POINT LOMA NAZARENE UNIVERSITY

Using Data Rich Problem Tasks to Promote Understanding of Causal Relationships in Ecosystems

A thesis submitted in partial satisfaction of the

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by

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The thesis of Marin Elizabeth Silva is approved, and it is acceptable in quality and form for publication:

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Chair

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2015

I dedicate this thesis to my wonderful husband, Judd, and my family and friends who supported me through this rollercoaster of a journey and in achieving this monumental task.

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I would like to acknowledge the amazing professors at Point Loma Nazarene who provided me with an incredible educational experience; specifically, Dr. April Maskiewicz who spent an immeasurable amount of time guiding me through this thesis. I would also like to acknowledge my 7th grade students for their excitement and willingness to participate in this study.

Abstract of Thesis

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In this study, a design-based research approach was used in the creation of data-rich problem (DRP) tasks intended to support students constructing knowledge about food webs and ecosystem dynamics, specifically the effects from a loss of species. This iterative process of DRP task creation included qualitative results from two rounds of interviews. The interview results informed the creation of a set of DRP tasks that were implemented in two 7th grade science classrooms. Qualitative results from the culminating assessment demonstrate that students reached proficiency in “dissipation vs. persistence” and “energy arrows concepts”, and are approaching proficiency in “linear vs. nonlinear” and “food chain concepts”. These findings provide evidence of the effectiveness of design-based research and data-rich tasks in promoting students’ understanding of ecosystem dynamics.

Introduction

Student understandings of any topic should seemingly tend to increase as a student progresses through school. However, student understanding of ecology seems to peak rather early and then become stagnant; especially when focusing on ecological relationships and the functioning of ecosystems (Brody & Koch, 190; Grotzer & Basca, 2003; Trowbridge & Mintzes, 1988; Webb & Boltt, 1990). Research has shown that initially acquired knowledge as well as alternative views regarding ecology remain intact as students progress through their school years. Potentially adding to this issue is that students tend to learn about ecology (specifically ecosystems) primarily in 3^{rd}-6^{th} grade. Unfortunately, during the remaining time in school students rarely return to these concepts in depth. High school biology content has historically focused more on the cellular and genetic level and only rarely touched upon the ecological side of life science. Though these topics are part of the curriculum, the weight of the high school course has fallen on cellular biology and genetics (California Department of Education, 1998). The science course of study for K-12 in the San Diego Unified School District only provides the exceptional students access to advanced courses (Biology and Environmental Science) in which more depth, detail, and understanding is achieved in ecology and evolution.

Though standard middle school and high school science courses do contain standards relating to ecology and food web dynamics, the standards (California Department of Education, 1998) in which students are exposed to and are to "know" do not describe the depth of knowledge necessary for students to construct scientific ecological conceptions. Based on the language used, all of the ecology standards could be taught in a way that focuses more on a food chain model instead of a food web model, and in instances where food web interrelationships are addressed, they could be learned by focusing on linear progressions through a food web instead of the nonlinear relationships. The newly adopted Next Generation Science Standards (NGSS) do contain language that seems less linear, such as *evaluating* the complex interdependent relationships in ecosystems (NGSS Lead States, 2013). Yet, at the time of this study most high school classes have not yet implemented NGSS. Therefore it remains to be seen how effective the new standards will be on student understanding of interdependent ecological relationships. If we continue to limit instruction in ecology to focus primarily on linear relationships, we cannot expect our students to become citizens capable of making informed and responsible decisions that could in turn affect Earth's ecosystems. How are learners to develop an understanding of the true impacts of changes in an ecosystem if their knowledge stems from limited and oversimplified information?

As residents of San Diego, my students and I are part of a coastal community that is in a constant interaction with the marine environment in several ways: storm water, pollution, recreation, seawalls, commercial fishing, etc. San Diego students should, arguably, be intimately knowledgeable about the interactions within the marine ecosystem; however, based on my previous pilot study findings, this does not seem to be the case. While students may be able to list the factors (e.g. storm water runoff) that could affect the marine environment, they are unable to accurately describe the nonlinear and sustaining effects of such causes. To fully grasp the depth of how an ecosystem is affected by various interactions, students must first understand food web interactions and the complexity of the relationships within an ecosystem's food web. And to fully understand food webs, one must “recognize all possible pathways through which the effect of a change in one population is transmitted to a second population...” (Griffiths & Grant, 1985, pg. 434). In other words, when understanding is restricted to food chains, the student is limited in the depth of understanding one can attain about how changes can affect an ecosystem. By using the marine environment as the context, the purpose of this study is to determine if a set of specially designed data rich problem tasks can positively affect student understanding and conceptions of food webs and the nonlinear and sustaining effects of loss of species in an ecosystem. Recognizing the breadth of interactions between organisms within an ecosystem could lead our students to become responsible citizens in their community when considering the effects of human interactions and loss of species.

Literature Review

Background/Theoretical Perspective

Brown, Collins, and Duguid (1989) argued that “approaches such as cognitive apprenticeship that embed learning in activity and make deliberate use of the social and physical context are more in line with the understanding of learning and cognition that is emerging from research” (pg. 71). This stance resonates with my personal learning history and philosophy; one that is situated in activity. Before becoming a classroom science teacher, the hands-on experiences and interactions I encountered when working specifically as a Marine Science Instructor at SEACAMP San Diego provided a plethora of knowledge and understanding regarding the marine environment. While teaching students marine science in an outdoor education setting I was constantly exposed to the actual marine environment through snorkeling and SCUBA diving with students and boat trips. When experiencing new organisms or phenomena in this environment, I increased my understanding and my knowledge of marine science. In other words, by being immersed in the marine environment, I learned *about* the marine environment. According to Brown, Collins, and Duguid (1989), classic "school work" is not authentic or productive. Instead, purposeful activities and experiences are authentic and productive. These activities have meaning because they are authentic. Working at SEACAMP was an immersion experience of the typical practices of the "culture" of a Marine Science Instructor. Therefore, the learning gained was useful, applicable, and meaningful. As a student in the classroom environment in college I did not have the types of interactions or experiences necessary to be successful as a Marine Science Instructor and therefore was not a successful science student nor a successful Marine Science Instructor upon the start of my employment.

In a classroom environment, interventions that include interactions, experiences, and model-based approaches are more effecting for promoting learning for students than worksheet-based or direct instruction with limited interactions (Papaevripidou, Constantinou & Zacharia, 2007). Julyan and Duckworth (2005) stated "our beliefs about how the world works are formed around the meanings we construe from the data of our experiences" (pg. 63). Though they may not have been specifically referring to actual data when writing this statement, the meaning still holds true for well-designed interventions utilizing data to promote students' knowledge construction. The learning that a student is attempting to achieve needs to be actively and internally constructed, it cannot come solely from a teacher explaining a process (Julyan & Duckworth, 2005). When students engage in the work of biologists, students have opportunities to "articulate their ideas, to test those ideas through experimentation and conversation, and to consider connection between the phenomena that they are examining and other aspects of their lives" (Julyan & Duckworth 1989, pg. 64). These experiences are more reflective of scientists' activities and elicit curiosity and student buy-in because the knowledge is constructed by the students and connects to their own personal lives. In short, in these authentic activities, students mold their experiences instead of trying to fit their prior experiences into someone else's model. The purpose of this study is to develop authentic data-rich problem tasks that help students successfully construct knowledge regarding ecological relationships.

Student Conceptions - General Ecology

An understanding of ecology integrates cellular, molecular, and organismal biology; this creates a very difficult subject for students across all grade levels to understand. One important aspect in understanding ecology is the interrelatedness between species in an ecosystem. Trowbridge and Mintzes (1988) researched alternative conceptions about animal classification and found that early conceptions remain relatively unchanged into adulthood. This can pose a problem if these conceptions are "alternative" to scientific conceptions. For example, with the exception of college biology majors, around 25% of students did not consider a fish an animal at all (Trowbridge & Mintzes, 1988). These misunderstandings could cause confusion when learning more complex ecological ideas. If students do not know what different animals are and their role in the environment, they will struggle to understand the relationships between organisms, and thus the functioning of an ecosystem. Another study by Palmer (1997) demonstrated that even if students do recognize and are able to identify the type of organisms involved in ecological relationships, they do not necessarily recognize their importance to the ecosystem. Palmer interviewed 63 twelve year-old students and 60 sixteen year-old students to assess their decision-making process in determining their stance on the preservation of species. The ecological concept of interdependence was expressed as the student's reasoning behind preserving various organisms. Students explained that particular species should be saved because the organisms have a role in nature and other organisms depend on them. However, this was not universally applied to all organisms. Instead, students were selective as to which organisms were worthy of being preserved. Only two percent of 12 year-old students and 27% of 16 year-old students recognized that all species have a role in nature and as such other organisms depend on them. The reason primarily given for which species to preserve were "[those that] have a larger impact on the food chain" or those that "we'd really need in the long term future" (Palmer 1997, pg. 845). Students found the other organisms in an ecosystem to be not as important and therefore not having interdependent relationships within the ecosystem. This research confirms that many students do not recognize relationships within a food web beyond a series of food chains.

A study conducted in Maine included a very broad focus on the marine ecosystem (Brody & Koch, 1990). One hundred eighty-seven students in, 4th, 8th, and 11th grade were interviewed to assess student understanding of concepts relating to marine ecology and natural resources. The study looked at 15 major content principles related to marine science and natural resource issues which were then grouped and diagramed to create five concept maps (geography and ocean bottom topography, physical and chemical oceanography, ecology, natural resource, and natural resource decision making). The ecology concept map covered the following three major content principles: 1. Energy flows through this system from the sun to plants and animals. 2. Within the system, plants capture light energy and use it to make food. 3. Within the system, plants and animals interact in a complex food chain and web. Interview questions focused on the premade concept maps. The interview responses were scored on a 0-3 scale, 0 for completely missing the concept and 3 for a full and complete understanding of the concept. On average, for all three major content principles, the highest level of understanding among students from 4th to 11th grade was below "partially correct" (level two) and closer to "little conception" (level one). The third major content principle aligns with the focus of this current study. On average, students in 4th and 8th grade scored below 1.5 in their level of understanding regarding plant and animal interactions. In comparison, 11th graders scored above 1.5 but below two (ibid). In essence, there were no substantial gains from each grade level in a student's level of understanding. Brody and Koch (1990) later report that from these principles, more than 86% of students were missing the following concepts from their understanding: Marine species and distribution, complexity of trophic relationships; [and] examples of food chain relationships" (Brody & Koch, 1990 pg. 22). Therefore, not only are students at best "partially correct" in their understanding regarding plant and animal interactions; the most students are missing conceptions regarding the complexity of ecosystem relationships and the relationships within food chains. This study shows the lack of depth in understanding as students progress through school.

Brody & Koch's (1990) study would be interesting to replicate, but a limitation is that it is specific to marine science and natural resources in Maine. This, on some level, would be difficult to compare to San Diego because the biology and geography of the Gulf of Maine is quite different than our Pacific coastline. Also, the study does not state the location of students in relation to the Gulf of Maine. We do not know if students closer to the Gulf have more understanding than students that live further away. All of San Diego County could be considered coastal; therefore, the question remains as to whether or not San Diego County students would have more understanding of the marine environment or similar understanding. As such, the reasoning as to why students have a difficult time with the major content principles may be different if the same research was conducted in San Diego. Besides geography and location of the student population, another limitation to the Brody & Koch (1990) study is that it was conducted over 20 years ago. Conducting a current study is necessary to determine if such conceptions are still held by students today.

Student Conceptions – Food Web Specific

A very clear pattern in student understanding ranging from eight and nine year old students (Grotzer & Basca, 2003), to 11-year old students (Hogan 2000), to high school students (Barman & Mayer, 1994; Barman, Griffiths & Okebukola, 1995; Griffiths & Grant, 1985; Webb & Boltt, 1990), to college undergraduates (Webb & Boltt, 1990; White 1997; White, 2000) regarding food web dynamics is that they view the complex relationships as linear instead of cyclical or systemic. Some of these researchers believe this is the cause of alternative conceptions related to ecology and food webs (Grotzer & Basca, 2003; Hogan & Thomas, 2001; White, 1997; White, 2000). The alternative conceptions commonly seen throughout various age groups as mentioned (student conceptions in general ecology, organismal relationships and their importance in ecosystems, and seeing complex relationships as linear) may seem vast; however, they can still be generalized as not seeing the food web as a system, but instead as direct and isolated cause and effect relationships. Location (physical location on a food web compared to other organisms such as at the top of a food chain) and proximity (how close an organism is to other organisms in a food web such as whether or not they are on the same food chain) are also shown as influencing the alternative conceptions (Webb & Boltt, 1990). An example of a proximity alternative conception is the idea that a change in a population is not passed along different pathways within a food web. Similarly, a location alternative conception example is the idea that a change affects another population only if they are related as predator-prey and on the same pathway (e.g. within a food chain) (Barman, Griffiths, & Okebukola, 1995; Barman & Mayer, 1994; Griffiths & Grant, 1985; Webb & Boltt, 1990). Issues regarding location and proximity seem the most prevalent among students. Webb & Boltt's study (1990) found that among 100 high school and college students, only two percent recognized that effects can be transmitted along more than one route. On a slightly lesser degree, high school students also described populations located higher in a food web as a predator of all organisms below (Barman, Griffiths, & Okebukola, 1995; Griffiths & Grant, 1985; Munson, 1994).

Three other difficulties students have with food webs involve the degree to which other populations of organisms are effected when a perturbation has occurred. For some students, no changes occur in a predator population if the prey population size changes (Barman, Griffiths, & Okebukola, 1995; Griffiths & Grant, 1985). Less often and from the opposite viewpoint, other students described the changes in one population changing all other populations in an equal manner (Barman, Griffiths, & Okebukola, 1995; Barman

& Mayer, 1994; Griffiths & Grant, 1985). Lastly (also less frequently), students described a change in a primary consumer not affecting producer populations (Barman, Griffiths, & Okebukola, 1995; Barman & Mayer, 1994). The degree or strength of changes influencing other populations in a food web are not consistent either. The proximity conception mentioned earlier as a general conception plays a role in student understanding as well. Students demonstrated that magnitude of a change is determined by literal proximity to each other in the food web (Griffiths & Grant, 1985; White, 1997; White, 2000). In other words, the effects of a disturbance can vary; they can be stronger or dissipate depending on the location of the disturbance in the food web.

White (1997 & 2000) described the "dissipation effect" as, "a tendency to judge [the] effects of a perturbation at a particular locus in an ecosystem [to] weaken or dissipate as they spread from that locus (1997, pg. 229). According to White (2000), the number of links and the length of links away from the original change determines the magnitude of effect. The links inversely determine the strength of effect from the perturbation. Shorter routes and fewer links away will show a stronger effect, while longer routes and greater number of links away will be affected less. Two other determinants noticed were the "branching effect" and the "terminal effect". The branching effect described that species found along a branched path (opposite of a direct food chain model) show less severe of a change from a perturbation. For example, in Figure 1, a change in P1 would affect C3 more than C1 or C2 because C3 is not as branched as where C1 and C2 are located in the food web.

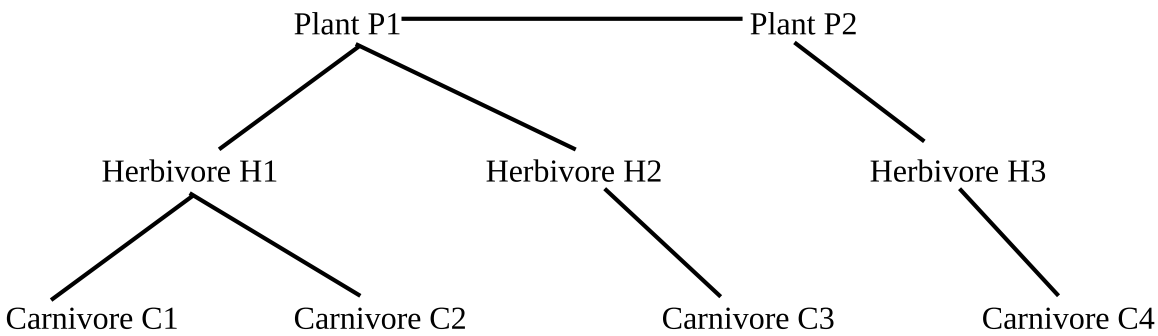

Figure 1. Example Food Web (White, 1997)

The terminal effect describes how organisms that are located at a terminal location in a food web are affected more severely than another organism at an equal distance away from the perturbation but not at a terminal location. For example, a change in P2 would affect C4 (two steps away) more than H1 (two steps away) because C4 is at a terminal location and H1 is not (see Figure 1). In his research, White (1997) proposes confidence as a possible reason for such conceptions. Since moving further away from the perturbation creates more opportunity for more complexity in the relationships and the possible effects of such changes, students may be less confident in their judgments regarding the strength of changes and therefore rate the degree of changes less than the populations closer to the perturbation. According to White (1997), people seem to think that an object's motion dissipates naturally instead of recognizing that external forces like friction are acting on the object. Though this understanding is alternative to scientific views, dissipation and linear effects are often what is observed in everyday life and therefore influences students' conceptions; like an object travelling in a straight line slowing to a stop. It is possible that misunderstandings of food web dynamics stems from applying dissipation reasoning.

With such a generally linear understanding of food webs and ecosystems there remains a need to understand where and how these alternative conceptions are forming. To try to uncover the role the classroom plays in these conceptions, researchers have looked at instructional materials as well as the successes and failures of various classroom activities. The outcomes from this research led to attempts to design effective interventions.

Solutions to Promote Ecological Understanding

Almost 25 years ago, Webb and Boltt (1990) describe that while there is much literature on ecological education in general, "there is a paucity of data on concept development in this topic, particularly as regards to relationships within communities" (p. 187). This remains true today. Though there seems to be evidence that we understand the knowledge held by students in regards to ecology, there are only a handful of studies that describe successes or failures of interventions in order to improve student knowledge of relationships within ecosystems. Papers by Ballantyne and Bain (1995), Ballantyne and Packer (1996), Hogan and Thomas (2001), and Papaevripidou, Constantinou, & Zacharia (2007) provide insight on approaches for creating an intervention to improve student knowledge of understanding species loss in an ecosystem. These researchers designed an intervention, implemented it, and researched its effectiveness.

One study (Papaevripidou et al., 2007) noticed that fifth grade students' recognition of interactions, instead of just objects in various scenarios, is limited if taught with a worksheet-based approach versus a modeling-based approach. Hogan and Thomas (2001) found similar results using computer-based modeling to show relationships within an ecosystem. They found that middle and high school students showed greater depth in their understanding of relationships when learning from models.

Ballantyne & Packer (1996) reminded educators that a single style of teaching (values-education approach vs. knowledge-based approach) is not best when teaching the development of environmental conceptions. Typically, a values-education approach (one where expected attitudes towards topics are taught) has been the norm, leaving out the strict knowledge-based approach (one based only on developing knowledge and skill). It is suggested that both approaches taught together serve students best. Supporting Ballantyne and Packer's findings, another study pointed out that students rely on their emotional responses when taking a stance on environmental concepts (Ballantyne & Bain, 1995). Ballantyne & Bain (1995) used an intervention called structured controversy in which the learners formulate a position on an issue, have their position challenged creating cognitive conflict, defend their position, question other student positions, seek more information regarding the issue, and then finish by coming to a deeper understanding of the issue. After this intervention, students elicited less emotional stances and more scientific stances. The goal in teaching science is to create knowledgeable scientifically literate citizens. Arguing, voting, or taking action based on emotion is not the science citizen we are trying to create. Ballantyne and Bain (1995) demonstrated a way to help students be more environmentally-minded by increasing science understanding and not merely relying on emotion.

When examining pedagogical approaches in ecology one must also consider the plethora of science textbooks utilized in the classroom and how they lean towards the "drill and kill" approach instead of creating authentic, purposeful activities that immerse the student in doing science. Multiple studies have analyzed textbooks and have come to find that many are inadequate (Barman & Mayer, 1994; Stern & Roseman 2003). Stern and Roseman's study (2003) analyzed nine middle school science textbooks to determine how well they focus on matter cycles and energy flows from one living thing to another as well as how well the materials align with what is known about how students learn these ideas. These textbooks had been adopted and were widely used among schools. The analysis showed that eight of the nine sets of curriculum "include[d] content that matches the key ideas; [however], the instructional support for these ideas is minimal" (p. 547). In addition, the curriculum approach is primarily repeating the knowledge instead of applying the knowledge to higher levels of cognition. For example, students are learning the definition followed by diagramming matter cycling, followed by creating a food web for a chosen ecosystem (repeating knowledge) instead of applying this knowledge to evaluate the potential effects of species loss in an ecosystem (high level cognition).

Barman and Mayer (1994) conducted a similar study analyzing 11 high school science textbooks with the explicit focus on food web concepts and interactions. One goal of the study was to determine alternative conceptions held by students regarding food webs. The other focus was to analyze the textbooks for information regarding these conceptions. Barman and Mayer found that the textbooks omitted information pertaining to the four alternative conceptions found. The authors of the textbooks "appeared to assume that students are able to make specific connections of terms and generalizations about food relationships on their own" (pg. 162). Therefore, information that would have helped revise these alternative conceptions was completely missing from the curriculum.

Griffiths and Grant (1985) did not attempt to create an intervention, however, their work provides the groundwork for developing a knowledge progression relating to food webs. Instead of just reporting on what alternative conceptions were found, they attempted to develop and refine a "learning hierarchy" of such conceptions. This would provide those developing future interventions with a baseline in understanding what students may need to know before being able to understand a more complex ecological problem. In other words, a student may have an alternative conception because they are missing the prior pieces of required knowledge (based on the hierarchy) to understand the new or current knowledge. Griffiths and Grant (1985) found that within their hierarchy of skills, the most important skill necessary in understanding food web concepts is, "Given a food web diagram, recognize all possible pathways through which the effect of a change in one population is transmitted to a second population" (Table 1, p. 424). Without the ability to recognize "all possible pathways" the learner will see food chains instead of a food web and will therefore demonstrate restricted understanding of interconnectedness and causal relationships within food webs.

Solutions Utilizing Problem Tasks

Since the learning sciences literature shows that students construct their own knowledge, a successfully designed intervention should include the student as an active participant in the learning process. Edelson's (2001 & 2002) "Learning-for-Use" framework is one such approach that does not separate content and process learning but instead integrates them. It is suggested that if the three steps of the Learning-for-Use framework are followed (motivate, construct, and refine), learners will be able to "construct new understanding that more closely resembles scientific understanding"

(Edelson 2002, pg. 19). Interventions need to first motivate students, to create a demand for knowledge which causes the learner to be curious and want to seek understanding. Once this motivation has been created the students then construct understanding through experiences and observations that allow them to formulate new knowledge structures within their current structures. Once this has occurred, students then refine their knowledge through application to meaningful (to the student) new areas or problems (which elicits new motivation). The success of interventions designed to improve causal understanding of ecosystems and food webs seem to be dependent on how well Edelson's (2001 & 2002) "Learning-for-Use" framework was incorporated in the design of the intervention and how well such an intervention was implemented; whether or not the Learning-for-Use model continued throughout the intervention.

A successful study that utilized two of three Learning-for-Use concepts (construct and refine) came from Grotzer and Basca (2003) in which they demonstrated that while activity interventions are useful, activities with discussion are more successful. Students constructed knowledge by participating in a game that resulted in constructing a food web by role playing different organisms. This activity was followed by a second activity where students created their own food web using information about different animals. One group of students participated in discussions throughout both activities and were able to refine their knowledge. The other group of students did not have discussions throughout their learning process and therefore did not refine their knowledge. As noted, Grotzer and Basca (2003) found that students gain more understanding with the addition of "refine" from the Learning-for-Use framework.

A more successful study from Eilam (2002) utilized all three of the Learning-for-Use concepts. Eilam's (2002) study followed the students through a year-long scientific inquiry task of their choice regarding ecology (motivation). Students constructed their knowledge through the monitoring of the ecosystem of their choice and making sense of the interrelations occurring in the ecosystem (understanding why variables changed or when they did not). The students also refined their knowledge by discussing "ecology issues with teachers in a constructivist manner, raising topics according to their own understanding, timing, and needs, as stemming from questions triggered by materials covered in the theoretical lessons or by their own inquiries [while conducting their project]" (Eilam, 2002, p. 648). While successful at improving student understanding at the macro level of feeding relations, the intervention did not succeed at promoting understanding in the micro level processes of ecosystem functioning.

Where Eilam was unsuccessful, students using White and Maskiewicz's (2014) Data Rich Problem (DRP) tasks regarding ecological processes, specifically cellular respiration, did show improvement on micro level relationships. Maskiewicz's (2006) design of the DRP tasks is to first have students bring forth their existing knowledge with preliminary problems or activities. An Ecosphere (a self-sustaining closed ecosystem) is the backdrop for the data presented in the problem tasks. Once this knowledge or understanding is apparent to the student, they are then challenged by data that puzzles or does not fit their current understanding, causing disequilibrium. This elicits curiosity and the need to learn and understand (first step of Learning-for-Use). The next tasks provide the opportunity for students to construct their knowledge based on their observations and being challenged with the data provided. Students use their prior and initial knowledge to work with the actual data of the Ecosphere thereby constructing new knowledge. "Unlike traditional problem tasks…students were not provided the information to solve the task ahead of time, nor were they given text in which they could read and locate the answer. Rather, the problems required the student to reason and synthesize information to create a solution" (Maskiewicz, 2006, p. 36). In high school classes where the DRP tasks were utilized, White and Maskiewicz (2014) found significant gains on student reasoning related to ecological processes; including some students showing the most complex and scientific reasoning. The growth of student conceptions to reach complex scientific reasoning demonstrates construction of understanding and refinement of knowledge.

When an intervention did not follow the Learning-for-Use framework or did not have students as active participants in constructing their knowledge, only moderate success was seen. For example, one study exploring the use of an Eco-Column as the primary activity during an Ecology unit of study did not show sufficient change in student understanding from prior to the intervention to after (Hogan 2000). Possible causes of students lacking understanding could have stemmed from the original 25 lessons being shortened to 10 or that "[student] inquiries were guided by the teacher rather than self-designed and class discussions were typically recitation-based rather than exploratory" (Hogan, 2000, p. 23). Though students participated in activities and observed changes in the Eco-Column that they created, they were not in charge of their learning nor constructing their knowledge. The teacher still directed the activity instead of students exploring. In relation to the Learning-for-Use concepts, this study only utilized "construct". Hogan and Thomas (2001) later described that scaffolding (not direct information) is very important throughout the process and student success is increased with instructional scaffolding.

For this current study's intervention, the Learning-for-Use framework is used as the backdrop to design data rich problem tasks intended to increase student understanding of causal relationships within ecosystems. Since research has demonstrated that student conceptions about organism relationships tend to be linear and not systemic, there exists a need for an intervention that will improve their understanding. True robust knowledge of such relationships is required in order for better management and ecologically sustainable decisions to be made today and in the future by our students. More specifically, the focus of this study was to design data rich problem tasks that promote student understanding of marine food webs relationships and the effects of a loss of species in a marine ecosystem. The following research question guided the current study:

> Does completion of a data-rich species task affect student's understanding of the nonlinear and sustaining effects of loss of species in an ecosystem?
>
> Before this research question was answered, two sub-questions were first pursued. (a) What scenario(s) about ecological relationships promote cognitive conflict among middle school students? And (b), what data promote student construction of knowledge about nonlinear and sustaining effects of the loss of species in an ecosystem?

Methods

The goal of the data rich problem (DRP) task is to help students construct an understanding of the interdependent relationships within a marine ecosystem, and to begin to apply nonlinear causal reasoning to ecosystem functioning. I used Edelson's

(2001) “Learning for Use” framework to inform the design of the DRP task. According to the “Learning for Use” framework, students need to be motivated to acquire new knowledge, allowed time to construct their knowledge, and be provided the opportunity to refine their knowledge. In order to satisfy the Learning-for-Use framework, the DRP task begins by promoting some cognitive conflict (motivate) followed by the students analyzing data to support knowledge construction. The pathway of creating the DRP task is one of design research; a research approach that is described as an iterative process (Collins et al, 2004; Design Based Research Collective, 2003; Fortus et al, 2004; Plomp, 2009). According to Collins et al (2004), “this approach of progressive refinement in design involves putting a first version of a design into the world to see how it works” followed by constant redesign (pg. 18). In other words, the DRP task is designed, the task is implemented, the task is refined, and then this process is repeated (Figure 2). Therefore, by completing rounds of trials (testing the DRP tasks), I continue to get closer to an effective intervention. By sharing this study following the final refinement of the DRP tasks I continue to follow the design research approach by providing an intervention to be researched by other practitioners; continuing the cycle of revision (Design Based Research Collective, 2003).

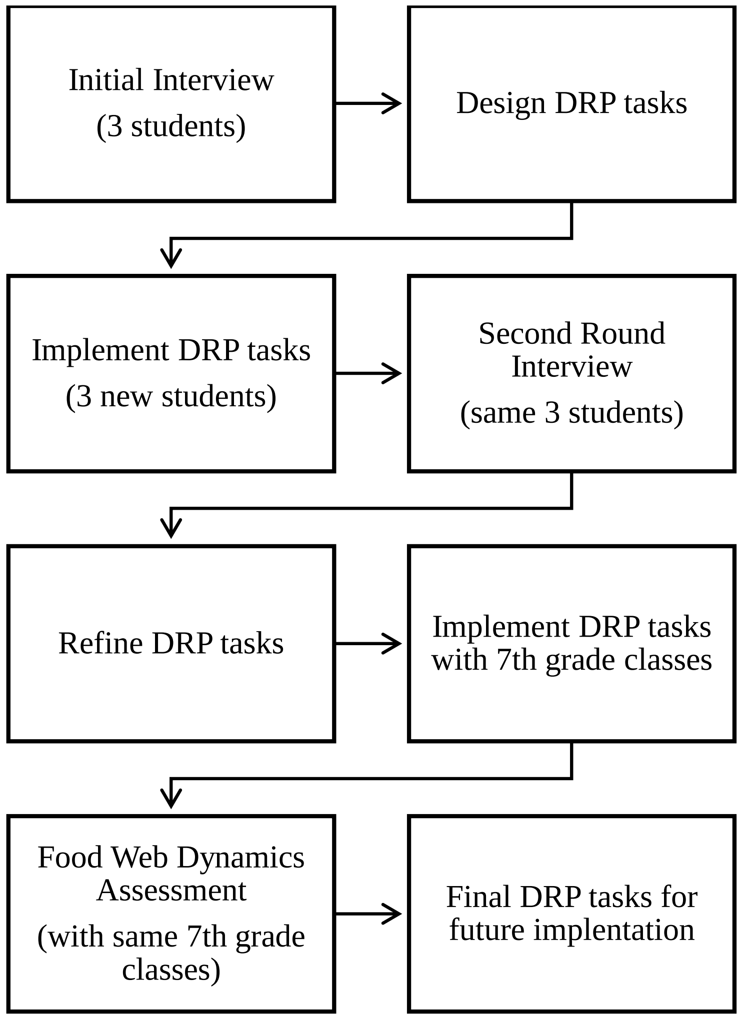

Figure 2: Interview, Refine, Implement Rounds

Research Design

The research method involved engaging in the iterative process of problem task development. Three students participated in the initial interview process and the findings from these interviews guided the design of the initial DRP tasks. The initial DRP tasks were then implemented during an interview with a new set of three students. These three students' responses determined the effect of the initial DRP tasks. Further refinement was not conducted considering the results from these interviews indicated that any further improvement from students would be aided by working in a group setting. The DRP tasks were implemented in the middle of the second semester with two 7th grade science classes with a maximum enrollment of 28. At the commencement of the DRP tasks, I assessed the students' knowledge and understanding of the interdependent relationships in food webs by using the Food Web Dynamics Assessment (see Appendix A). This assessment consists of a new ecosystem and food web with questions similar to the DRP tasks as well as a modified version of the Food Web Relationships task (adapted from Webb and Boltt, 1990) used in the initial interviews.

Relation of tasks to Next Generation Science Standards. As seen in Table 1, the DRP tasks address the Next Generation Science Standards MS-LS2 Ecosystems: Interactions, Energy, and Dynamics 1, 2, and 4 (NGSS Lead States, 2013). San Diego Unified has adopted the integrated model for implementing NGSS at the middle school level. This is described as grades six through eight having portions of Earth Science, Life Science, and Physical Science in each year of middle school. These ecosystems standards described will be part of the 7th grade science curriculum once NGSS is fully implemented. In the past, ecosystem standards were part of the 6th grade science curriculum.

Table 1: Connection to Next Generation Science Standards

<table>
<tr><th>Next Generation Science Standard</th><th>Connection to Study</th></tr>
<tr><td>MS-LS2-1: Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem.</td><td rowspan="3">All three standards ask students to demonstrate their understanding of cause and effect relationships and the interdependence relationships among organisms and between ecosystems when change occurs. Without scientific knowledge of the nonlinear relationships within ecosystems, students will be unable to achieve these standards.</td></tr>
<tr><td>MS-LS2-2: Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems.</td></tr>
<tr><td>MS-LS2-4: Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.</td></tr>
</table>

Study Site & Participants

This study was conducted at a neighborhood K-8 magnet school in San Diego, CA with a population of approximately 600 students. It is located in a city neighborhood of approximately 18,000 residents living within a greater city of 1.33 million. The student population at the school is 51.3% Hispanic or Latino, 25.1% Caucasian, 16.5% African American, 4.9% identify as multiple ethnicities, and 0.9% Asian. At the middle school level, the science content focus for each grade level includes Earth Science for 6th

grade students, Life Science for 7th grade students, and Physical Science for 8th grade students. Sixth grade standards include ecology concepts (California Department of Education, 1998); therefore, the 7th grade students that participated in the interviews had prior experience with ecology concepts during their 6th grade science class. Students volunteered to participate in the interviews. Students were randomly selected and provided a $10 gift card in appreciation for their time. The study was conducted in accordance with Point Loma Nazarene University's Institutional Review Board's guidelines. This study began at the end of the first semester with 7th grade students. Interviews were conducted with students that had previously completed 6th grade science instruction, including instruction in ecology and ecological relationships. Students were primarily selected based on availability and willingness to participate in order to gather authentic data. The DRP tasks were implemented during the second semester with my 7th grade classes. These same students were also assessed with the Food Web Dynamics Assessment.

Development of Tasks

Interview Methods – Round One

Interviews were conducted in my classroom after school and were both audio and video recorded. The initial three interviews utilized two tasks to elicit student understanding regarding food webs, nonlinear relationships, and the effects of the loss of species in a habitat (See Appendix B). The first task (Card Sort) was previously conducted in my pilot study with fewer cards and with shorter descriptions on each card. However, even with the more limited card sort, the task was found to be effective in drawing out student ideas about relationships in an ecosystem. Follow-up questioning to student ideas were also limited in the pilot study. Therefore, the task was implemented again with the questions being more specific to the focus of this study. The second task (Food Web Relationships) was adapted from Webb and Boltt (1990). This task provides a food web with letters representing organisms. This allows students to describe relationships within an ecosystem without the influence of knowledge regarding specific species. Therefore, students' understanding regarding relationships in the entire food web are more likely to be exposed instead of focusing on the organisms they are familiar with.

Interview Results – Round one

The first interviews were conducted to answer the first of the two sub-questions. (a) What scenario(s) about ecological relationships promote cognitive conflict among middle school students? Three students were interviewed utilizing the two tasks found in Appendix B to collect data to answer this question. Five unscientific ideas emerged from these interviews: (a) Students do not recognize arrows in a food web as energy transfer (energy arrows); (b) Effects of population change do not affect populations on a different food chain pathway (linear relationships); (c) Effects of population change are unidirectional (unidirectional food chain); (d) Effects of population change dissipate (dissipation); (e) An ecosystem can fix itself by a species changing food sources if the original food source decreases or becomes extinct (selective food source).

Energy arrows. All three students demonstrated their knowledge of arrows in a food web as something other than energy transfer. This limited understanding was primarily demonstrated during Task 2: Food Web Relationships (Appendix B). This was evident in statements for each student seen in Table 2 below.

Table 2: Energy Arrows Responses during round one of interviews.

Student	**Response** Arrows point from E to F to H. See Appendix B for Task 2: Food Web Relationships. Underlined segments of the transcript exemplify evidence of student conceptions.
Ilse	*Interviewer: What affect will a sudden decrease in population H have on population E?* *Student: Nothing. Because H and E are related but they can't go from back to forward. Because it is E, F, H and then goes back to E it can't do that.* *Interviewer: When you say, "goes to", what do you mean by that?* *Student: <u>Um, like they can follow each other.</u>*
Lily	*Interviewer: Okay, so what do the arrows mean to you?* *Student: The food goes to…for example if they were animals, the animal eats that animal then eats that one, then the animal wouldn't eat that anymore.* *Interviewer: If there was a sudden increase in H, how might that affect the size of population F?* *Student: <u>F would probably be able to eat a lot of H.</u>*
Sofia	*Interviewer: If there was a sudden decrease in population F, how might this affect the size of population H?* *Student: If the population F decreases then the population H increases.* *Interviewer: How so?* *Student: <u>Because the population F eats the population H.</u> So if they are wiped out then there is no one to eat population H.*

Ilse describes the arrows as reflecting which organism follows or goes after another (see underlined statements). This could be interpreted as which organism eats which. However, throughout her interview she never explicitly described the arrows as "eats" nor as energy transfer. The other two students clearly state their understanding of the arrows as "eats". The pattern of the three students utilizing the arrows as something other than energy transfer continued throughout Task 2: Food Web Relationships. If the coding scheme had been utilized for the interviews all three responses would have been coded as a score of 1. One interesting exchange with Sofia demonstrates how deeply she sees the arrows as representing "eats".

> *Interviewer: What does J eat?*
>
> *Student: I suppose a plant?*
>
> *Interviewer: So if there was a sudden increase in J, would there be any other affect besides those populations?*

Student: No. Yes, because there would not be as many plants so the other ones, H and I would start dying because there wouldn't be as much food for them.

Interviewer: If those started dying what could happen then?

Student: Population F, K, and D and C would die since they wouldn't have food. Then if those die then E, G, and B would die. If they all die then A dies.

Interviewer: What do you suppose A represents?

Student: An animal.

Interviewer: Why?

Student: If you turn it upside down like that then these are going to be like the plants, and these are going to be minor animals, these would be bigger animals, and A would be like the big thing.

Sofia could only see the food web arrows as being one organism "eating" another so much so that she needed to flip the food web upside down in order for it to make sense. From these responses, all three students demonstrated their understanding of food web arrows to be unscientific. Their responses clearly showed a need for future tasks to include the opportunity for students to recognize that arrows represent energy transfer. If students are unable to understand this concept then all of their relationships would always be unscientific.

Linear relationships. Out of the three students, only one student demonstrated unscientific reasoning when describing the effects of one population on another when the two populations were not in the same linear pathway. Ilse's responses consistently showed that she did not believe that one species can affect another if they are not directly linked in a singular pathway. The other two students however were able to trace a pathway outside of a linear food chain and describe the potential effects of a disturbance as shown in Table 3.

Table 3: Linear vs. Nonlinear responses during round one of interviews.

Student	**Response** Underlined segments of the transcript exemplify evidence of student conceptions.
Ilse	*Interviewer: What about if there was an increase in wolf eels? Would anything that lived in the ocean be affected if there was more of them?* *Student: No.* *Interviewer: No? Okay. What if there was a predator of snails that was added to this ecosystem, what could happen?* *Student: Um, nothing. It depends on what type of snail.* *Interviewer: Okay, let's say this predator ate wavy turban snails. What could happen?* *Student: Hmm, the wavy turban snails would decrease. And I don't think that it would make much difference in the ecosystem.*
	Interviewer: What affect would a sudden increase in population I have on the size of population K? *Student: Um, nothing.* *Interviewer: How come?* *Student: Because K isn't related to I.* *Interviewer: Why is it not related to I?* *Student: Because the last thing that K is related to is J and I is like way across from K.*
Lily	*Interviewer: If there was a sudden increase in population I, how might that affect the size of population K?* *Student: Maybe there would be more C's because if it goes from I to K then C is in the middle.* *Interviewer: So when you say goes to, can you use different words to explain?* *Student: Eats. So I increases so there will be more and C usually eats I, so it will go a lot, and J eats a lot of C so they will have a lot of C to eat and so there would be a lot of I. Then K will eat J because there will be a lot of C in it so it all goes to I since there is more I.*
Sofia	*Interviewer: If there was a sudden increase in population I, how might that affect the size of population K?* *Student: Population C would start eating it more so there wouldn't be as many of the predators on population J. So population K would increase because they would have more food so they would increase as well.*

Ilse's response would have been coded as a score of 1 for only seeing a food web as linear while Lily and Sofia would also be scored as 1 since they utilize the arrows backwards. However, if looking only at their reasoning, they would be scored a 3 since they were able to trace the effects of the disturbance to organisms in a nonlinear manner. These students were able to recognize connections within a food web beyond a singular food chain. Ilse's response supports the literature that students view complex relationships as linear instead of cyclical or systemic (Barman, Griffiths, & Okebukola, 1995; Barman & Mayer, 1994; Griffiths & Grant, 1985; Grotzer & Basca, 2003; Hogan, 2000; Webb & Boltt, 1990; White, 1997; White, 2000). However, the questions in the interview for Task 2 were very specific in asking about how one population affects another. Students had not been asked to describe if a disturbance in one population could affect the entire ecosystem. With this in mind, the need for pushing the students to their limits of understanding was recognized as necessary for future tasks.

Unidirectional food chain. Two of the three students showed evidence of understanding a food chain as a unidirectional pathway. Ilse showed this throughout her interview while Lily demonstrated this sporadically. Sofia on the other hand consistently showed scientific reasoning when describing the multidirectional relationships in a food web. Table 4 demonstrates their ideas.

Table 4: Unidirectional Food Chain Responses during round one of interviews.

Student	**Response** Underlined segments of the transcript exemplify evidence of student conceptions.
Ilse	Student describes the effect as only towards the prey of the CA mussel. Predators of the mussel are not considered. *Interviewer: What do you think would happen if the CA mussel became extinct?* *Student: Hmm, I don't know. I think they wouldn't be able to eat on plankton as much.* *Interviewer: Okay, if they weren't able to eat plankton as much what would happen?* *Student: They would die.* *Interviewer: The mussels would die? (student nods head) So if the mussels were no longer there at all, they were completely gone, what could happen?* *Student: Um, I don't know. I don't think there would be such a difference.* *Interviewer: The ecosystem would be okay?* *Student: Ya.*
	Interviewer: What affect will a sudden decrease in population H have on population E? *Student: Nothing.* *Interviewer: How come?* *Student: Because H and E are related but they can't go from back to forward. Because it is E, F, H and then goes back to E it can't do that.*
Lily	Student describes the effect as only towards the predators of the sea otter. Prey species of the sea otter are not considered. *Interviewer: So, if the sea otter went extinct, what could happen?* *Student: Other animals that feed off of sea otters would not eat the sea otters.* *Interviewer: So if they were gone, would the ecosystem be changed at all?* *Student: Um, maybe, but not with the stuff on the cards. Maybe if whales or something ate sea otters then ya.* *Interviewer: So only the things that ate the sea otters would get affected, but not the things the sea otter eats.* *Student: Ya.*
Sofia	Student describes the effects in both top-down and bottom-up scenarios. *Interviewer: What would happen if the plankton went extinct? If there was no plankton at all?* *Student: Then a lot of these would die. Like the CA Mussel would start dying and then the octopus would start dying and then the Wolf Eel would start dying and also the Sea Otter.* *Interviewer: Would the same be true if the sea urchin went extinct?* *Student: No because [the CA Mussel, Wolf Eel, and the octopus] can still feed on all of these [points to other mollusks]. But these two [points to plankton and kelp] would increase in population.* *Interviewer: If the sea urchin was gone then the plankton and the kelp would increase in population but the other snails and such would stay the same?* *Student: Yes.* *Interviewer: If the Wolf Eel population decreases, would it have any effect on the kelp?* *Student: Yes, because if it decreases then there is more of these (points to mollusks) and these would eat this one (points to kelp) more. So this one would run out and eventually become extinct.*

Both Lily and Ilse would have been coded as a 1 using the coding scheme. Their reasoning is unscientific in that they only consider the effects of a disturbance to happen in one direction of a food chain. Ilse's response supports the literature in that some students do not consider changes occurring in a predator population if the prey population size changes (Barman, Griffiths, & Okebukola, 1995; Griffiths & Grant, 1985). Lily's response demonstrated the opposite of Ilse; only the predator is effected, not the prey. Sofia on the other hand displays a level 3 for her scientific reasoning. Being unable to describe the effects of a disturbance scientifically in a food chain may impede being able to read a food web as interconnected food chains.

Dissipation. All three students seemed to show dissipation in their reasoning when describing the effects of a disturbance in an ecosystem. None of the students directly stated that there would be less of an effect on populations as they went further away from the disturbance. However, all three students would stop describing the effects of the disturbance at the next level in the food chain. When pressed further about the next level populations, all three students stated that those populations would not be affected (Table 5).

Table 5: Dissipation Responses during round one of interviews.

Student	**Response** Underlined segments of the transcript exemplify evidence of student conceptions.
Ilse	Students describes the effect of the disturbance as only affecting the next level in the food chain. *Interviewer: Okay, what if there was an increase in plankton?* *Student: Then there would probably be more of these two (points to the Wavy Turban Snail and the CA Mussel).* *Interviewer: If there were more wavy turban snails, would there be any influence on the ecosystem if there were more turban snails?* *Student: Um, no.*
Lily	Student describes the effect of the disturbance as only affecting the next level above and below. *Interviewer: So back to my question, if there was a decrease in the mussel population, what could happen?* *Student: There would be a lot of plankton since it eats a lot of it. So maybe some animals would start to die or get sick.* *Interviewer: Which animals?* *Student: Like the ones that eat it, like snails and the octopus. The sea otter is probably fine because it eats other stuff.*
Sofia	Student describes the effect of the disturbance as only affecting the next level above and below in the food chain. *Interviewer: What if the sea otter has a decrease in its population?* *Student: More of the sea urchins and these would increase in population because there would be no otters to eat them.* *Interviewer: Would there be any other affect besides the things that the otter eats?* *Student: Yes, the things that eat the otter would also die because they wouldn't eat anything.* *Interviewer: So whatever would eat the sea otter would not have the sea otter to eat so they would die.* *Student: Yes.*

When Lily was asked how a disturbance in one level of the ecosystem could affect another population two levels below she was unable to describe a continuous effect.

> *Interviewer: What if there was an increase in the sea otter population? Would that have any effect on the plankton population?*
>
> *Student: Probably not no. Because it doesn't eat off of that. It just feeds off the animals that eat the plankton. I mean if the animals that eat the plankton ate more plankton then ya.*

Lily was unable to put into words that more sea otters would cause a decrease in animals that fed off of plankton which would then increase the plankton population. Instead she had to break apart the food chain and describe the effect in pieces. This was apparently the only way that she could see that a disturbance in the sea otter population could have an effect on the plankton population. Even though these organisms could be found on the same food chain, they are not directly related as predator-prey. Therefore, her response supports the literature that proximity of one organism to another on a food chain influences whether or not a student can describe the effects of the disturbance scientifically (Barman, Griffiths, & Okebukola, 1995; Barman & Mayer, 1994; Griffiths & Grant, 1985; Webb & Boltt, 1990).

All the questions that students were asked in Task 1 of the interviews were primarily open-ended. In other words, students were generally asked if or how a disturbance in an ecosystem would affect the ecosystem. During Task 2 of the interview students were specifically asked if or how a disturbance in one population specifically affected another. In this task students were able to look at a food web with arrows. During these tasks students spoke generally about populations increasing or decreasing as they followed the arrows from the disturbance to the final population the question had asked about. They did not specifically state that the affect dissipated. Since the responses between Task 1 and Task 2 almost show contrasting scientific ideas, there was clearly a need to elicit the depth of understanding that the students have regarding dissipation versus persistence of a disturbance in an ecosystem in the future tasks being developed.

Selective food source. Two of the three students interviewed demonstrated the idea that animals are able to be selective with their food source. When the students were pressed about what could happen to a population when the food source decreased or went extinct, their responses described the organism simply electing to consume a different type of organism (Table 6).

Table 6: Selective Food Source Responses during round one of interviews.

Student	**Response** Underlined segments of the transcript exemplify evidence of student conceptions.
Lily	Student describes the population leaving the ecosystem to find more food. *Interviewer: What affect will a sudden decrease in population H have on population E?* *Student: It will go all back because they are all connected so um if there is a decrease in H then F won't be able to get H and then if F can't get H then F will probably go or move to a different place to get more H or start dying. So E probably wouldn't get to F.*
	Arrows point from B to K to J. Student describes K typically consuming J. If J is not around K will instead consume B. *Teacher: What affect will a sudden decrease in population J have on population B?* *Student: A decrease in J, will make K probably not go to J for food, or it will eat all of it. Then K will probably go to B and there will be a decrease in B because K is eating B a lot.* *Interviewer: K usually eats what?* *Student: J.* *Interviewer: What do you mean K will go to B? In what way?* *Student: Like go and eat B.* *Interviewer: So K will go and eat B instead?* *Student: Ya.* *Interviewer: Does B normally eat K?* *Student: Yes.* *Interviewer: But in this case, K will try to eat B instead?* *Student: And then B would eat K too I guess.*
Sofia	Student describes a predator changing their diet when their food source goes extinct. *Interviewer: What if a predator of snails and sea stars were introduced to this ecosystem?* *Student: The otter would run out of food. Also, the octopus and the wolf eel would all run out of food. The Kellet's Welk and the Knobby Sea Star would decrease in population and become extinct.* *Interviewer: What would happen if they went extinct?* *Student: Everything would go crazy because then the sea otter would not have a lot of food. The octopus would start feeding on something else.* *Interviewer: Something besides those ones?* *Student: Ya.*

When these students describe the population of organisms being able to elect to consume a different prey species than it typically consumes, they are demonstrating that the ecosystem can "fix" itself. It follows from this idea that an ecosystem is not in danger of collapsing when a species goes extinct. As such, an activity should allow students to analyze shifts in population sizes over time when a disturbance occurs.

Summary. Many of the five unscientific ideas that emerged from these interviews support the literature on student conceptions regarding food webs. The most problematic connection between all conceptions is that as Hogan (2000) described "students tend to interpret food webs in terms of individual rather than interconnected food chains" (pg. 27). There is a clear need for students to engage in tasks in which they can experience how species in an ecosystem are interconnected. Before they can reach that point; however, they also should have a scientific understanding of how to read a basic food chain and food web with arrows, and then be able to recognize the effects of a disturbance in a food chain (no matter where the disturbance occurs). Finally, students should have opportunities to build their scientific reasoning of food web relationships by recognizing the effects of a disturbance on the entire food web. This should include the ideas that populations are interconnected. If students cannot see populations as interconnected, then they are not going to see that disturbances can persist in a food web. The conceptions that emerged from this first round of interviews provided useful ideas for the initial design of the DRP tasks implemented in the second round of interviews.

Interview Methods – Round Two

The second round of interviews consisted of a new group of three 7^{th} grade students. A total of seven tasks were utilized to help determine what types of experiences promote student construction of knowledge about nonlinear and sustaining effects of the loss of species in a habitat (see Appendix C). The first task (Food Chain Construction) provided students the opportunity to construct a food chain utilizing cards with pictures of the different organisms in the food chain. The task also included arrows with the words "provides energy" printed on them. This combination of cards allowed students to try to construct a food web not only with the organisms in the appropriate order, but also to see if students could capture the idea that arrows meant energy instead of merely pointing in the direction from predator to prey. The second task (Food Chain Comparison) consisted of three food chains with overlapping organisms. These food chains together create a food web. One of the food chains was from task one. The other two were essentially food chains within the broader food web. Student performance with this task was centered on two main objectives. First, can students recognize that organisms are interconnected even when listed on separate food chains? Secondly, with the addition of specifying the amount of energy transferred from one organism to another (printed on the arrows) can students construct this knowledge into recognizing that the loss of a species would mean the loss of energy available in the ecosystem? Task three (Food Web Construction) provided students the opportunity to utilize their constructed knowledge from tasks one and two to build a food web. Students were provided picture cards of the organisms utilized in task two and asked to draw a food web with arrows. The dilemma of trying to have all organisms no longer in separate food chains but now in a food web causes students to struggle and pushes them to construct interconnected relationships. These first three tasks were designed to bring out prior student knowledge as well as to push that prior knowledge to recognize the loss of species creates the loss of energy in an ecosystem as well as the relationships within a food web. The next three tasks utilize the initial food chain from task one as well as population data.

Tasks four through six provide students the opportunity to become familiar with analyzing population data with familiar relationships (the initial food chain) all while applying their constructed knowledge to a new population change scenario. Task four (Bottom-Up DRP) asks students to consider the effects on the rest of the food chain when there is a change in population numbers at the primary producer level (kelp). Task five (Top-Down DRP) provides students with the opposite scenario. In this task there is a change in population numbers to the tertiary consumer (killer whale). Students are again asked to determine the effects of this disturbance on the rest of the food chain. Task six (Mid-Level DRP) demonstrates a change in population numbers to the secondary consumer. In this task students are asked to trace the effects of this disturbance in both predators and prey of this species. This task has students consider that disturbances in a food chain can be multidirectional. The final task took these ideas a step further by asking students to apply these experiences to a food web (the same food web from task three).

Task seven (Food Web DRP) contained a food web constructed from the organisms from task three as well as population data for all of the organisms over a 20 year time span. In this task a change in a branched organism (one that is not on a linear food chain) was described as the disturbance. Students were again asked to consider the effects of this disturbance on various populations in the food web by utilizing the food web as well as the population data provided. After students had time to consider the nonlinear relationships within this food web they were then asked to consider a new scenario affecting this ecosystem. Students were also provided population data for the following ten years. At the end of this task students were asked to consider if they thought the ecosystem could survive with these disturbances in place. Ideally, at the conclusion of this task (with the help of the scaffolded tasks prior to task seven) students would be able to come to the conclusion that with this disturbance the ecosystem could not continue to function and that ecosystem collapse is possible.

Interview Results – Round Two

The second round of interviews helped determine what data would promote student construction of knowledge about nonlinear and sustaining effects of the loss of species in an ecosystem. Utilizing the findings from the first round of interviews, a series of data rich problem tasks were developed. The intent of the second round of interviews was to try out these newly developed tasks with students. Three students were interviewed utilizing the DRP tasks found in Appendix C. Of the five unscientific ideas that students demonstrated in the first round of interviews, all but one idea did not show improvement. Students demonstrated scientific reasoning in four main areas: (a) Students recognized arrows in a food web as energy transfer (energy arrows); (b) Effects of population change do affect populations on a different food chain or pathway (nonlinear relationships); (c) Effects of population change are multidirectional (multidirectional food chain); (d) Effects of a population change do not dissipate (dissipation). The one idea that did not show improvement was selective food source. Students continued to describe that an ecosystem would be sustainable after a decrease in food source because a species would simply change food sources.

Energy arrows. The first task (see Appendix C) in the second round of interviews contained arrows with the words "provides energy" printed on them. Initially only one of the three students recognized this from the beginning and constructed a food chain with the arrows pointing in the appropriate direction. The other two students constructed their food chain with the arrows representing who eats what; ignoring the words on the arrows. Once these students were asked what the arrows represented they discovered the words and consequently rearranged the arrows in the direction of energy transfer. During task three when the students were asked to construct a food web, the same two students that ignored "energy transfer" on the arrows during task 1 also reverted back to drawing their web with arrows as "eats". Katalina, the student that set up her food chain with recognition of "energy transfer" continued with this scientific understanding when setting up her food web. However, when pressed further as to why she set up her food web the way she did her reasoning was more unscientific.

> *Interviewer: So if you had to insert a word for your arrow and I start at giant kelp, giant kelp something urchin.*
>
> *Student: Is smaller or like is eaten by.*
>
> *Interviewer: Is eaten by the urchin?*
>
> *Student: Ya.*
>
> *Interviewer: What does the kelp provide the urchin?*
>
> *Student: The kelp provides it food.*
>
> *Interviewer: What is food for an animal?*
>
> *Student: It is an energy source.*
>
> *Interviewer: Okay so your arrows are food source, showing where the food is going?*
>
> *Student: Ya.*
>
> *Interviewer: How come you arranged them in that direction? For example why not point down?*
>
> *Student: Because the whale is at the top of the food chain, so why would it be at the bottom?*
>
> *Interviewer: Okay, for example, why make the arrow point up all the way towards the killer whale instead of pointing down towards the kelp?*
>
> *Student: Because the killer whale is the biggest.*

Interviewer: So everything should point to it?

Student: Ya.

At first, Katalina seems to describe her arrows scientifically; "the kelp provides it food…it is an energy source". However, her reasoning as to why the arrows point up is based on the idea that the arrow should point towards the biggest animal. Even though students demonstrated unscientific reasoning when constructing their own food chains or food webs, they were able to read pre-constructed food chains and food webs without misunderstanding the arrows in future tasks.

Nonlinear relationships. During round one of the interviews the students did show scientific reasoning when describing how a disturbance in one area of a food web can affect another population in the food web. However, the questions did not ask *if* a disturbance can affect other populations in a food web, much less an entire ecosystem. The tasks in round two of interviews probed further the students' understanding and gave them multiple opportunities to answer open-ended questions regarding the effects of a disturbance on an ecosystem. All three students were able to describe the nonlinear effects of a disturbance in a food web (Table 7).

Table 7: Nonlinear Relationships Responses during round two of interviews.

Student	**Response** Underlined segments of the transcript exemplify evidence of student conceptions.
Jayla	During task 7 the student describes nonlinear effects on an ecosystem when a disturbance occurs in one area of a food web. *Interviewer: So this was an ecosystem that we saw the sea lions decrease for an unknown reason. We don't know why. What do you predict will happen in the next 20 years to the sea otter?* *Student: They would probably die.* *Interviewer: Why?* *Student: Because <u>if the killer whale is not eating any sea lions then it is constantly going to be eating sea otters which would probably go to extinction.</u>* *Interviewer: What do you see happening to the sheephead population?* *Student: It is getting increased somehow.* *Interviewer: <u>Okay, so why do you think the sheephead population has increased?</u>* *Student: <u>Because there is not as many sea lions!</u> There ya go.* *Interviewer: <u>Why do you see the sea urchin population not really changing?</u>* *Student: Because there is not really any sea otters, well barely. So they are only eating a little bit of the urchins.* *Interviewer: Okay so how come they are not increasing?* *Student: Ya, okay because if the sea otter…oh <u>because the sheephead and the sea otter eat the urchin!</u>*
Damascus	During task 3 the student describes nonlinear effects on an ecosystem when a disturbance occurs in one area of the food web he constructed. *Interviewer: Okay, what could happen if sea otters became extinct?* *Student: <u>Then the killer whales would start eating more sea lions.</u>* *Interviewer: So would anything happen after that? After eating more sea lions?* *Student: <u>The CA sheephead population would start to grow because there is not a lot of sea lions killing the sheephead.</u>* *Interviewer: Anything with the urchins? Or the mussels?* *Student: <u>Then there would be a huge population of sheepheads and they would start killing the sea urchins and then that would decrease. Then I guess the giant kelp would grow.</u>*
Katalina	During task 3 the student describes nonlinear effects on an ecosystem when a disturbance occurs in one area of the food web she constructed. *Interviewer: What if there was a sudden decrease in mussels, would the killer whale population be affected?* *Student: Ya, but like half way. Well ya they would because <u>since the fish and the otter are both connected to the whale so that is what they eat and so it would go down.</u>* *Interviewer: So if the mussels go down what would happen to the sheephead?* *Student: <u>The sheephead would go down also.</u>* *Interviewer: And the sea otters?* *Student: <u>Would also go down and so when these go down (points to the sea otter) this goes down (points to the killer whale).</u>*

Task 7 seemed to challenge students the most as they described food web dynamics. This task combined a complex food web with a data table of population numbers over 20 years. Students never described the unscientific idea that some populations are not affected because they are not on the same food chain (as seen occasionally in round one of interviews). Instead, students were consistent in describing nonlinear effects.

Occasionally students did get confused the further they moved from the disturbance. While they continued to describe populations being affected as they moved further away, they started to forget what was driving the changes. Katalina demonstrated this towards the end of Task 7.

> *Teacher: So after tracking the ecosystem for 20 years, the sheephead population is found to be abundant. Fisherman have noticed this abundance and begin fishing the sheephead without any regulations. For the next 10 years, the population numbers continue to be recorded for this ecosystem. What do you think will happen to the ecosystem over the next 10 years?*
>
> *Student: The sheephead will go down because the fisherman are eating them.*
>
> *Teacher: Anything else besides the sheephead going down?*
>
> *Student: The mussels because no one is eating them, mussels would go up and then the sea lions would go down because they can't eat any sheephead now.*
>
> *Teacher: Can the ecosystem still exist without regulating fishing?*
>
> *Student: I don't think so because the sheephead and then what would the sea lions eat? The killer whales would have just sea otters to eat.*
>
> *Teacher: Anything else besides the sea lion and the killer whale and the sea otter being affected?*
>
> *Student: No, well the CA mussel would go up because no one is going after them besides the sea otter.*
>
> *Teacher: Anything else?*
>
> *Student: So the sea otters would go up so that would make the killer whales go up.*

Right at the end of Katalina's reasoning she starts to forget how the original disturbance was driving the changes to the ecosystem. Before her last statement she had appropriately described the sea otters being eaten more by the killer whales. However, once she mentioned that this would drive the CA mussels to increase she changed her thinking about the sea otter. This sort of confusion only occurred two other times throughout all three interviews. This confusion is not considered to be the same as White's (1997) description regarding confidence. White described student confusion increasing as students moved further away from the disturbance which then caused students to describe the effects on further populations to be not as severe. His work describes the possible reasons students describe dissipation or linear effects. The instances in these interviews that confusion occurred did not demonstrate dissipation nor linear reasoning. Instead, the students described persistence and nonlinear effects.

Multidirectional food chain. All three students demonstrated multiple times their ability to scientifically describe the effects of a disturbance in a food chain to be multidirectional (Table 8).

Table 8: Multidirectional Food Chain Responses during round two of interviews.

Student	**Response** Underlined segments of the transcript exemplify evidence of student conceptions.
	During Task 6 the student describes the multidirectional effects of a disturbance in the middle of a food chain. *Interviewer: So if we reintroduced sea otters it would go back to this food chain?* *Student: Ya.* *Interviewer: What would happen to the population numbers do you think?* *Student: It would probably, <u>for the sea otters it would probably start to increase, for the killer whales it would increase before the urchins and kelp start to decrease. Or for the urchins it would start to decrease but the kelp it would start to increase.</u>*
Damascus	During Task 6 the student describes the multidirectional effects of a disturbance in the middle of a food chain. *Interviewer:…the Sea Otters were driven to extinction by humans hunting them for their fur pelts to make the newest fur coat fashion. Using the same food chain and the new data table, what do you think will happen to the other populations? For example, what could be some possible population numbers for the killer whales over time?* *Student: Umm, I guess <u>the killer whales will decrease too since there is no more sea otters to eat.</u>* *Interviewer: So if they are starting at 12, what do you think are some possible population numbers?* *Student: So I guess at 5 years it would be 8. Then at 10 there would be like 4 and then at 15 there would be like 1 and then probably at 16 there would be zero.* *Interviewer: How come?* *Student: Because there is no more sea otters.* *Interviewer: What could be some possible population numbers for kelp over time?* *Student: <u>It would decrease too since there is no more sea otters to eat the urchins then the urchins will grow and start eating a lot of kelp.</u>*
Katalina	During Task 2 the student describes the multidirectional effects of a disturbance in the middle of two food chains listed side by side. *Interviewer: What if there was a sudden increase in sheephead?* *Student: Um, if there was more? <u>Then maybe there would be a lot more sea lions around.</u>* *Interviewer: Would there be any other change besides more sea lions?* *Student: <u>You would probably run out of sea urchins or mussels</u> because they wouldn't be able to eat enough.* *Interviewer: What wouldn't, the sheephead wouldn't be able to eat enough?* *Student: Ya.* *Interviewer: Okay, if there was less urchins and mussels would anything else be affected?* *Student: <u>Then there would be more giant kelp and plankton.</u>*

These findings do not corroborate with the literature stating that some students do not consider changes occurring in a predator population if the prey population size changes

(Barman, Griffiths, & Okebukola, 1995; Griffiths & Grant, 1985). In contrast, the students consistently described the effects on the various populations in a food chain even when the disturbance was a prey population in the middle of the food chain.

Dissipation. None of the three students interviewed demonstrated the unscientific conception that a disturbance in an area of a food chain will dissipate the further away other species are from that disturbance. It is unknown from these interviews if this is because of the types of tasks and questions that were asked or if the students have the scientific reasoning to understand persistence. Dissipation vs. persistence was further tested in the assessment questions (Table 2).

Selective food source. It is interesting that even though all three students seemed to have some level of scientific reasoning when discussing the dynamic relationships in a food web, all three also described predators changing their diets in order to continue to survive. All three students sought a way for the ecosystem to be sustained instead of collapsing. This was demonstrated numerous times for all three students (Table 9).

Table 9: Selective Food Source Responses during round two of interviews.

Student	**Response** Underlined segments of the transcript exemplify evidence of student conceptions.
Jayla	*Interviewer: If those prey items were not available…* *Student: It would probably eat something else.* *Interviewer: You were just mentioning how the sea lions would go extinct. So what would happen to the killer whales?* *Student: They would stay the same.* *Interviewer: Why?* *Student: There is other things to eat in the ocean besides that stuff.* *Interviewer: Like what?* *Student: Like fish.* *Interviewer: So killer whales eat fish?* *Student: They can.* *Interviewer: If the urchins went extinct what would happen to the sea otters?* *Student: They would probably decrease by the years that are passing because they are not getting their nutrients from the urchins.* *Interviewer: Is it a possibility that they would exist in 20 years?* *Student: Yes because there is other animals that it would eat.*
Damascus	*Interviewer: What if there was a decrease in sea urchin population? What might happen?* *Student: It will disrupt the food chain.* *Interviewer: How so?* *Student: If there is a decrease in sea urchins then I guess there wouldn't be enough for the sea otters and the CA sheephead or something like that to eat so I guess they would have to start eating the ones below them, the giant kelp.* *Interviewer: So if there food source wasn't there they would just eat a different food source?* *Student: Ya.* *Interviewer: If there was a decrease in the sheephead population, what might happen?* *Student: Then these (the sheepead) will eventually leave and then the sea lion would start to eat the sea urchin and the CA mussel probably.* *Interviewer: Okay so since the sheephead is gone they are going to start eating the urchins and the mussels?* *Student: Ya.*
Katalina	*Interviewer: Okay. What would happen if sea otters become extinct? What might happen to this ecosystem?* *Student: Then the killer whales would have to like evolve and find something new to eat and there would probably be more sea urchins.*
	Interviewer: Do you think this ecosystem could survive? *Student: Ya.* *Interviewer: How come?* *Student: You just find a way for the animals to like find like another food source so not only like urchins so something else so they have two different ways to stay alive. It is better to have 50, like half and half instead of relying on only one species.*

Summary. From the five unscientific ideas that emerged in round one of the interviews only one continued in round two, energy arrows. However, students were able to utilize the arrows appropriately in the tasks even if they did not draw their own food chains and food webs scientifically. In round two, the DRP tasks that students were asked to complete seem to support students developing scientific food web dynamics reasoning. Students were able to describe the effects on a population in a food chain in a multidirectional pattern. This may support the improvement in reading a food web as a series of interconnections instead of singular food chains. This may also be why there was no indication of dissipation reasoning. From the positive results in round two it was determined that the DRP tasks should be utilized in the classroom instead of another round of interviews. It was thought that any continued areas that were unscientific (primarily energy arrows, selective food source, and occasional confusion when moving away from the disturbance) would be improved if students worked in a group setting in the classroom.

Classroom Study

Implementation of DRP Tasks Methods

After completing the second round of interviews it was determined that the DRP tasks were ready to be implemented in the classroom. There were no modifications or refinements to the actual tasks from the second round of interviews prior to implementation. The outcomes from the second round of interviews demonstrated that any further improvement of students constructing knowledge would come not from refining the tasks but instead with the support of working with their group members.

In the classroom, students worked in groups of four to complete all seven tasks. This implementation took a total of eight 50-minute class periods. The typical flow for each task was to introduce the task with expectations of collaboratively working together.

Students were expected to work in teams to complete the task by defending and arguing their ideas before the team answers the questions for each task. Finally, students were also expected to participate in a class discussion following each task. This discussion was purposeful in that it elicited major scientific ideas as well as allowed students to work though unscientific ideas. As mentioned by Grotzer & Basca (2003), refinement of ideas can be achieved through discussion. All tasks, except Task 1, were completed on poster paper. The purpose for the poster paper was to allow all students to see the answers being written as well as allow multiple students to work on an answer at the same time. Final modifications to the DRP Tasks came after the assessment results and can be found in Appendix D with recommendations for future implementation.

Task one is introductory. It allows students to not only bring forward their prior knowledge regarding relationships in an ecosystem, but it also allows students to complete the problem with confidence. By the time students have reached the 7^{th} grade they have typically had experience with a food chain. By providing information about each organism the students are able to easily construct a food chain. The potentially new experience is recognizing what the arrows in a food chain represent. After a brief description of the task, students completed their food chain and the additional question as a team. Once students completed the task two groups were chosen to share their results with the class. One group chosen demonstrated their arrows representing “eats” while the other group’s arrows demonstrated “provides energy”. By allowing all teams to see this major difference the students were able to recognize visually how the arrows should point. From the sharing of these food chains a brief discussion ensued regarding what the arrows mean and why this knowledge is necessary to understand food chains and food webs. Now that students have familiarized themselves with food chains they are challenged with task two.

Task two involved students discussing together the similarities and differences among three food chains. These three food chains are all part of the same food web; therefore, there was some overlap of some species in the different food webs. The food chains also provided approximate amounts of energy transferred from one organism to the next. The task was introduced as well as the expectation for students to engage in a continuous discussion about the questions with their group members while they worked. Once students had completed task two there was a class discussion of the similarities and differences between the food chains as well as the answers to the questions. From this discussion two major ideas emerged. First, students shared that the amount of energy transferred was decreasing when moving from producer to consumer because some energy is utilized by the organism. Highlighting the connections of energy being transferred from one organism to the next allowed students to recognize that the loss of a species is a loss of energy to the ecosystem. Also during the class discussion, the students pointed out connections between the three food chains. Instead of simply answering how a change in one organism affected their predator or prey the students recognized that this change could also influence organisms in another food chain that shared the same species. These connections between the three food chains provided a scaffold for students to create a food web in task three.

Task three challenged students to collaboratively work together to take all the organisms that were provided in task two and create a flowing food web. Students were provided cards with pictures and descriptions of the different organisms. The students constructed this food web on a new poster. Once the students completed their food web the groups rotated around the room to view the other teams' food webs. Immediately after viewing the other posters a class discussion ensued to describe what students noticed as similarities and differences among the constructed food webs. All groups were able to construct a food web with all of the cards. However, only half of the teams utilized the arrows in a scientific manner. The viewing of other posters and the discussion allowed these groups to be reminded of what the arrows represent scientifically. By viewing and discussing this idea all students were able to begin the questions about the relationships in the food web with this constructed knowledge in place. Students answered the questions on their poster followed by a class discussion of their answers. Now that students have developed their knowledge regarding the relationships in food chains and food webs, tasks four through seven added in the component of population data to further challenge students in constructing their knowledge about the dynamic relationships in an ecosystem.

The scenarios introduced in the beginning of each of tasks four through seven satisfied step one of Edelson's (2001) "Learning for Use" framework. The scenarios motivated the students to acquire the knowledge necessary to determine what happened to the other organisms in the ecosystem. Utilizing the food chain and data table in each task, students were provided the opportunity to construct their knowledge. Since the tasks are similar in design and the students were able to discuss their ideas within their team and with the class they were also able to refine their knowledge.

Task four, a bottom-up scenario, was completed as a class. Students were introduced to the scenario and the data table. The teams were then asked to discuss question one. Individual teams were called upon to share their ideas and reasoning. Once a class consensus had been developed for question one the teams were then asked to discuss their ideas for question two. This pattern of group discussion, class discussion, and class consensus continued for each question in task four. The purpose of completing these questions together provided the expectations for the rest of the tasks as well as clear up any misunderstandings of how to read the data tables. From this experience students were able to trace the effects of a bottom-up disturbance in a food chain supported by data. For task five students were asked to be more independent with the top-down disturbance.

For task five students worked in teams to complete the questions. There was no whole class discussion regarding the questions until the end of the task. Some groups needed help to get started as they seemed overwhelmed with looking at the data and looking at the food chain together. However, once I helped guide the students with question one they were able to complete the rest of the task. All groups were able to continue the construction of their scientific knowledge regarding ecosystem relationships. Though teams may have had various population numbers for each of the species, their reasoning was similar and scientific with a top-down disturbance. Task six provided the challenge of looking at the same food chain with a mid-level disturbance.

Task six was more challenging for students in two ways. First, the disturbance was mid-level causing students to navigate a food chain in two directions. Secondly, there was not a class discussion after the tasks, thereby removing a scaffold for knowledge construction. At this point the students needed to rely on their prior constructed knowledge as well as the conversations within their group to continue refining their knowledge.

Task seven challenged the students even further by reintroducing the food web from task three coupled with a new scenario and population data. Students were again asked to make sense of how a disturbance in the food web influenced the populations of the other organisms. At this point students have been motivated multiple times by various ecosystem scenarios and have had numerous experiences to construct their knowledge regarding the relationships within an ecosystem. Throughout these tasks students have also refined their knowledge with a new scenario causing the students to think of the disturbance and the ecosystem in a new way. This combination of experiences positioned the students to apply this knowledge to a food web system.

In order to determine if data-rich problem (DRP) tasks affect students' understanding of the nonlinear and sustaining effects of loss of species in an ecosystem two sub-questions needed to be answered. The first round of interviews set out to identify what scenarios about ecological relationships promote cognitive conflict for students. The second round of interviews identified what promotes student construction of knowledge about nonlinear and sustaining effects of the loss of species in an ecosystem. The answers to these sub-questions were then utilized for the implementation of the DRP tasks in the classroom. After completing the DRP task implementation, the final assessment measured what knowledge students held regarding nonlinear and sustaining effects of loss of species in an ecosystem.

Assessment Data Collection and Analysis Methods

After implementation in the classroom the final assessment, Food Web Dynamics Assessment (see Appendix A) was coded using an adapted version of the coding scheme used in Dauer et al (2013) (see Table 10). In Dauer et al (2013) language including "accurate" and "inaccurate" was utilized. To be in line with the philosophical learning approach of this study, these words have been changed to "unscientific" and "scientific".

Table 10: Modified Coding Scheme (detailed version in Appendix E)

Code	Description
0	Missing; question was unanswered
1	"Unscientific", inappropriate
2	Marginally "scientific", ambiguous or poorly worded
3	As "scientific" as it can be expected

Student responses were coded in four categories, linear vs. nonlinear, dissipation vs. persistence, food chain, and energy arrows. Specific examples and descriptions for each category of coding can be found in Appendix E. Table 11 specifies the assessment questions coded for each concept. Some questions were coded in two or more categories based on the knowledge necessary to answer the question.

Table 11: Assessment questions coded for each concept.

Concepts	**Assessment Questions**
Linear vs. Nonlinear	1c, 1e, 2a, 2b, 3c, 3f, 3g, 3h
Dissipation vs. Persistence	2a, 2b, 3c, 3d, 3e, 3f, 3g, 3h
Food Chain	1b, 1c, 1d, 1e, 1f, 1g, 3a, 3b, 3d, 3e
Energy Arrows	1a

Students who did not answer 20% or more (four or more) of the assessment questions were dropped from the analysis. In each category of questions, students who did not answer three of the questions in that category were dropped from analysis within that category. If at least 20% of the students (9 students) received a coded score of three then the question was deemed as useful in this analysis because it revealed that the question was coded at an appropriate level for middle school. All questions met this criterion. Question 1a was the only question that directly asked students what the arrows in a food web represented. The energy arrows category was first coded with this singular question. Since students needed to utilize their understanding of energy arrows throughout the rest of the assessment the students were reanalyzed based on whether they misused the energy arrows. If a student misused the arrows two or less times in the other questions then their answers for those questions were coded based on their reasoning. If the student misused the arrows three or more times, then their answers were coded as a one. Each time that a student misused the arrows in any question on the assessment it was recorded. When reanalyzing a student score for energy arrows the following parameters were applied:

Less than 2 misuses of arrows = score is coded as a 3

Three and four misuses of arrows = score is coded as a 2

More than four misuses of arrows = score is coded as a 1

Once all questions had been coded each student was given an average score to represent their conceptual knowledge in each category. A class average was calculated from each student average. A class average of 2.1 was determined as the baseline for students achieving understanding in each category since this equates to a 70%, a percentage considered to be proficient.

At random, eleven students' assessments (24.4% of total) were provided to a second researcher to determine the consistency of my coded data. Twenty-five percent of the questions were coded by this researcher using the coding scheme in Appendix E. Initial comparison showed 61.8% interrater agreement. After a discussion, the researcher changed 12 of the 21 contrasting codes to agree with the author, the author changed one of the 21 dissimilar codes to agree with the researcher, both the researcher and the author changed to the same code for two of the 21 incongruent codes. The researcher and author were unable to come to an agreement for five of the 21 contrasting codes. After this discussion, coding agreement between researcher and author increased to 89.1% (Cohen's kappa = 0.854).

Implementation of DRP Tasks Results

At the conclusion of the implementation and completion of the DRP tasks students were given an assessment (Appendix A) that included questions similar to the DRP tasks as well as a modified version of the Food Web Relationships task (Appendix B) from the first round of interviews (adapted from Webb and Boltt, 1990). The assessment results reflect students' knowledge regarding nonlinear and sustaining effects of loss of species in an ecosystem. Each response was analyzed and coded utilizing the mentioned adapted coding scheme similar to Dauer *et al*. (2013) (Table 10). An average score for each student for each of the four concepts was determined. A class average for each concept was then calculated. These class averages are summarized in Table 12. A score of 2.1 out of 3 points possible indicates understanding since it corresponds to a 70% (proficiency). Although not all class averages demonstrate a proficient score overall, it does reveal that students are approaching proficiency in all concepts.

Table 12: Summary of class averages in all four concept areas.

Concepts	**Class Averages**
Linear vs. Nonlinear	1.97
Dissipation vs. Persistence	2.12
Food Chain	2.09
Energy Arrows	2.78

Linear vs. nonlinear written responses. Assessment analysis shows that students are approaching proficiency in their ability to navigate nonlinear relationships within a food web with a class average of 1.97. Individual student average scores show half of the students demonstrating some level of scientific reasoning with a score of 2.0 or higher (Figure 3). However, only 17 of 44 students scored a proficient average score of 2.1 or higher.

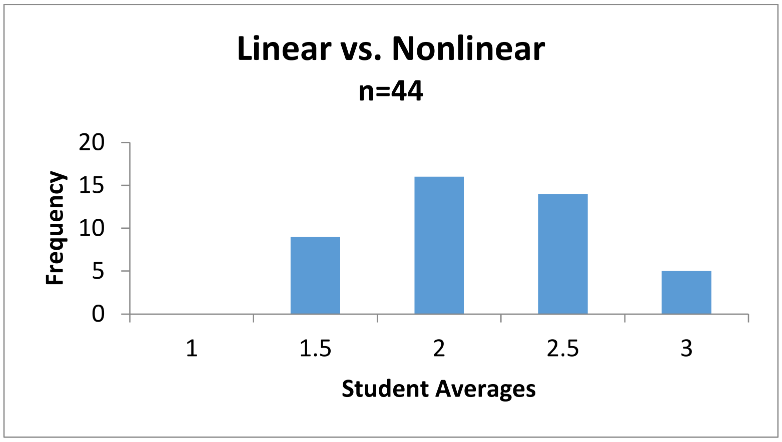

Figure 3: Histogram of student averages for questions pertaining to the linear vs. nonlinear concept.

Upon further analysis, students that scored below an average of 2.0 (n=21) seemed to have difficulty in this area because of four main themes. In question 1c ("The trout population is: (i) increasing, (ii) decreasing, (iii) staying more or less the same. Why do you think it has changed in this way?") and 1e ("Why do you think the Garter Snake population has not really changed?") students demonstrated unscientific reasoning by ignoring the scenario and information provided when answering the questions. Instead, students made up their own scenario as to why population numbers may change. This occurred with 13 of 21 students with a score of less than 2.0. Another unscientific theme that students demonstrated in these questions was only considering the predator as influential in affecting population numbers (6 of 21).

The other two unscientific themes were primarily seen in Question 3c, 3f, and 3g (where nonlinear reasoning was assessed). The most common unscientific answer was that the change in one population did not affect another because they were not connected (on different food chains within the food web). This occurred with 11 of 21 students. The other unscientific theme noticed in these questions was that students were able to state that populations were connected (even though on different food chains within the food web); however, they were unable to explain beyond this how a change might affect a different population (6 of 21 students). Some of these students' difficulty arose from consistently tracing the arrows backwards, as "eats" instead of "providing energy" (3 of 21 students). These four common errors highlight the areas where students still had limited knowledge regarding nonlinear relationships.

Dissipation vs. persistence written responses. Assessment analysis shows that overall, students are proficient with a class average of 2.12. Students recognized that changes in an area of a food web do not dissipate the further away a population is from the disturbance; that instead, persistence is possible. Of the 44 students, 47.7% of students showed proficiency. Furthermore, 31.8% of students scored an average score of 2.5 or higher; thereby demonstrating their clear ability to use scientific reasoning when answering questions with the dissipation vs. persistence concept highlighted (Figure 4). Questions 2a and 2b provided a scenario and population data for a food web over time. They probed student reasoning in nonlinear relationships and the possibility of persistent affects from a disturbance. For these questions only four students showed unscientific reasoning, earning a score of less than 2. Areas of difficulty were isolated within questions 3c-3h. These questions also assessed student understanding of nonlinear relationships and persistent affects from a disturbance. However, the major difference is that they questions pertained to a food web that had only letters representing organisms instead of specific species. Also, these questions did not have data of population values for students to reference.

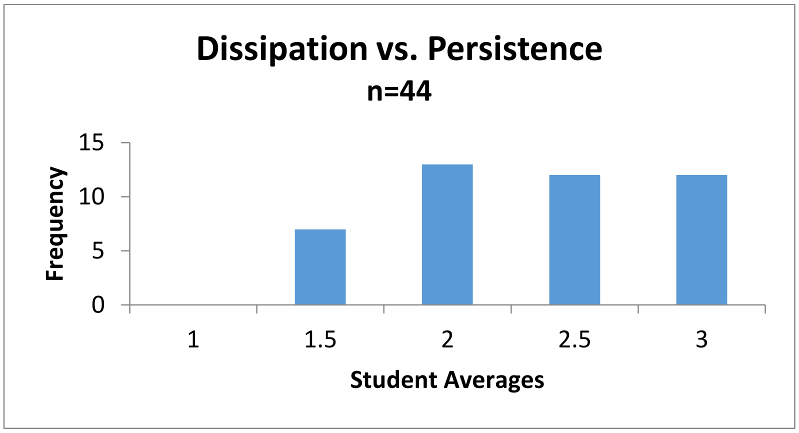

Figure 4: Histogram of student averages for questions pertaining to the dissipation vs. persistence concept.

Similar to the linear vs. nonlinear concept, there were some unscientific themes that emerged in student responses that caused students to be coded as a 1 (unscientific). The themes were again pulled from students with an average score of less than 2.0 (n=19). The main unscientific theme that caused students to be scored a 1 was not seeing connections between different populations. If a student does not consider the populations effecting one another (because they are not connected) then they essentially see the effect of a disturbance to dissipate; therefore, they were coded as a 1 (9 of 16). In other words, students seeing food web relationships as linear will not be able to see how a disturbance can be persistent in a food web. Another theme leading to unscientific reasoning was consistently reading the arrows backwards in the food web. Students described connections and described persistence; however, their consistent use of the arrows as “eats” caused them to earn a score of 1 (6 of 16). Lastly, 5 of 16 students described connections as well as persistence; however, their reasoning was unscientific because they were unable to continuously trace the pathways within the food web. Overall, these themes show how linear vs. nonlinear essentially supports whether or not students can recognize persistence in a food web. Since these themes emerged solely in questions 3c-3h, where no actual organisms were utilized, this may also show that these students are unable to read a food web without the anchor of organism background knowledge.

Food chain written responses. Assessment analysis of the food chain concept questions show that students are just shy of being proficient in their scientific understanding of food chains with and average class score of 2.09. Figure 5 demonstrates the range of the individual student averages. Even though the class average describes the class as overall not proficient, of the 45 students coded for the food chain concept, the majority of students earned a proficient average score of 2.1 or higher (n=26).

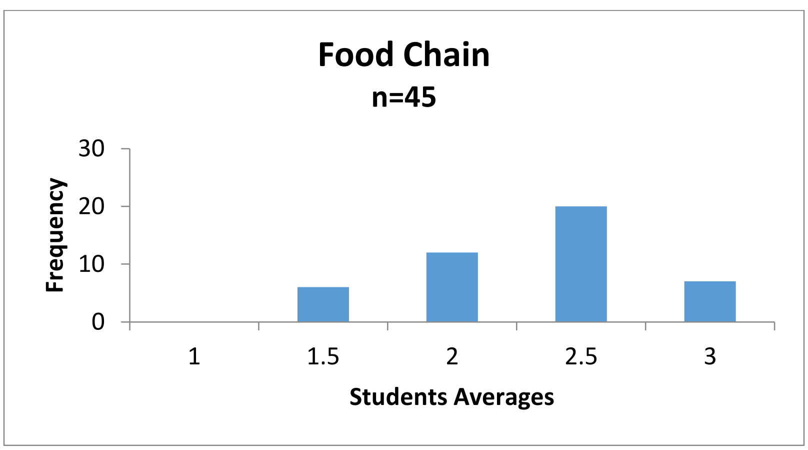

Figure 5: Histogram of student averages for questions pertaining to the food chain concept.

Even though most students demonstrated proficiency in the food chain concept, there were still 16 students that scored below an average of 2.0. These students demonstrated an overall unscientific understanding of food chains. Upon analysis of these 16 students four main themes emerged as the basis for their difficulty. The most common difficulty for the food chain questions was that students simply did not consider all the information provided. This was primarily demonstrated in questions 1b-1g. Fifteen of these students essentially ignored the scenario described. For example, one student described the trout population as "[decreasing] because there are more people hunting it and there are things still eating it in the ecosystem as well". There was no mention of humans in the scenario provided for this question. The reasoning these students utilized in their answers did not show scientific reasoning. These same series of questions also showed students' answers considering the predator as the sole reason why a population may or may not be affected by a disturbance (6 of 16). These students either only accounted for the population numbers of the predator or they specifically stated that since there were fewer predators than prey, the prey population was going to increase. For example, one student described the trout population as "[increasing] because the things that eat it are not increasing by that much". This student only considered the predator of the trout instead of considering the scenario given; the trout's competitor drastically decreased. Another student described the Garter Snake population not really changing because "their predator Great Blue Heron population is low and hasn't really change[d] much either". Not only did this student ignore the scenario that the Garter Snakes have essentially lost one prey species while the other increased, they also consider a smaller predator than prey population to not affect the prey population.

The third theme was revealed within the answers to questions 3a-3h. This series of questions again showed students tracing arrows backwards, reading them as "eats" instead of “provides energy to”, and causing the reasoning in their answer to be unscientific (6 of 16). Lastly, 6 of 16 students quite simply did not show understanding of a food chain. They demonstrated this unscientific understanding by not tracing a food chain pathway appropriately. Of these 6 students, 4 were only able to trace a pathway in a unidirectional pattern. For example, when one student was asked how an increase in the population H (predator) would affect population F (prey) the student stated, “This would not affect that much [because] population F doesn’t eat population H”. This student was only able to move from prey to predator. He was not able to describe how a change in a predator population may affect the prey population. Overall, the majority of students developed scientific reasoning of food chain dynamics. However, the area that students showed the most difficulty was an inability to utilize multiple sources of information when determining the answer to a question. This does not demonstrate that they cannot understand a food chain, but instead that their limit of information synthesis may have been reached.

Energy arrows written responses. Question 1a was the only question that directly asked what the arrows in a food web represented. Of the 43 students that answered the question, only three students scored a 1. All of the other 40 students scored a 3, stating that the arrows represented energy. However, since students needed to utilize their understanding of the arrows to answer the rest of the questions in the assessment their scores were modified based on how well they continued to demonstrate their knowledge of the arrows (see Appendix E). These overall scores are shown in Figure 6. Of the 45 students that were coded for the energy arrows concept, only two students scored a 1. The number of students that scored a 1 dropped from three to two because one of the students answered question 1a unscientifically yet utilized the arrows scientifically for all but one other question for rest of the assessment. As such, her score was modified to reflect scientific understanding of arrows. Once these overall scores had been determined the class average score was calculated as 2.78. Students clearly have scientific understanding of arrows representing the transfer of energy in a food web.

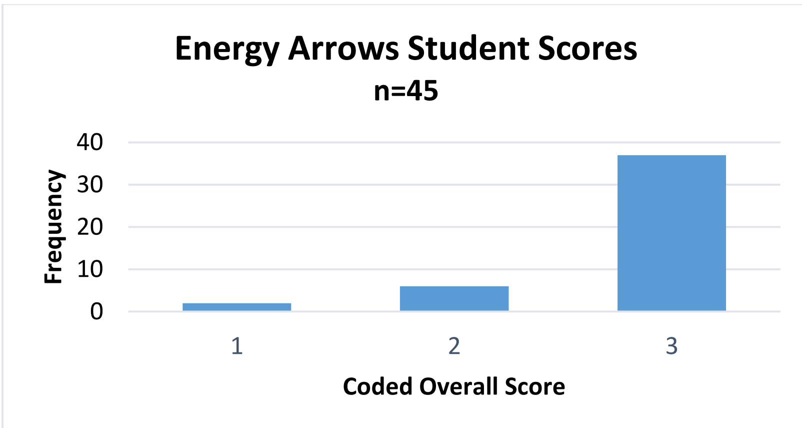

Figure 6: Graph of overall student scores for questions pertaining to the energy arrow concept.

Summary. The assessment results show mixed results in student understanding of food web dynamics. The questions assessing the student knowledge were focused on two main areas, conceptual knowledge and factual knowledge. Conceptual knowledge pertained to nonlinear vs. linear relationships and dissipation vs. persistence. The factual knowledge was assessed by looking at students understanding of food chains and energy arrows. Though students did not show proficiency in all four areas assessed, it seems that students are at least approaching proficiency in their understanding of food web dynamics.

Discussion

This study focused on designing and testing DRP tasks rooted in real-world ecosystem scenarios. This provided students the opportunity to construct their knowledge of ecosystem dynamics by actively participating in their learning. The construction of the DRP tasks satisfied the goal of design-based research by refining the DRP tasks through research, construction, and practice of the tasks (Collins et al, 2004; Design Based Research Collective, 2003; Fortus et al, 2004; Plomp, 2009). The data collected from the assessment provides some answers to the research question, "Does completion of a data-rich species task effect student's understanding of the nonlinear and sustaining effects of loss of species in an ecosystem?" The results demonstrate that the process of design-based research, while utilizing the Learning-for-Use framework on the topic of food web dynamics, is useful in supporting students to approach if not reach proficiency in their scientific reasoning.

The interviews conducted at the beginning of this study demonstrated that students held conceptions about food webs and ecosystems that were synonymous with current literature; complex relationships are linear instead of cyclical or systemic (Barman, Griffiths, & Okebukola, 1995; Barman & Mayer, 1994; Griffiths & Grant, 1985; Grotzer & Basca, 2003; Hogan, 2000; Webb & Boltt, 1990; White, 1997; White, 2000), changes do not occur in a predator population if the prey population size changes (Barman, Griffiths, & Okebukola, 1995; Griffiths & Grant, 1985), and proximity effects whether or not a student can describe the result of the disturbance scientifically (Barman, Griffiths, & Okebukola, 1995; Barman & Mayer, 1994; Griffiths & Grant, 1985; Webb & Boltt, 1990). The initial tasks used in the first round of interviews supported these findings. The tasks were modified and utilized in the second round of interviews. This second round showed improvement in student ideas about relationships within ecosystems. This improvement continued in the implementation of the tasks in the classroom.

The second round of interviews demonstrated that student knowledge construction improved compared to the first round of interviews. It was determined that the addition of working collaboratively in a team on the DRP tasks would further improve knowledge construction and therefore the tasks from the round 2 interviews were implemented in a 7th grade classroom. The assessment given after the completion of the classroom DRP tasks indicate that students are either approaching scientific understanding of ecosystem dynamics (linear vs. nonlinear = 1.97 and food chains = 2.09) or have reached proficiency (dissipation vs. persistence = 2.12 and energy arrows = 2.78). These conclusions as well as the observational outcomes from the implementation of the tasks in the classroom supported the refinement of the final DRP tasks (see Appendix D).

The first major refinement came in allowing students to continue to collaborate with other teams for each task. During the original implementation, the students had progressively less and less class discussion with each task and therefore less support in their knowledge construction. The first four tasks allowed for the teams to have whole class discussion about their ideas. This discussion allowed for students to hear the reasoning of other teams; providing reflection of various ideas in constructing their own knowledge. For the last three tasks the students had only their teammates to collaborate with and negotiate their ideas and conceptions; therefore, if unscientific ideas emerged, the likelihood of these ideas being modified diminished because they only had access to at most three other student conceptions. The justification for decreasing the discussions at the time of the implementation was to provide a glimpse into what students were able to do from the tasks alone. In an everyday classroom environment without the intention of data collection, the use of collaboration and class discussions throughout the tasks are encouraged.

Other refinements to the DRP tasks consisted of excluding the Food Chain Construction task and the Bottom-Up DRP task. The results from the Food Chain Construction task demonstrated that all groups but one were able to navigate the scientific construction of a food chain. Therefore, it is not seen as necessary in the construction of nonlinear relationships in an ecosystem as students have already constructed this knowledge and demonstrated as such even without the scaffold of working within an ecology unit. Task four was excluded from the final version because it seemed repetitive. There were three tasks that utilized the same food chain with three different scenarios. With the increased support of collaboration among groups and with the class it was deemed as unnecessary to have three tasks so similar. Instead, the more complex Top-Down DRP task and Mid-Level DRP task were maintained in the final refinement of the DRP tasks.

Though the results showed that learning occurred from the implementation of the DRP tasks, there were multiple limitations to this study. Since the purpose of this study was to utilize design-based research to construct DRP tasks, there was no pre- or post- assessment conducted. It is therefore hard to determine the true scope of how students' knowledge has changed or been influenced by the DRP tasks. Since previous studies showed that students did not have scientific understanding of ecosystem relationships (Barman & Mayer, 1994; Barman, Griffiths & Okebukola, 1995; Griffiths & Grant, 1985; Grotzer & Basca, 2003; Hogan 2000; Webb & Boltt, 1990; Webb & Boltt, 1990; White 1997; White, 2000), one could assume that the 7th grade students in this study also did not hold scientific conceptions prior to the implementation of the tasks. Nevertheless, it is hoped that future research-educators will implement these tasks comparing student conceptions before and after. Another limitation is that this study was conducted at a single school site and implemented as stand-alone tasks (not within a unit of ecosystem functioning). By expanding these tasks to various schools a more complex understanding of student knowledge of ecosystem dynamics and the effectiveness of the DRP ecosystem tasks could be determined. It is also unclear how the incorporation of these tasks into an ecology unit would support student knowledge construction. By using the tasks outside of an ecology unit, the students were being asked to make connections between their prior learning experiences (up to a year prior) and the current DRP tasks. There was no build up to these tasks nor were there more robust learning experiences centered around ecosystems.

The DRP tasks could also be expanded to areas that this study did not focus on. For example, though energy units were included in the Food Chain Comparison task, the tasks and questions did not explicitly have the intention to draw out student understanding of energy flow through an ecosystem and what happens to the ecosystem energetically speaking with the loss of species. Expanding on this idea can also support another area that students sporadically struggled with: the need for more producers compared to consumers in an ecosystem. Students showed unscientific understandings at times when they spoke about predator population numbers not influencing prey population numbers because there were less predators compared to prey. In other words, if there are fewer predators than prey, how can those few predators (in comparison) really have a major effect on a prey species that has such higher population numbers? Students did not make the connection that the energy available decreases as one moves through a food web and therefore the lower trophic levels have to have higher population numbers in order to support the higher trophic levels. Without more producers and primary consumers, we would have an ecosystem collapse. While the Food Chain Comparison task did lead students to notice the changes in the energy transferred, this study focused more on the general relationships and it did not force students to make this connection specifically. Future studies should expand on this concept.

Through design-based research and using the Learning-for-Use framework this study demonstrates that students are able to learn by first being motivated by an interesting problem or scenario, then constructing their knowledge through the use of data, and finally refining their conceptions through activities that build upon the prior tasks. This type of learning environment allows students to take an active role in their learning instead of passively listening as is often the case with direct instruction. The Next Generation Science standards are described as moving away from “students will know” to what students “can do” to demonstrate their knowledge. This move in student learning may address the challenge of students thinking linearly instead of systematic by incorporating cross-cutting concepts that scientists utilize to understand science (NGSS Lead States, 2013). The DRP tasks designed for this study support these cross-cutting concepts by incorporating patterns, cause and effect, system and system models, energy and matter, and stability and change. Not only have these tasks supported the move to NGSS, but the students themselves described their experiences as positive and engaging: “At first I had the most basic ideas about how one thing can affect another but after the last task I learned that, just like in the human body, if one thing fails, it is likely that everything else in the chain will fail”. Students also described their experience as a way to view a problem in a different way: “I found these tasks very interesting and fun, also it was interesting to know what other people thought of these things and how they see things in a different point of view that can be totally different from my perspective.” One student summed up the experience nicely: “Yes I think it helped me learn, because by doing the tasks I got to see how one thing affects another, and what helped a lot is different people have different opinions on things and you disagree then you get deeper into the tasks and that makes you think more.” Clearly the students enjoyed the experience and were therefore motivated to continue constructing their knowledge throughout the tasks.

It is hoped that research into the effectiveness of these DRP tasks continues with other educator-researchers, continuing the refinement in order to reach a compelling and effective intervention aligned with NGSS and focused on students being active members in the construction of their knowledge. Without continued research in this area of student learning and causal relationships in ecosystems our students will be stunted in developing their knowledge and will continue to see the relationships in an ecosystem as linear. When students have opportunities to construct their scientific understandings through active learning, they can become citizens capable of making informed and responsible decisions based on their knowledge of the dynamic cause and effect cyclical relationships that exist in nature.

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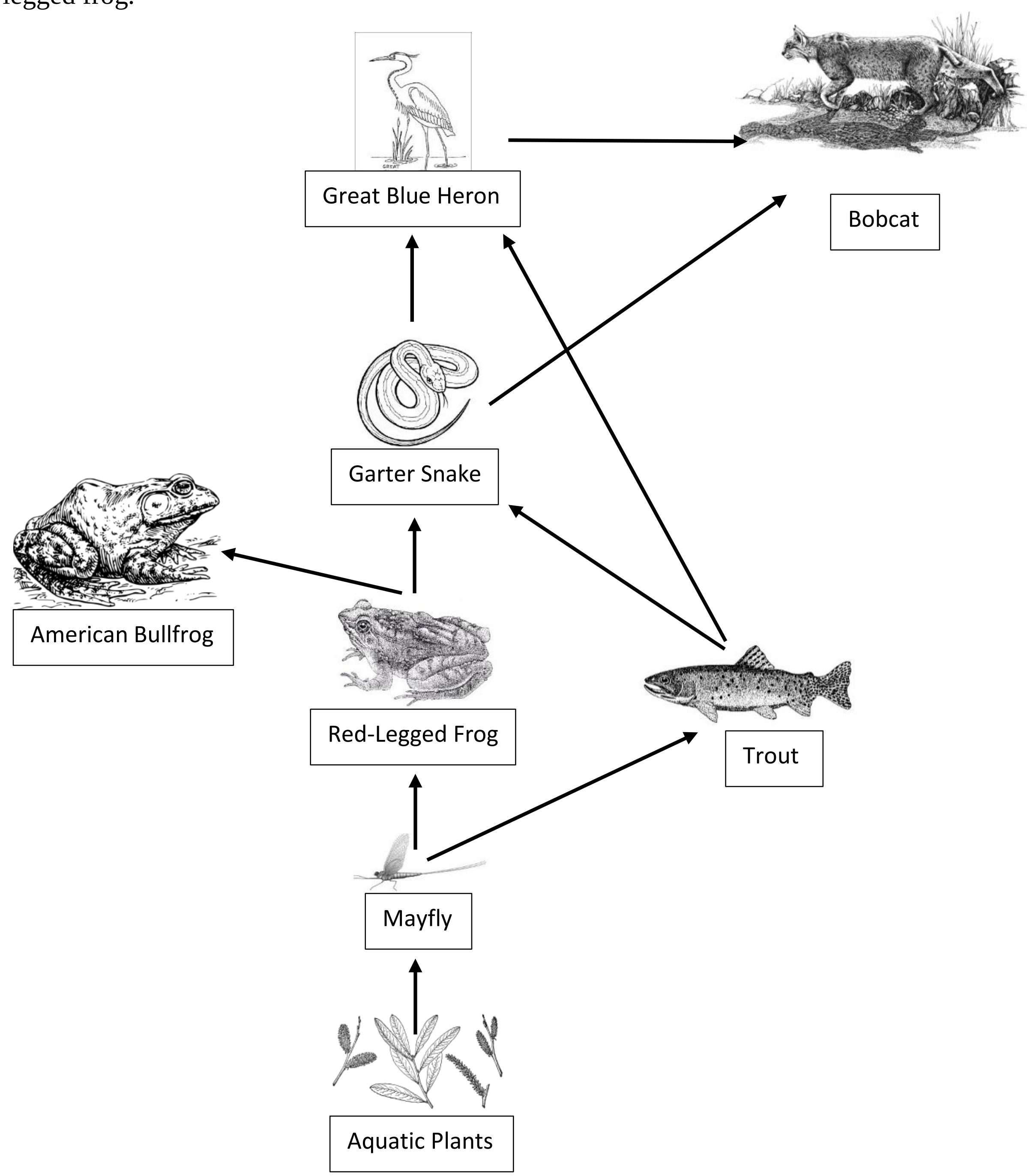
APPENDIX A

Food Web Dynamics Assessment

1. Below is a food web of an ecosystem in a shallow freshwater stream in California. Years ago there was a drastic decline in the trout population. Humans decided to add more trout to the stream. However, they accidentally also transferred American Bullfrog tadpoles that eventually grew into adult Bullfrogs. This stream was not the natural habitat for the Bullfrog. Overtime there was a drastic decline of the red-legged frog.



a. What do the arrows represent in the food web?

	Population size over years				
Species	0 years	1 year	2 years	3 years	4 years
Aquatic Plants	83,000	83,050	83,010	83,060	83,040
Mayfly	2,750	2,800	2,760	2,780	2,755
Red-legged Frog	225	153	113	76	8
Garter Snake	50	52	51	53	51
Great Blue Heron	10	11	12	13	14
Trout	600	670	715	750	810
Bobcat	3	3	3	4	4
American Bullfrog	0	2	3	4	6

Red-legged Frog and American Bullfrog population values inspired by Lawler, S.P. et al (1999).

b. Overtime there was a drastic decline of the red-legged frog. Why do you think it declined?

What do you predict will happen to the population in years 5 and 6? Why do you make that prediction?

c. The trout population is (circle one): (i) Increasing, (ii) Decreasing, (iii) Staying more or less the same. Why do you think it has it changed in this way?

What do you predict will happen to the population in years 5 and 6? Why do you make that prediction?

d. Why do you think the Aquatic Plant population has not really changed much?

e. Why do you think the Garter Snake population has not really changed?

f. The Heron population is (circle one): (i) Increasing, (ii) Decreasing, (iii) Staying more or less the same. Why do you think it has changed in this way?

What do you predict will happen to the population in years 5 and 6?

g. The American Bullfrog population is increasing. Why do you think it has changed in this way?

What do you predict will happen to the population in years 5 and 6? Why do you think this?

2. After tracking the ecosystem for four years, scientists found that the American Bullfrog has led the red-legged frog to extinction. This permanently effected the ecosystem. At first, the trout seemed to be increasing in population. However, due to the recent effects of climate change, severe drought has stricken this ecosystem, drying up much of the river. The trout now have a smaller area to live in. For the next two years, the population numbers continue to be recorded for this ecosystem.

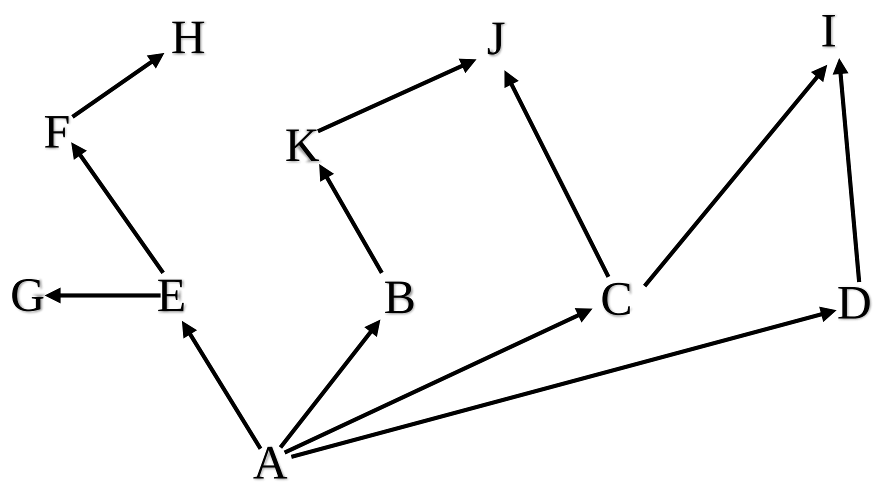
   a. What do you think will happen to this ecosystem over the next two years? Fill in the 3rd & 4th columns in the table below with your predictions of the population size of each of the species for year 8 and your reason for that prediction (in rows without an "X").

	Population size over years		Prediction	Reason for that prediction
Species	5 years	6 years	8 years	
Aquatic Plants	41,500	20,760		
Mayfly	5,500	10,800		**X**
Red-legged Frog	0	0		**X**
Garter Snake	25	12		
Great Blue Heron	7	4		
Trout	400	210		
Bobcat	2	1		
American Bullfrog	0	0		**X**

   b. Do you think this ecosystem will continue to be functioning if this drought continues? Why or why not?

3. Take a minute to look over this food web. Below are a series of questions about different letters in the ecosystem and how the population of one letter effects the population of another letter.

Figure 1. The Food Web (Webb& Boltt, 1990)



Questions are modified from Webb & Boltt, 1990.

a. If there was a sudden decrease in population F, how might this affect the size of population H? (Circle one): (i) Increase (ii) Decrease (iii) Stay more or less the same. Explain your answer.

b. If there was a sudden increase in population H, how might this affect the size of population F? (Circle one): (i) Increase (ii) Decrease (iii) Stay more or less the same. Explain your answer.

c. If there was a sudden increase in population G, how might this affect the size of population F? (Circle one): (i) Increase (ii) Decrease (iii) Stay more or less the same. Explain your answer.

d. If there was a sudden increase in population B, how might that affect the size of population J? (Circle one): (i) Increase (ii) Decrease (iii) Stay more or less the same. Explain your answer.

e. If there was a sudden decrease in population J, how might that affect the size of population B? (Circle one): (i) Increase (ii) Decrease (iii) Stay more or less the same. Explain your answer.

f. If there was a sudden increase in population I, how might that affect the size of population K? (Circle one): (i) Increase (ii) Decrease (iii) Stay more or less the same. Explain your answer.

g. What effect will the extinction of C have on H?

h. True or False: A change in population I will effect population H. Explain your answer.

APPENDIX B

Round One Interview Protocol

Topic: Student understanding of food web dynamics and the loss of species effects within the ecosystem.

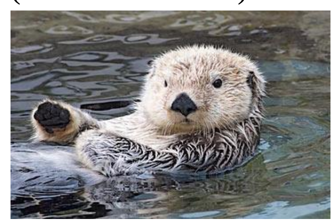
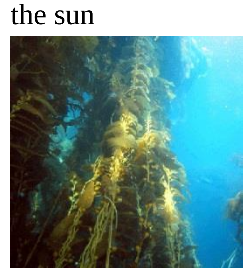
Goal: To know the level of understanding that students have regarding food webs and the resulting effects of changes within a food web. I want to know if they are able to connect the effects of a loss of species to the entire ecosystem.

Introduction Script:

Thank you for helping me with my research today. I will be asking you some questions and I am interested in your honest answers in your own words. If you don't understand something just let me know. I really want to find out what you think about food webs. I am not interested in right or wrong answers. Your ideas will be used to help understand how people learn so that researchers, including myself, can develop better ways of helping people to learn about ecosystems and food webs.

Task 1: Card Sort

(All cards are laid out on the table) Share any relationships you can find between these cards.

The Ocean 	The Sun 	Sea Otter – a small marine mammal that feeds in the kelp forest on invertebrates like urchins, sea stars, and mollusks (snails and mussels) 
Purple Sea Urchin – an invertebrate that primarily feeds on kelp 	Knobby Sea Star – an invertebrate that feeds on other invertebrates 	Kellet's Whelk (snail) – a mollusk that feeds on other invertebrates 
Wavy Turban Snail – a mollusk that feeds on kelp and plankton 	California Mussel – a mollusk that feeds on plankton 	Octopus – feeds on mollusks 
Plankton – microscopic algae or bacteria that gets energy from the sun 	Wolf Eel – feeds on urchins and mollusks 	Giant Kelp – algae that attaches to the bottom of the ocean on rocks, can grow to be over 100 feet tall, and gets energy from the sun 

Follow-up Questions:

- Does _________ eat anything else besides _____________?
- What if ___________ has a decrease/increase in its population, what might happen?
- If ______________ decreases/increases in its population, will it affect the population size of _____________? Explain why you think that.
- What if a predator of snails and sea stars were introduced to this ecosystem, what could happen?
- Do any cards seem to play a bigger/lesser role in this ecosystem than the others? Why?
- What would happen if _______________ becomes extinct, what would happen to the ecosystem?

Task 2: Food Web Relationships

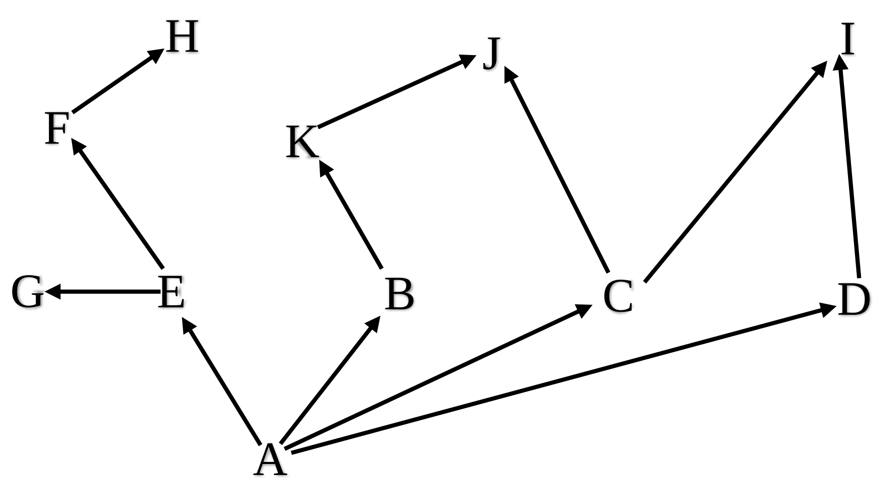


Figure 1. The Food Web (Webb & Boltt, 1990)

Take a minute to look over this food web. I am going to ask you a series of questions about different letters in the ecosystem and how the population of one letter effects the population of another letter.

Questions (Table 1, Webb & Boltt, 1990):

- What effect will a sudden decrease in population F have on the size of population H? Explain your answer.
- What effect will a sudden increase in population H have on the size of population F? Explain your answer.
- What effect will a sudden decrease in population E have on the size of population H? Explain your answer.
- What effect will a sudden increase in population G have on population F? Explain your answer.
- What effect will a sudden decrease in population H have on population E? Explain your answer.
- Write down the letters indicating populations though which an increase in population A is passed on to population J. Explain your answer.
- What effect will a sudden increase in population B have on population J? Explain your answer.
- What effect will a sudden decrease in population J have on population B? Explain your answer.

What effect will a sudden increase in population I have on the size of population K? Explain your answer.

APPENDIX C

Round Two Interview Protocol

Topic: Construction of student knowledge of food web dynamics and the loss of species effects within the ecosystem.

Goal: To know the level of understanding and the construction of knowledge that students have regarding food webs and the resulting effects of changes within a food web. I want to know if they are able to construct knowledge of the effects of a loss of species to the entire ecosystem.

Introduction Script:

Thank you for helping me with my research today. I will be asking you some questions and I am interested in your honest answers in your own words. If you don't understand something just let me know. I really want to find out what you think about food webs. I am not interested in right or wrong answers. Your ideas will be used to help understand how people learn so that researchers, including myself, can develop better ways of helping people to learn about ecosystems and food webs.

Task 1: Food Chain Construction

(All cards are laid out on the table)

Take a moment to look at and read over the cards and arrows. Whales eat sea otters, sea otters eat sea urchins, and sea urchins eat kelp. Construct a food chain using these pieces.

1. Have students explain their thinking as they are arranging the food chain.
2. Why are the arrows pointing in the direction you placed them?

Killer Whale

Provides energy

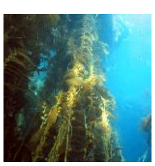
Sea Otter

Provides energy

Sea Urchin

Provides energy

Giant Kelp



Task 2: Food Chain Comparison

Killer Whale

1 gram = 0.6 units of energy

Sea Otter

1 gram = 4 units of energy

Sea Urchin

1 gram = 27 units of energy

Giant Kelp

Sea Lion

1 gram = 1.15 units of energy

CA Sheephead

1 gram = 4 units of energy

Sea Urchin

1 gram = 27 units of energy

Giant Kelp

Sea Lion

1 gram = 1.15 units of energy

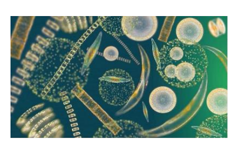
CA Sheephead

1 gram = 7 units of energy

CA Mussel

1 gram = 45 units of energy

Plankton



Energy units inspired by Griffiths, D. (1977) and Williams, T. et al (2004).

Directions and Questions:

Take a moment to look at and read over the cards and arrows. These are three food chains in a marine ecosystem.

1. What are some similarities between each food chain? What is happening with the energy?
2. What are some difference between each food chain? Are there differences regarding the energy?
3. What do the arrows represent? What patterns do you notice when moving from one arrow to the next?
4. What if ___________ has a decrease/increase in its population, what might happen?
5. If ______________ decreases/increases in its population, will it affect the population size of _____________? Explain why you think that.
6. What would happen if sea otters become extinct, what could happen to the ecosystem?
7. If the sea urchin population drastically decreases, what could happen to the ecosystem?

Task 3: Food Web Construction

Take a moment to look at and read over the cards. These are different populations of organisms that make up a food web in a marine ecosystem. Spread out the organisms on this piece of paper and draw a food web that makes sense to you. Explain your thinking as you are arranging the pieces and drawing the arrows.

Giant Kelp –sea urchins eat this. 	**Sea Urchin** – Sea Otters and CA Sheephead eat this. 	**Sea Otter** – Killer Whales eat this. 
CA Sheephead – Sea lions eat this. 	**CA Mussel** – Sea Otters and the CA Sheephead eat this. 	**Killer Whale** – needs 240,271 units of energy per day. 
Steller's Sea Lion – Killer Whales eat this. 		

Killer Whale energy needs converted from Williams, T. et al (2004)

Follow-up Questions:

1. What do the arrows represent? Why did you arrange them in the direction that you did?
2. What if ___________ has a decrease/increase in its population, what might happen?
3. If ______________ decreases/increases in its population, will it affect the population size of _____________? Explain why you think that.
4. What if another predator of sea lions were introduced to this ecosystem, what could happen?
5. Do any cards seem to play a more important or less important role in this ecosystem than the others? Why?
6. What could happen if sea otters become extinct, what might happen to the ecosystem?
7. If the sea urchin population drastically decreases, what would likely happen to the ecosystem?

Task 4: Bottom-Up DRP

In a marine environment, scientists noticed that heavy winter storms caused the kelp forests to be partially destroyed. In order to replenish the kelp forest, these scientists decided to help regrow kelp in this environment. Over a span of 20 years they performed numerous SCUBA dives to attach young kelp to the rocks in this environment. After completing all of their restoration efforts scientists were happy to see that they were successful in the regrowth of kelp in this environment. Look over the food chain and the data table to predict what you think happened to the other populations.

Kelp → **Urchin** → **Sea Otter** → **Killer Whale**

	Population Size Over Years				
Species	0 years	5 years	10 years	15 years	20 years
Kelp	124,000	200,000	257,000	330,000	400,000
Urchin	13,000				
Sea Otter	124	191		324	391
Killer Whale	12		25		34

Questions:

1. What could be some possible population numbers for the urchins over time? Why do you think that?
2. What could the population of killer whales be at 5 years? Why do you think that?
3. What about at 15 years? Why do you think that?
4. What could the population of sea otters be at 10 years? Why do you think that?

Task 5: Top-Down DRP

In a different marine environment scientists noticed the killer whale population decreasing over 20 years until there were no longer any killers whales in this environment. Scientists were unclear what caused this extinction. Many locals believed that illegal whale hunting occurred during these years without anyone knowing. Use what you know about the relationships between these organisms and the data table below to predict what you think will happen to the populations.

Kelp → **Urchin** → **Sea Otter** → **Killer Whale**

	Population Size Over Years				
Species	0 years	5 years	10 years	15 years	20 years
Kelp	124,000		213,000		332,000
Urchin	13,000				
Sea Otter	124		279	336	
Killer Whale	12	8	4	2	0

Questions:

1. What could be some possible population numbers for the urchins over time? Why do you think that?
2. What could the population of kelp be at 5 years? Why do you think that?
3. What about at 15 years? Why do you think that?
4. What could the population of sea otters be at 10 years? Why do you think that?
5. What do you think will happen in another 20 years? Why do you think that?

Task 6: Mid-Level DRP

One result of climate change has been that winter storms have been bigger than ever in some places that had not experienced such types of storms before. People living in these areas are looking for the newest trend in winter clothing; fashionable and warm. Sea Otter fur is extremely warm and soft. As a result, in one marine environment, the Sea Otters were driven to extinction by humans hunting them for their fur pelts to make the newest fur coat fashion. Use what you know about the relationships between these organisms and the data table below to predict what you think will happen to the populations.

Kelp → **Urchin** → **Sea Otter** → **Killer Whale**

	Population Size Over Years				
Species	0 years	5 years	10 years	15 years	20 years
Kelp	124,000				
Urchin	13,000		27,000		63,000
Sea Otter	124	58	21	0	0
Killer Whale	12				

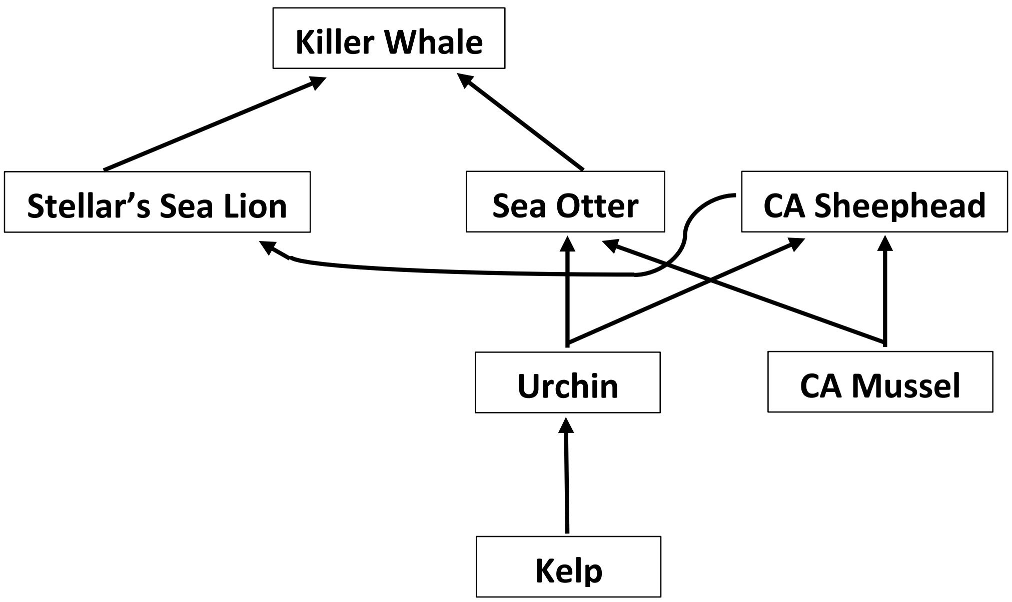
Questions:

1. What could be some possible population numbers for the killer whales over time? Why do you think that?
2. What could be some possible population numbers for the kelp over time? Why do you think that?
3. What could the population of urchin be at 5 years? Why do you think that?
4. What about at 15 years? Why do you think that?
5. Can the ecosystem continue to survive in this way? Why do you think that?
6. After 20 years, sea otters were reintroduced to the ecosystem. Would there be any effects on the ecosystem populations?

Task 7: Food Web DRP

(Only years 0 thru 20 are shown to students for the first part of the task)

In one marine ecosystem, there was a sudden decrease in Sea Lions for an unknown reason. The populations of the rest of the food web were recorded to determine the effects of that change. Using the food web and the data table, try to make sense of what is occurring in this ecosystem.



	Population size over years						
Species	0	5	10	15	20	25	30
Kelp	28,500,000	28,800,000	28,600,000	28,400,000	28,700,000	20,000,000	6,700,000
Urchin	4,670	4,400	4,780	4,500	4,200	6,600	14,500
Sea Otter	154,000	92,000	46,000	29,000	11,000	4,000	120
Killer Whale	170	172	171	173	172	168	169
Sea Lion	70,000	40,000	13,000	12,000	8,000	5,300	3,500
CA Sheephead	136,000	198,000	244,000	261,000	279,000	124,000	42,000
CA Mussel	1,800,000	1,840,000	1,830,000	1,860,000	1,850,000	2,340,000	4,800,000

Killer whale, sea lion, and sea otter population values inspired by Williams, T. et al (2004).

Kelp population values inspired by van Tamelen, P.G. & Woodby, D. (2001).

1. What do you see happening with the sea otter population? Why do you think the sea otter population has changed the way it has? What do you predict will happen in the next 20 years to the sea otter?
2. What do you see happening with the Sheephead population? Why do you think the Sheephead population has changed the way it has? What do you predict will happen to the sheephead in the next 20 years?
3. Why do you think the killer whale population has not really changed?
4. Why do you the sea urchin population has not really changed?
5. Why has the kelp population not really changed?
6. Why has the Ca Mussel population not drastically changed?
7. Do you think the ecosystem can survive the next 20 years based on these 20 years? In other words, do you think all the organisms in this ecosystem will still be around after another 20 years? Why or why not?

(Students are now shown years 25 thru 30)

After tracking the ecosystem for 20 years, the Sheephead population is found to be abundant. Fisherman have noticed this abundance and begin fishing the Sheephead without any regulations. For the next 10 years, the population numbers continue to be recorded for this ecosystem.

1. What do you think will happen to this ecosystem over the next 10 years?
2. Can the ecosystem still exist without regulation of fishing? Why or why not?

APPENDIX D

Final Version of DRP Tasks

(All instructional days are assumed to be ~50 minute periods.)

<u>DAY 1</u>

Task 2: Food Chain Comparison (in groups)

(Each team is provided a laminated copy of the food chains and the follow-up questions. Teams complete the task on a poster paper.)

Projected on the board:

Take a moment to look at and read over the cards and arrows. These are three food chains in a marine ecosystem.

1. On your poster paper, create a T-chart for similarities and differences.
    a. What are some similarities between each food chain?
    b. What are some differences between each food chain?

2. On your poster, answer the questions regarding the food chains.

The class should discuss student ideas at the completion of the task. A similarities and differences list can be generated on the board for the class to see as the discussion occurs. Student answers for the questions should also be discussed. It is important to use questioning strategies to highlight student ideas that demonstrate connecting the food chains together instead of strictly discussing them as individual food chains. For example, question six directly asks students if a change in a population in one food chain can affect a population in another. It is important for students to recognize that these food chains are interconnected. Question seven and eight ask about the changes to the ecosystem. Students should be pushed to explain the effects to the entire ecosystem, not just the species within an individual food chain.

Questions:

Take a moment to look at and read over the cards and arrows. These are three food chains in a marine ecosystem.

1. What do the arrows represent?
2. What is happening with the energy when moving from one arrow to the next?
3. When looking at the three food chains, are there differences regarding the energy? Explain.
4. What if the plankton has a decrease in its population, what might happen?
5. What if the killer whale has an increase in its population, what might happen?
6. What if the sea lion population drastically decreases in its population, will it affect the population size of the sea otter? Explain why you think that.
7. What would happen if sea otters become extinct, what could happen to the ecosystem?
8. If the sea urchin population drastically decreases, what could happen to the ecosystem?

Killer Whale

1 gram = 0.6 units of energy

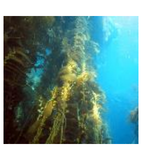
Sea Otter

1 gram = 4 units of energy

Sea Urchin

1 gram = 27 units of energy

Giant Kelp



Sea Lion

1 gram = 1.15 units of energy

CA Sheephead

1 gram = 4 units of energy

Sea Urchin

1 gram = 27 units of energy

Giant Kelp

Sea Lion

1 gram = 1.15 units of energy

CA Sheephead

1 gram = 7 units of energy

CA Mussel

1 gram = 45 units of energy

Plankton

Energy units inspired by Griffiths, D. (1977) and Williams, T. et al (2004).

Day 2

Task 3: Food Web Construction (in groups)

(Each team is provided a laminated copy of the organism cards and the follow-up questions. Teams complete the task on a poster paper.)

Projected on the board:

Take a moment to look at and read over the cards. These are different populations of organisms that make up a food web in a marine ecosystem.

1. On your poster spread out the organisms and draw a food web that makes sense to you (tape/glue organisms to the poster paper).

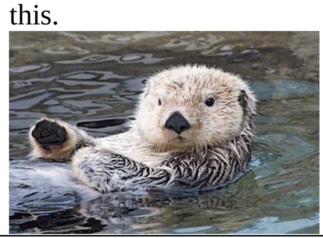
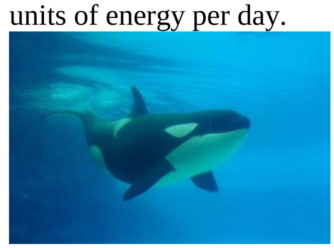
2. While arranging your food web, explain your thinking to your teammates.

After students have completed their food web students should rotate to each group to view their food web. Hold a brief class discussion identifying similarities and differences among the various posters. The major difference between the food webs will be that some groups pointed their arrows in the direction of energy flowing while others pointed their arrows in the opposite direction representing "what eats what". Students should be guided to compare the previous task arrows to how the arrows should be represented in this task and future tasks. Within an ecology unit or a matter and energy unit the distinction of what the arrows represent could be highlighted (they can demonstrate how matter cycles and energy flows). The class should come up with a "final" food web to be projected on the board before moving on to the questions.

3. On your poster, answer the questions regarding your food web.

Questions:

1. What do the arrows represent?
2. What if the CA Mussels increase in its population, what might happen?
3. If the CA Sheephead decreases in its population, will it affect the population size of the sea otter? Explain why you think that.
4. What if another predator of sea lions were introduced to this ecosystem, what could happen?
5. Do any cards seem to play a more important or less important role in this ecosystem than the others? Why?
6. What could happen if sea otters become extinct, what might happen to the ecosystem?
7. If the sea urchin population drastically decreases, what would likely happen to the ecosystem?

Giant Kelp –sea urchins eat this. 	**Sea Urchin** – Sea Otters and CA Sheephead eat this. 	**Sea Otter** – Killer Whales eat this. 
CA Sheephead – Sea lions eat this. 	**CA Mussel** – Sea Otters and the CA Sheephead eat this. 	**Killer Whale** – needs 240,271 units of energy per day. 
Steller's Sea Lion – Killer Whales eat this. 		

Killer Whale energy needs from Williams, T. et al (2004)

DAY 3

Task 3: Group and Class Discussion

Students should first review their answers their team came up with the previous day. Students should then turn to another team member to share, discuss, and argue their ideas. Task 3 is finished by holding a class discussion reviewing the questions regarding the food web the students constructed the previous day. Questions four through seven ask how a disturbance will influence the ecosystem. Students should again be pushed to describe how this disturbance will affect the entire ecosystem, not just the species directly connected to where the disturbance occurred.

Task 5: Top-Down DRP

(Each team is provided a laminated copy of the scenario, food chain and the scenario. Teams complete the task on a poster paper.)

Projected on the board:

In a marine environment scientists noticed the killer whale population decreasing over 20 years until there were no longer any killers whales in this environment. Scientists were unclear what caused this extinction. Many locals believed that illegal whale hunting occurred during these years without anyone knowing. Use what you know about the relationships between these organisms and the data table below to predict what you think will happen to the populations.

Kelp → **Urchin** → **Sea Otter** → **Killer Whale**

	Population Size Over Years				
Species	0 years	5 years	10 years	15 years	20 years
Kelp	124,000		213,000		332,000
Urchin	13,000				
Sea Otter	124		279	336	
Killer Whale	12	8	4	2	0

1. On your poster, write your answers to the questions given to you.

This task should be completed together as a class as a way to model expectations for answers as well as how to navigate the questions utilizing the organism relationships and the information in the data table. Students should still respond to the questions on their poster. For each question, have students discuss at their table before answering the question on their poster. Some students rely strictly on the data to explain their answers instead of describing the relationships between the organisms as well. For example, they may see that the sea otter numbers are increasing so they will simply state values that continue that trend instead of describing how this is possible. Some students will also utilize the data alone to describe what the population numbers are of another species. For example, even though this scenario is a top-down disturbance, students may describe that the urchin population is increasing because the kelp population is increasing. This type of situation is common over the rest of the tasks. Students will need a continuous reminder for the rest of the tasks to make sure to consider the scenario that is driving the changes to the ecosystem. Lastly, depending on how comfortable students are at utilizing evidence to state a claim, the students may need reminders that their answers must be based on the data and relationships provided instead of their reasoning being based off of observations in the past (for example, "I saw a killer whale eat fish so they can eat other stuff"). A discussion of each question occurs directly after the students respond on their poster instead of at the end of the task.

Questions:

1. What could be some possible population numbers for the urchins over time? Why do you think that?
2. What could the population of kelp be at 5 years and at 15 years? Why do you think that?
3. What could the population of sea otters be at 5 years and at 20 years? Why do you think that?
4. What do you think will happen in another 20 years to this ecosystem? Why do you think that?

DAY 4

Task 6: Mid-Level DRP

(Each team is provided a laminated copy of the scenario, food chain and the scenario. Teams complete the task on a poster paper.)

Projected on the board:

One result of climate change has been that winter storms have been bigger than ever in some places that had not experienced such types of storms before. People living in these areas are looking for the newest trend in winter clothing; fashionable and warm. Sea Otter fur is extremely warm and soft. As a result, in one marine environment, the Sea Otters were driven to extinction by humans hunting them for their fur pelts to make the newest fur coat fashion. Use what you know about the relationships between these organisms and the data table below to predict what you think will happen to the populations.

Kelp → **Urchin** → **Sea Otter** → **Killer Whale**

	Population Size Over Years				
Species	0 years	5 years	10 years	15 years	20 years
Kelp	124,000				
Urchin	13,000		27,000		63,000
Sea Otter	124	58	21	0	0
Killer Whale	12				

1. On your poster, write your answers to the questions given to you.

When students have completed the questions students should turn to discuss their team ideas with a person from a different team. This forces students to engage in a scientific argument to defend or modify their ideas. This can be done multiple times for students to engage in this process more than a singular time. Allow students the opportunity to bring these ideas back to their team to discuss and compare to their original ideas. A class discussion will follow to share any ideas that are still conflicting or those that go deeper than the questions, resulting in a deeper discussion regarding relationships in an ecosystem.

Questions:

1. What could be some possible population numbers for the killer whales over time? Why do you think that?
2. What could be some possible population numbers for the kelp over time? Why do you think that?
3. What could the population of urchins be at 5 years and at 15 years? Why do you think that?
4. Can the ecosystem continue to survive in this way? Why do you think that?
5. After 20 years, sea otters were reintroduced to the ecosystem. Would there be any effects on the ecosystem populations? Explain.

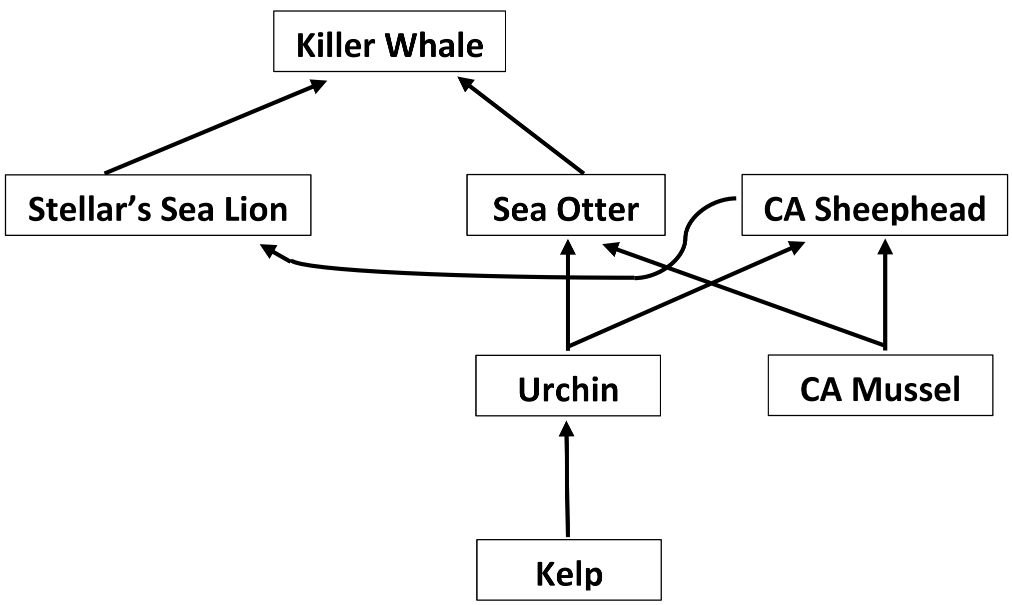
DAY 5

Task 7: Food Web DRP

(Each team is provided a laminated copy of the scenario, food web and the scenario. Only years 0 thru 20 are shown to students for the first part of the task. Teams complete the task on a poster paper.)

Projected on the board:

In one marine ecosystem, there was a sudden decrease in Sea Lions for an unknown reason. The populations of the rest of the food web were recorded to determine the effects of that change. Using the food web and the data table, try to make sense of what is occurring in this ecosystem.



	Population size over years						
Species	0	5	10	15	20	25	30
Kelp	28,500,000	28,800,000	28,600,000	28,400,000	28,700,000	20,000,000	6,700,000
Urchin	4,670	4,400	4,780	4,500	4,200	6,600	14,500
Sea Otter	154,000	92,000	46,000	29,000	11,000	4,000	120
Killer Whale	170	172	171	173	172	168	169
Sea Lion	70,000	40,000	13,000	12,000	8,000	5,300	3,500
CA Sheephead	136,000	198,000	244,000	261,000	279,000	124,000	42,000
CA Mussel	1,800,000	1,840,000	1,830,000	1,860,000	1,850,000	2,340,000	4,800,000

Killer whale, sea lion, and sea otter population values inspired by Williams, T. et al (2004).

Kelp population values inspired by van Tamelen, P.G. & Woodby, D. (2001).

1. On your poster, write your answers to the questions given to you.

Students will need continuous reminders to consider the scenario as the driving force behind the changes to the populations. With so many relationships and data students will at times forget to consider that the population numbers are changing because of the scenario. When students have completed the questions the collaborative process from task six should be repeated. Students should turn to another classmate to engage in a scientific argument regarding the answers to the questions. Allow students the opportunity to bring these ideas back to their team to discuss and compare to their original ideas. A class discussion will follow. Within this discussion, the idea of what it means for an ecosystem to "survive" should be highlighted. Students may think that if there are some of the original species left that the ecosystem has "survived". This understanding will be necessary for the second part of this task.

Questions:

1. What do you see happening with the sea otter population? Why do you think the sea otter population has changed the way it has? What do you predict will happen in the next 20 years to the sea otter?
2. What do you see happening with the Sheephead population? Why do you think the Sheephead population has changed the way it has? What do you predict will happen to the Sheephead in the next 20 years?
3. Why do you think the killer whale population has not really changed?
4. Why do you think the sea urchin population has not really changed?
5. Why has the kelp population not really changed?
6. Why has the CA Mussel population not drastically changed?
7. Do you think the ecosystem can survive the next 20 years based on these 20 years? In other words, do you think all the organisms in this ecosystem will still be around after another 20 years? Why or why not?

Projected on the board:

After tracking the ecosystem for 20 years, the Sheephead population is found to be plentiful. Fisherman have noticed and begin fishing the Sheephead without any rules or regulations. For the next 10 years, the population numbers continue to be recorded for this ecosystem.

1. What do you think will happen to this ecosystem over the next 10 years?

(Students are now shown years 25 thru 30)

2. Can the ecosystem still exist without regulating how much Sheephead are allowed to be caught? Why or why not?

Students should hypothesize question one with their team first and then with students in different teams (the same process as the previous tasks). Students should be provided time to share these hypotheses with their teammates before moving on to viewing the new data and answering question two. When students have completed the question a class discussion will follow. The class should come to the conclusion that without regulation the ecosystem will collapse.

APPENDIX E

Coding Scheme

Adapted from Dauer et al (2013).

Linear vs. Nonlinear		
SCORE	DESCRIPTION	GENERAL IDEAS AND EXAMPLES
0	Missing	———
1	"Unscientific", inappropriate	Species not on the same food chain have no effect on one another. Effects are unidirectional (predator can affect prey OR prey can affect predator). a. "[The trout is increasing because] there are very few garter snakes and great blue heron's to eat the trout and there are so many mayflys for the trout to eat." (Q1c) b. Yes, the ecosystem can continue to be functioning. (Q2b) c. "It wouldn't affect K much since they don't interact." (Q3f)
2	Marginally "scientific", ambiguous or poorly worded	Species not on the same food chain do have an effect on one another and effects are multidirectional. Reasoning for why or how this occurs is missing, generic, or not specific. a. "I think they are increasing because humans added more trout to the ecosystem, and there were a lot of mayfly to eat." (Q1c) b. "[The ecosystem will not continue to function in this way] because if more things become extinct it will soon end." (Q2b) c. "Since I is going up C will go down and A will go up and as the cycle of increase and decrease it will probably stay the same." (Q3f)
3	As "scientific" as it can be expected	Species not on the same food chain do have an effect on one another and effects are multidirectional. Reasoning for why or how this occurs is specific and demonstrates reading a food web as a system. a. "Increasing because since there is less red-legged frogs it has less competition for food." (Q1c) b. "[The ecosystem will not continue to function in this way] because all of the animals would run out of food." (Q2b) c. "It would eat more C so J would have to depend on only K." (Q3f)

*Incorrect → unscientific
*Correct and accurate → scientific

Dissipation vs. Persistence		
SCORE	DESCRIPTION	EXAMPLES
0	Missing	———
1	"Unscientific", inappropriate	The effect from a change in a population decreases or has no effect on other species the further away they are from the disturbance in a food web. a. Yes, the ecosystem can continue to be functioning because the decrease of the trout will affect everything else less and less. (Q2b) b. "[K will stay more or less the same because] they're not in the same chain." (Q3f)
2	Marginally "scientific", ambiguous or poorly worded	The effect from a change in a population persists but is vaguely described. a. "[The ecosystem will not continue to function in this way] because if more things become extinct it will soon end." (Q2b) b. "Since I is going up C will go down and A will go up and as the cycle of increase and decrease it will probably stay the same." (Q3f)
3	As "scientific" as it can be expected	The effect from a change in a population persists and the reasoning for persistence is specific. a. "[The ecosystem will not continue to function in this way] because all of the animals would run out of food." (Q2b) b. "[K will increase because] less food for J, less C, but more K." (Q3f)

*Incorrect → unscientific

*Correct and accurate → scientific

Food Chain		
SCORE	DESCRIPTION	EXAMPLES
0	Missing	———
1	"Unscientific", inappropriate	Food chain is traced backwards or connections are ignored. a. "I think that it will continue to increase because already their population is climbing. I thought that if right now their population is going up, it will in the future." (Q1c) b. "[H will stay more or less the same because] H is not an energy source." (Q3a)
2	Marginally "scientific", ambiguous or poorly worded	Food chain is traced scientifically but reasoning does not support the scenario or is not specific. a. "I think they are increasing because humans added more trout to the ecosystem, and there were a lot of mayfly to eat." (Q1c) b. "[H will decrease] because anything that affects population F is going to hurt population H." (Q3a)
3	As "scientific" as it can be expected	Food chain is traced scientifically and the reasoning supports the scenario and is specific. a. "Increasing because since there is less red-legged frogs it has less competition for food." (Q1c) b. "H will decrease] because now it has no food source." (Q3a)

*Incorrect → unscientific

*Correct and accurate → scientific

Energy Arrows		
SCORE	DESCRIPTION	EXAMPLES
0	Missing	———
1	"Unscientific", inappropriate	Arrows are utilized as an organism "eats" another organism more than four times throughout the assessment (even if Q1a is coded as a 3). a. "They represent what eats what." (Q1a)
2	Marginally "scientific", ambiguous or poorly worded	Arrows are utilized as an organism "eats" another organism three or four times throughout the assessment (even if Q1a is coded as a 3).
3	As "scientific" as it can be expected	Arrows are utilized as an organism "eats" another organism less than three times throughout the assessment. Instead the students utilizes the arrows as an organism "provides energy to" another organism for all questions except up to two. a. "[The arrows represent] the energy being given." (Q1a)

*Incorrect → unscientific

*Correct and accurate → scientific