this situation. In particular, some students were careful and stated that their introduced species would only prey on the Bokkeltirs. This would lower the risk factor on the non-target organisms in the food web. This suggests that students were considering the impact of introducing another species and its potential effects. It's possible that students wanted to minimize the effect of their introduced organism which explains why their species only ate Bokkeltirs. However, students were not asked about their reasoning behind choosing a specific option so this is speculation.

Some students also chose to include a competitor species to the predator level (Table 3.2) as a means of controlling the population size of Bokkeltirs. Students who chose this option explained that adding the competitor would negatively affect the population size of Bokkeltirs directly (adding a predator to compete with Bokkeltir predators) because of the additional predatory pressure. This shows that to some extent, students understand that adding a competitor to the community will negatively impact the population sizes of the existing predators.

Implications

Expansive framing may not be an effective tool in promoting transfer of knowledge from a learning context to a similar, applicable scenario. This method, in large part, depends on the variables used to construct the learning situation and the depth to which students understand the material. Instructors using expansive framing to teach students should present concepts as applicable in multiple contexts and focus specifically on helping students develop a deeper understanding of the information through activities

and discussion. That means more emphasis on concepts such as trophic cascades and competition that can improve reasoning about the effects of food web disturbances. Students will have an easier time recalling information and applying their knowledge to other scenarios if they understand the information and are able to apply it in multiple contexts.

Developing an understanding of food web processes is only the beginning of ecological education. An education in ecology should set a foundation of knowledge students can build on as they develop their understanding about nature. Expanding the frame of teaching to exemplify how food web concepts and underlying processes are applicable across multiple food webs may enable students to think about the effects on a global scale and consider how we, as consumers, impact the environments we live in.

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APPENDIX A

Study 1 - Coding Rubric for Student Responses to During-instruction and Post-Instruction Questions

Category	Code	Description	Exemplar (Student Quotes)
Pop. Size	0	No data available	
	1	<ul style="list-style-type: none"> • Describes change generally (as in eats, affects) as a result of direct consumption • Quantifies change (increase or decrease) in 1 population as a result of direct consumption 	"Basic trophic, top-down modeling increasing predators = decrease prey, decrease predators = increase prey" -040
	2	<ul style="list-style-type: none"> • Quantifies change (increase or decrease) in 2-3 populations as a result of direct consumption (or lack thereof) • Other species may be described generally (as in this quote) 	"...the removal/decrease of white-tailed eagles in the population. It would affect secondary consumers and cause a rebound in producers across the food web." -076
	3	<ul style="list-style-type: none"> • Quantifies change (increase or decrease) in 4 or more populations as a result of direct consumption (or lack thereof) 	"Decrease. Mice increase due to another food source for snakes, which in turn will decrease rabbit and mice shared food sources; broadleaf decreases. Much less grass as grasshoppers increase need as population." -022
Food Web	0	• Describes one organism eating another (A --eats--> B)	"Detritus is consumed by all organisms except one, and Fish 3 feeds on organisms that feed on Detritus" -025
	1	<ul style="list-style-type: none"> • Describes a food chain with 3 or more organisms or; • Food chain - A hierarchical series of organisms each dependent on the next as a source of food (for example: Species A --eats--> B --eats--> C) • Attempts to but does not describe a food web as multiple organisms at each trophic level that are connected in direct or indirect ways 	"A food web is much more stable. For where an organism is losing another organisms is gaining. Each one replaced with another." -057
	2	<ul style="list-style-type: none"> • Describes a food web with multiple organisms at one trophic level connected to organisms at other trophic levels • Describes the organisms as connected through consumption (A--eats-->B) 	"There is less of a reaction in a food web than a food chain. This is because there are multiple produces herbivores and primary carnivores to balance out the web." -032

	3	<ul style="list-style-type: none"> • Describes a food web with multiple organisms at two or more trophic levels connected to organisms at other trophic levels • Describes the organisms as connected through consumption (A-eats-->B) 	"It should change the population size less because in a food web predators may have multiple prey so when a certain prey's population size gets low they will switch prey." -027
Competition	0	• Doesn't mention competition or describe the term	
	1	• Attempts to describe competition (or variations of the word) but does not explain that multiple organisms sharing a resource negatively affects the interacting organisms	"An increased number of competitors keeps the other populations of a food web in check due to increased competition." -009
	2	<ul style="list-style-type: none"> • Explains that multiple organisms sharing a resource negatively affects the interacting organisms • Possible negative effects include a decrease in available food sources (less prey), a decrease in population size of competitors, a decrease in carrying capacity (max number of organisms the environment is able to support), or forcing an organism to switch to a more abundant resource 	"Grasshoppers would have a potentially negative effect on broadleaf plants by consuming more grass and forcing rabbits & mice to focus more on broadleaf plants" -020
Stability	0	• Does not attempt to explain that populations in a food web are more resistant to changes in a food web	
	1	<ul style="list-style-type: none"> • Attempts to but does not explain that populations in a food web are more resistant to changes in population size • May use words such as balance or stability 	"Multiple trophic level competitors decreases the pop. size across the whole food web..." -040
	2	• Explains that populations in a food web are more resistant to changes in population size (more stable) because there are multiple organisms at each trophic level	Increasing the competition in a food web will reduce the predator effect on the food web. Therefore it will cause slight fluctuations to the food web but not dramatically effect and decrease pop. within the food web. -036

	3	<ul style="list-style-type: none"> • Explains that populations in a food web are more resistant to changes in population size (more stable) because there are multiple organisms at each trophic level • Explains that having multiple organisms at each trophic level supports and limits population size through competition (ex. If one predator in a food web is removed, the other predators will prevent the prey from becoming overabundant or; if one prey is removed, the predators won't decrease much because there are other available food sources) 	<p>"Having competitors at multiple trophic levels provides a more diverse and dynamic food web. It provides more balance between organisms. If five organisms are being preyed on by five organisms and also eating five different organisms, it's less likely to be affected if something happens to a population. The food chain doesn't have that option, if one population changes, they're all affected. It's more stable, less fluctuations." -065</p>
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APPENDIX B

Study 2 - Session 1 Protocol

Reasoning about Food Web Disturbances

Participants will be interviewed about their understanding of trophic cascades in novel ecosystems. They will be asked to evaluate an ecosystem model, consider the relationships between organisms, and how those relationships affect the underlying trophic cascades. The students will then be asked to transfer the information learned from the previous ecosystem to a different ecosystem and reason about the trophic cascades.

RESEARCH QUESTIONS

1. How does expansive framing in a learning context about food webs affect student ability to transfer knowledge to a novel context?
2. Does expansive framing encourage students to generalize knowledge about food web dynamics?

DATA OUTPUTS

1. Student written responses
2. Audio transcript of student interview

MATERIALS

1. This protocol
2. Pencil for student
3. Clipboard for interviewer
4. Prompt sheet for interviewer
5. Audio recorder
6. One folder labeled 'Consent Forms'
7. One folder labeled 'Interview Forms'
8. Consent form
9. Compensation form
10. Compensation
11. External hard drive for audio files

SCREENING

1. Recruit students in LIFE 120 (Dauer, Couch, Angelleti, Brassil). Email students based on interest.

PRE-INTERVIEW PROCEDURE

1. Email students 24 hours in advance with location and time of interview.

INTERVIEW PROCEDURE

Created by Nathaniel Niosco and Joe Dauer 2015

Introduction

Hello _____. My name is _____ and I will be conducting the interview today. Please have a seat so we may begin.

(Start audio recorder)

Background

For this project, I am interested in how students respond to different modes of instruction. I will begin by asking you a few questions to establish a baseline about your prior knowledge. I will then provide a short mini-lesson. You will be asked several questions throughout the mini-lesson about the content. Please answer each question with as much thought and detail as possible.

Part 1. Verbal Questions (baseline questions)

Directions: I am going to ask you a few questions to establish a baseline about your prior knowledge. Please answer each question with as much thought and detail as possible.

1. When you hear about food webs, what come to mind?
2. Can you define one example of a food web you know about?
 - What organisms are in this food web?
3. In your experience with food webs, have you learned about trophic cascades?
 - Can you provide an example of a trophic cascade in the food web you mentioned earlier? (Skip if student is unable to recall or define a trophic cascade)
4. Have you learned about competition?
 - Can you provide an example of a trophic cascade in the food web you mentioned earlier? (Skip if student is unable to recall or define a trophic cascade)

Part 2. Mini-lesson on Food Webs, Trophic Cascades, and Competition

Directions: I am now going to give a short lesson on food webs. Within this lesson, I will be asking you several questions about the content. As before, please answer each question with as much thought and detail as possible.

1. Run-through mini-lesson.
2. When finished, ask student if he/she has any questions.
3. Remind student of 2nd interview date and time.
4. Remind student that they must return for the second interview to receive their reimbursement.
5. Thank student for participating.

APPENDIX C

Study 2 - Session 1 Lesson Outline (Bounded and Expansive)

Learning Objectives

- Identify relationships between components
 - Recognize the meaning of arrows
 - Recognize the effect on both components of a relationship
- Use quantitative reasoning to deduce indirect effects of top-down relationships
 - Recognize multiple relationships in sequence
- Predict direct and indirect changes in population size
 - Reason through multiple levels of populations

Concepts

- Direct effects - when one species eats a second species
 - First species directly affects the second species
 - Population size of the second species is reduced
 - Example:
 - When a Hawk eats a Mouse:
 - Hawk directly affects mouse
 - Population size of mouse is reduced
 - When a Mouse eats Grass:
 - Mouse directly affects Grass
 - Population size of Grass is reduced
- Indirect effects - when one species eats a second species, this indirectly affects a third species that is eaten by the second species
 - Example:
 - When the Hawk eats the Mouse:
 - Hawk indirectly affects the Grass
 - Population size of Grass is increased
- Cascade effects - succession of stages arranged so that each stage derives from or acts upon the effects of the preceding stage
- Trophic cascade - occurs when predators in a food web suppresses the abundance or alter traits (e.g., behavior) of their prey, thereby releasing the next lower trophic level from predation (or herbivory if the intermediate trophic level is a herbivore)"
- Competition - occurs when two or more organisms prey on or consume the same organism
 - Organisms are competing for the same resource
 - The resource limits the population size of the organisms
- Food webs - organisms within a food web interact with each other in direct and indirect ways with multiple organisms represented as predators, herbivores, or plants


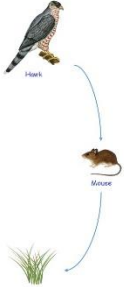

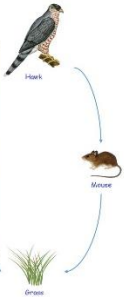
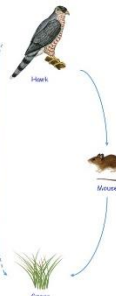

Questions

1. When the Hawk eats the Mouse, what do you think the effect is on the Grass?
2. What happens when the population of Hawks is reduced by 1? By 10?
3. What is the effect of adding the Snake as an organism in this scenario?
4. When the Hawk consumes the Mouse, what effect does that have on the Snake?
5. What happens to the population of Snakes when the population of Hawks is increased by 5? By 15?
6. What is the effect of increasing the population of Hawks by 5?

APPENDIX D

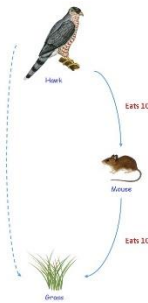
Study 2 - Session 1 Lesson Slides

Bounded Lesson

<p style="text-align: center;">Food Webs, Trophic Cascades, and Competition</p> <p style="text-align: center;">Nathaniel Niosco University of Nebraska – Lincoln 2015</p>	<p>Learning Objectives</p> <ul style="list-style-type: none"> Identify relationships between components <ul style="list-style-type: none"> Recognize the meaning of arrows Recognize the effect on both components of a relationship Use quantitative reasoning to deduce indirect effect of top-down relationships <ul style="list-style-type: none"> Recognize multiple relationships in sequence Quantitative relationships Predict direct and indirect changes in population size <ul style="list-style-type: none"> Reason through multiple cycles
<p>Direct Effects</p> <ul style="list-style-type: none"> When one species eats a second species: <ul style="list-style-type: none"> This directly affects the second species. Population size of the second species is reduced. 	<p>Direct Effects</p> <ul style="list-style-type: none"> When a Hawk eats a Mouse: <ul style="list-style-type: none"> Hawk directly affects Mouse. Population size of Mouse is reduced. When a Mouse eats Grass: <ul style="list-style-type: none"> Mouse directly affects Grass. Population size of Grass is reduced. 
<p>Question Time!</p> <ul style="list-style-type: none"> When the Hawk eats the Mouse, what do you think the effect is on the Grass? 	<p>Indirect Effects</p> <ul style="list-style-type: none"> When one species eats a second species, this indirectly affects a third species that is eaten by the second species. 
<p>Indirect Effects</p> <ul style="list-style-type: none"> When one species eats a second species, this indirectly affects a third species that is eaten by the second species. When the Hawk eat the Mouse, this indirectly affects the Grass. 	<p>Question Time!</p> <ul style="list-style-type: none"> What happens when the population of Hawks is reduced by 1? 

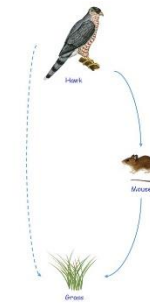
Question Time!

- What happens when the population of **Hawks** is reduced by **10**?



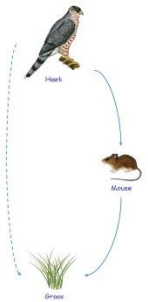
Cascade Effects

- A cascade is the *"succession of stages arranged so that each stage derives from or acts upon the effects of the preceding stage."*



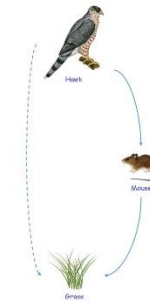
Cascade Effects

- A cascade is the *"succession of stages arranged so that each stage derives from or acts upon the effects of the preceding stage."*
- What does this mean with respect to the figure to the right?

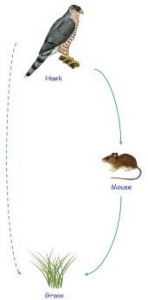


Trophic Cascades

- A trophic cascade occurs when *"predators in a food web suppress the abundance or alter traits (e.g., behavior) of their prey, thereby releasing the next lower trophic level from predation (or herbivory if the intermediate trophic level is a herbivore)."*

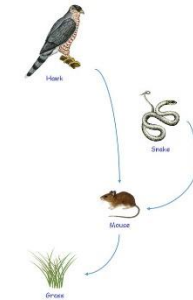


Any questions?



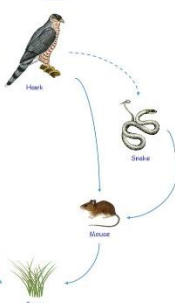
Adding more...

- Let's add another organism!



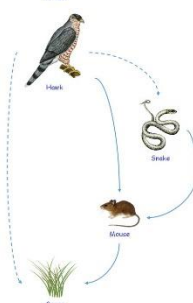
Question Time!

- What is the effect of adding the **Snake** as an organism in this scenario?



Adding more...

- When the **Hawk** consumes the **Mouse**, what effect does that have on the **Snake**?



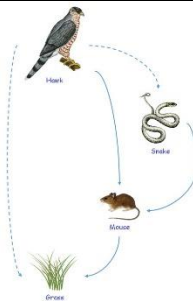
Adding more...

- When one species eats a second species, this *indirectly affects* a third species that *also eats the second species*.

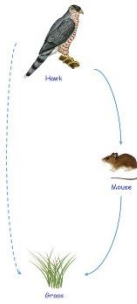


Adding more...

- When one species eats a second species, this *indirectly affects* a third species that *also eats the second species*.
- When the **Hawk** eat the **Mouse**, this *indirectly affects* the **Snake** and the **Grass**.

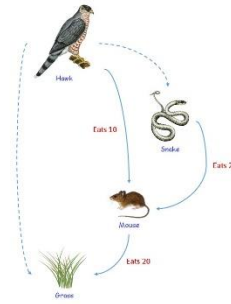


Any questions?



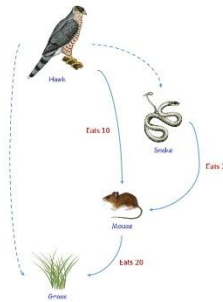
Question Time!

- What happens to the population of **Snakes** when the population of **Hawks** is increased by **5**?



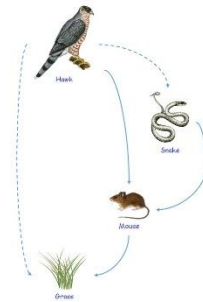
Question Time!

- What happens to the population of **Snakes** when the population of **Hawks** is increased by **15**?



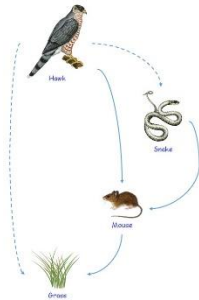
Competition

- Competition occurs when *"two or more organisms prey on or consume the same organism."*



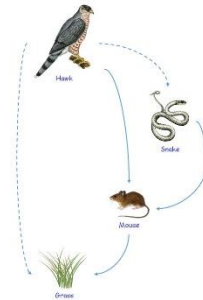
Competition

- Competition occurs when *"two or more organisms prey on or consume the same organism."*
- The organisms are competing for the same resource.



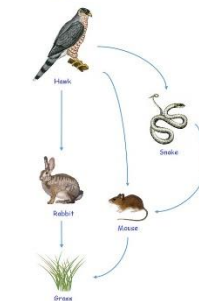
Competition

- Competition occurs when *"two or more organisms prey on or consume the same organism."*
- The organisms are competing for the same resource.
- The resource limits the population size of the organisms.



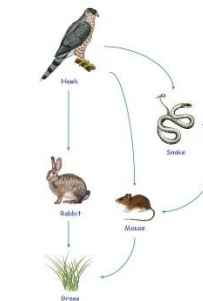
Food Webs

- Increase the number of organisms and we have the makings of a **food web**!



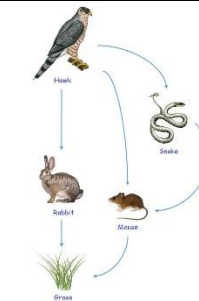
Food Webs

- Increase the number of organisms and we have the makings of a **food web**!
- Organisms within a food web interact with each other in **direct** and **indirect** ways.



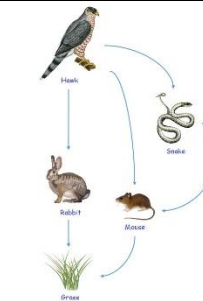
Food Webs

- Increase the number of organisms and we have the makings of a **food web**!
- Organisms within a food web interact with each other in **direct** and **indirect** ways.
- There are numerous **cascading effects** affecting each **trophic level**.

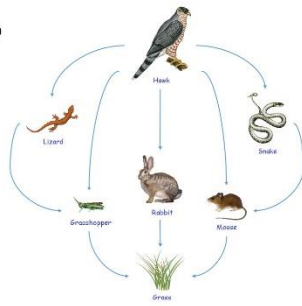


Food Webs

- Increase the number of organisms and we have the makings of a **food web**!
- Organisms within a food web interact with each other in **direct** and **indirect** ways.
- There are numerous **cascading effects** affecting each **trophic level**.
- Organisms are constantly **competing** for resources.

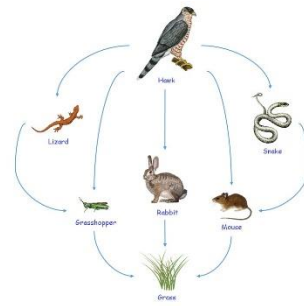


Food Web



Question Time!

- What is the effect of increasing the population of **Hawks** by 5?



Expansive Lesson

Food Webs, Trophic Cascades, and Competition

Nathaniel Niosco
University of Nebraska – Lincoln
2015

Learning Objectives

- Identify relationships between components
 - Recognize the meaning of arrows
 - Recognize the effect on both components of a relationship
- Use quantitative reasoning to deduce indirect effect of top-down relationships
 - Recognize multiple relationships in sequence
 - Quantitative relationships
- Predict direct and indirect changes in population size
 - Reason through multiple cycles

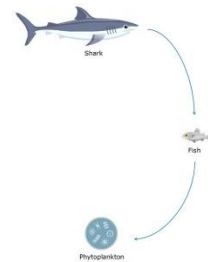
Direct Effects

- When one species eats a second species:
 - This **directly affects** the second species.
 - Population size of the second species is reduced.



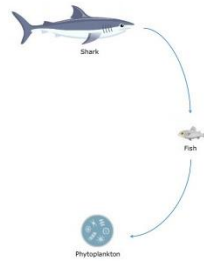
Direct Effects

- When a **Shark** eats a **Fish**:
 - Shark **directly affects** Fish.
 - Population size of Fish is reduced.
- When a **Fish** eats **Phytoplankton**:
 - Fish **directly affects** Phytoplankton.
 - Population size of Phytoplankton is reduced.



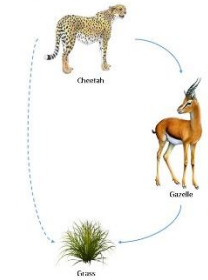
Question Time!

- When the **Shark** eats the **Fish**, what do you think the effect is on the **Phytoplankton**?



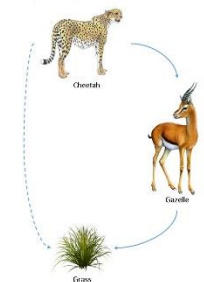
Indirect Effects

- When one species eats a second species, this **indirectly affects** a third species that is eaten by the second species.



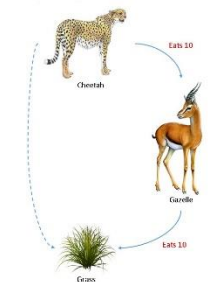
Indirect Effects

- When one species eats a second species, this **indirectly affects** a third species that is eaten by the second species.
- When the **Cheetah** eat the **Gazelle**, this **indirectly affects** the **Grass**.



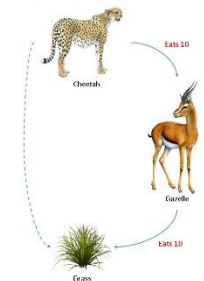
Question Time!

- What happens when the population of **Cheetahs** is reduced by 1?



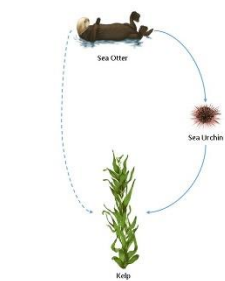
Question Time!

- What happens when the population of **Cheetahs** is reduced by 10?



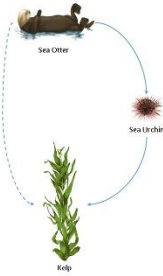
Cascade Effects

- A cascade is the "succession of stages arranged so that each stage derives from or acts upon the effects of the preceding stage."



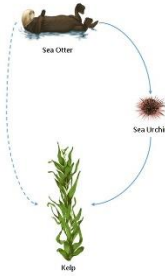
Cascade Effects

- A cascade is the “*succession of stages arranged so that each stage derives from or acts upon the effects of the preceding stage.*”
- What does this mean with respect to the figure to the right?

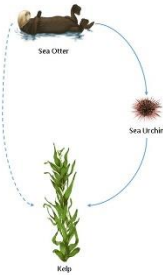


Trophic Cascades

- A trophic cascade occurs when “*predators in a food web suppress the abundance or alter traits (e.g., behavior) of their prey, thereby releasing the next lower trophic level from predation (or herbivory if the intermediate trophic level is a herbivore).*”

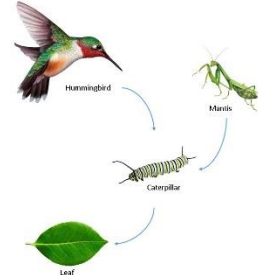


Any questions?



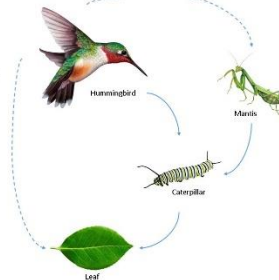
Adding more...

- Let's add another organism!



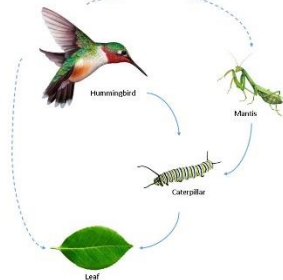
Question Time!

- What is the effect of adding the **Mantis** as an organism in this scenario?



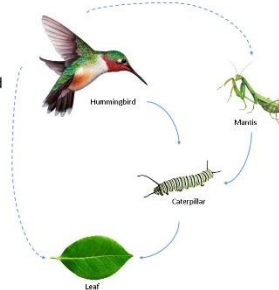
Adding more...

- When the **Hummingbird** consumes the **Caterpillar**, what effect does that have on the **Mantis**?



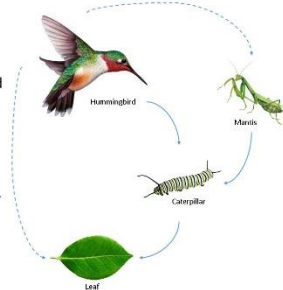
Adding more...

- When one species eats a second species, this *indirectly affects* a third species that *also eats the second species*.

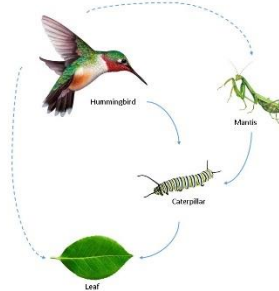


Adding more...

- When one species eats a second species, this *indirectly affects* a third species that *also eats the second species*.
- When the **Hummingbird** eats the **Caterpillar**, this *indirectly affects* the **Mantis** and the **Leaf**.

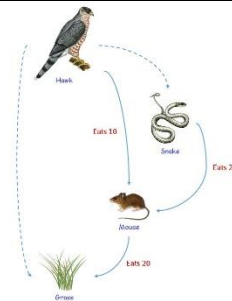


Any questions?



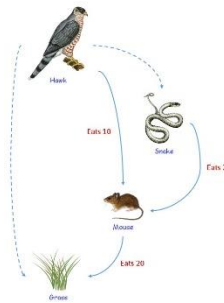
Question Time!

- What happens to the population of **Snakes** when the population of **Hawks** is increased by 5?



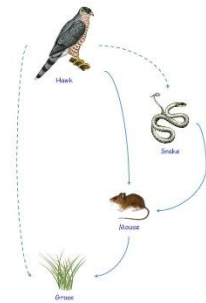
Question Time!

- What happens to the population of **Snakes** when the population of **Hawks** is increased by **15**?



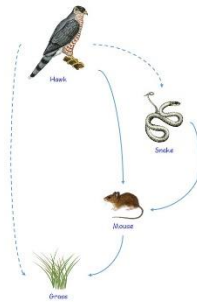
Competition

- Competition occurs when *"two or more organisms prey on or consume the same organism."*



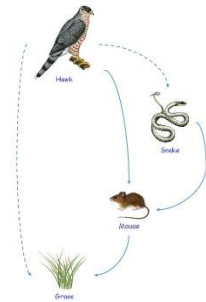
Competition

- Competition occurs when *"two or more organisms prey on or consume the same organism."*
- The organisms are competing for the same resource.



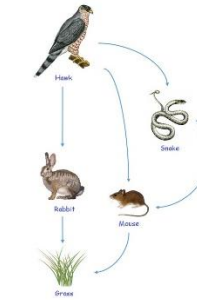
Competition

- Competition occurs when *"two or more organisms prey on or consume the same organism."*
- The organisms are competing for the same resource.
- The resource limits the population size of the organisms.



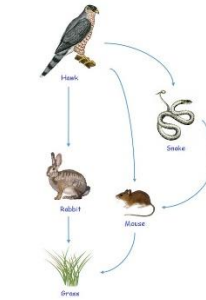
Food Webs

- Increase the number of organisms and we have the makings of a **food web**!



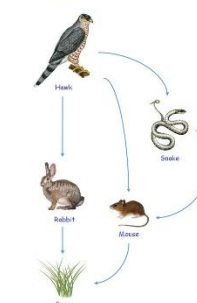
Food Webs

- Increase the number of organisms and we have the makings of a **food web**!
- Organisms within a food web interact with each other in **direct** and **indirect** ways.



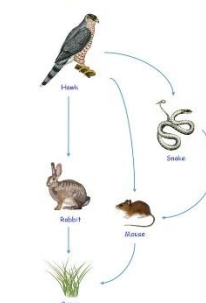
Food Webs

- Increase the number of organisms and we have the makings of a **food web**!
- Organisms within a food web interact with each other in **direct** and **indirect** ways.
- There are numerous **cascading effects** affecting each **trophic level**.

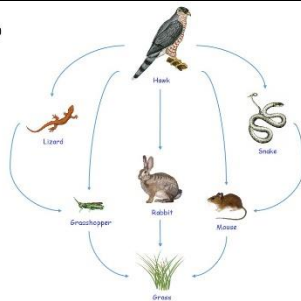


Food Webs

- Increase the number of organisms and we have the makings of a **food web**!
- Organisms within a food web interact with each other in **direct** and **indirect** ways.
- There are numerous **cascading effects** affecting each **trophic level**.
- Organisms are constantly **competing** for resources.

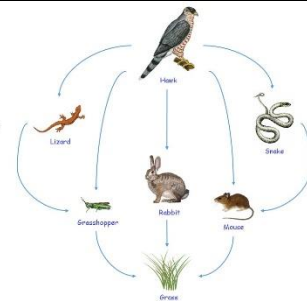


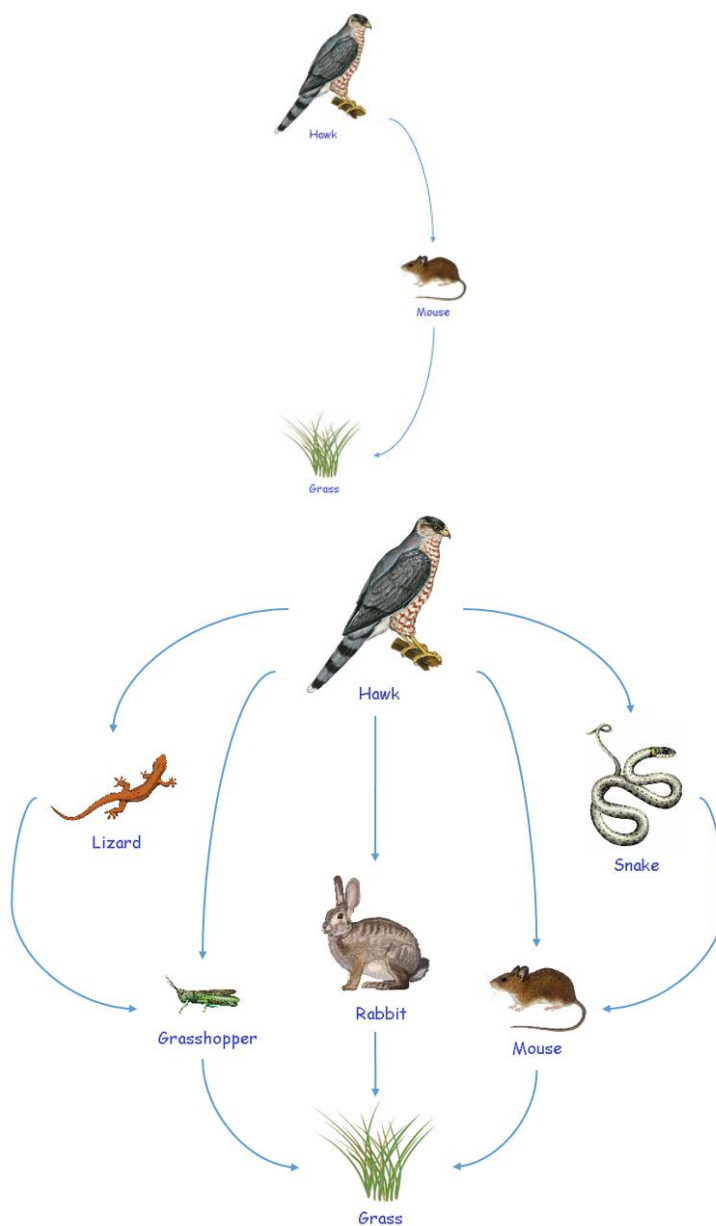
Food Web



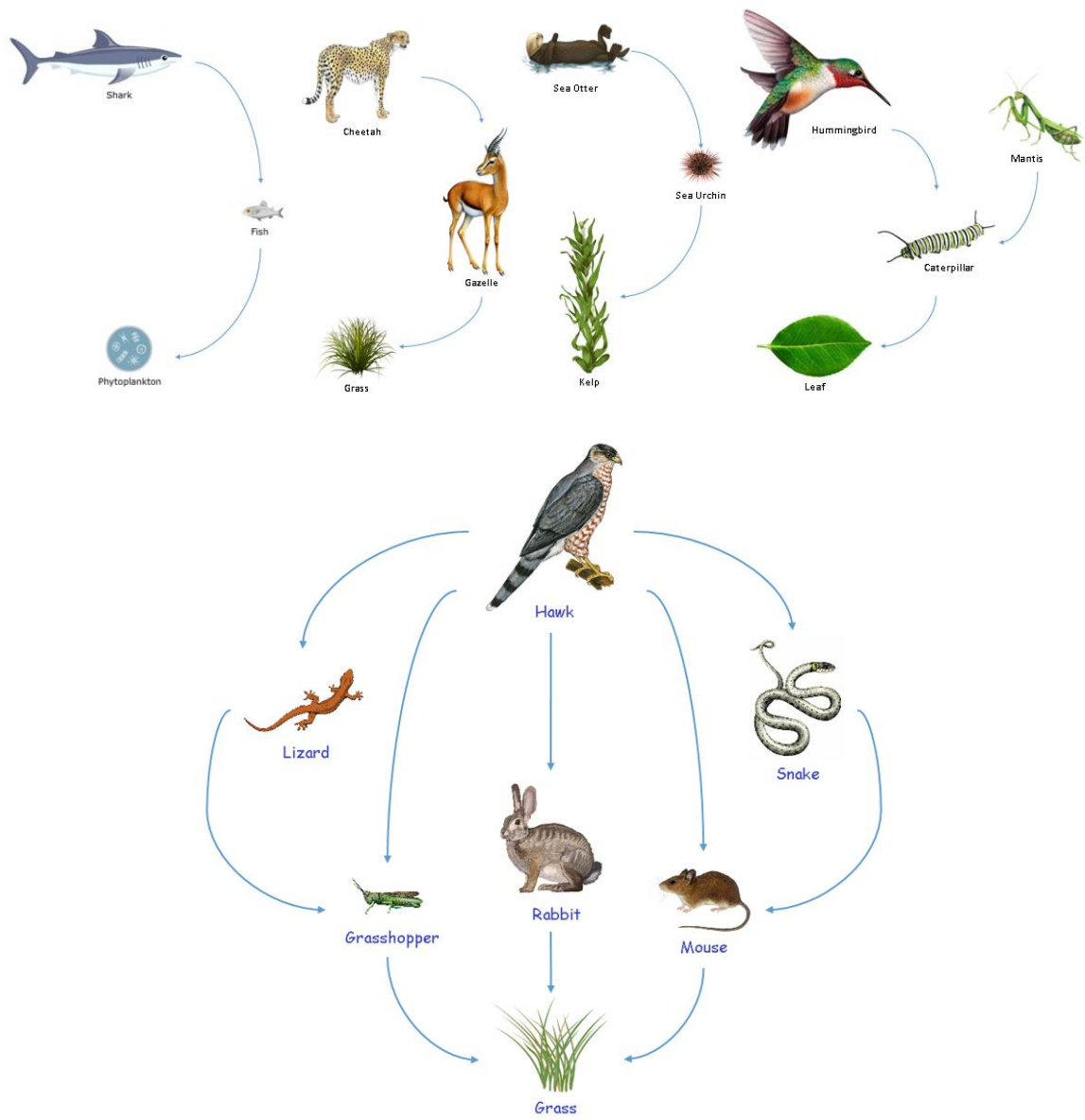
Question Time!

- What is the effect of increasing the population of **Hawks** by **5**?



APPENDIX E**Study 2 - Food Chains and Food Webs Used in Session 1****Bounded Lesson**

Expansive Lesson



APPENDIX F

Study 2 - Transfer Session Protocol

Research Questions

1. How does expansive framing in a learning context about food webs affect student ability to transfer knowledge to a novel context?
2. Does expansive framing encourage students to generalize knowledge about food web dynamics?

Interview Questions for Session 2

Part 1. Preliminary Questions

Directions: Before we begin, I would like to ask some follow-up questions to our first interview. During the time between the first interview and now, did you...

- Research or look up any information related to food webs or trophic cascades?
- Speak with anyone about food webs or trophic cascades?
- See anything relevant to food webs or trophic cascades in print or on TV?
- Remember anything about food webs or trophic cascades that you may have learned prior to the interview?

Part 2. Recall/Application Questions

Directions: In the following section, I will present you with a scenario. I will ask you to draw the scenario and then I will ask you follow up questions.

1. Scientists have recently discovered three new organisms. The **Schivelden**, **Ovelzet**, and **Krewenveds**. The **Schivelden** consumes only **Ovelzets** while the **Ovelzet** consumes only **Krewenveds**. Using this information, draw these organisms and their relationships.
2. Using your model, please describe an ‘indirect effect.’
3. Describe a ‘cascade effect.’
4. Using your model, describe a ‘trophic cascade.’
 - a. Describe any effects increasing the population of **Schiveldens** by 5 has on the food web. By 20.
5. Scientists have also discovered a fourth organism: the **Dibblevik**. The **Dibblevik** consumes only **Ovelzets**. Draw this organism and its relationship to these organisms.
 - a. Describe any effects adding **Dibbleviks** has on this food web.
6. [If interviewee doesn’t mention ‘competition’] Using your model, describe ‘competition.’
 - a. Describe any food web effects when the population of **Dibbleviks** is decreased by 5. By 25.

Part 3. Expansion Questions

7. Scientists have discovered a fifth organism: the **Bokkeltir**. The **Bokkeltir** consumes only **Krewenveds**. The **Schiveldens** and **Dibbleviks** both consume **Bokkeltirs**. The discovery of these organisms has impacted the survivability of all organisms in this food web. Draw this organism and its relationship to the other organisms.
 - a. Is there an effect of losing the population of **Schiveldens**?
 - b. Is there an effect of losing the population of **Schiveldens** and **Dibbleviks**?
 - c. Is there an effect of losing the population of **Ovelzets**?
8. Recently, the **Bokkeltirs** have experienced a rapid growth in population size. A committee has been tasked with creating regulations to control the population of **Bokkeltirs** in this food web. The committee would like you to come up with two options to regulate the **Bokkeltirs**. For each option, provide any effects that the option will have on the other organisms in the food web.