A CONSTRUCTIVIST APPROACH TO BIOLOGY EDUCATION: THE DESIGN AND IMPLEMENTATION OF AN ECOLOGY TUTORIAL

by

ALEXANDER P. KENDRICK

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Shawn Kolitch

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The greatest barrier to learning is not a student's lack of knowledge, but the prior knowledge that he or she brings into the classroom. Prior knowledge determines the learner's self-constructed framework that he or she uses to interpret and describe the universe. The Constructivist learning model states that in order to learn, this existing framework must be challenged and evaluated by the student. If shown how current conceptions are lacking and may in fact lead to contradictions with observation, and then presented with alternative conceptions that will provide a better understanding, a student will readily assimilate new information and apply it to the formation of a new conceptual paradigm. If teachers are unaware of existing conceptual frameworks they will be unable to properly challenge the student's conceptions and therefore, true learning will not take place. As an example of the constructivist approach applied to biology education, I have designed, implemented and evaluated a tutorial curriculum for wetland ecology at Creswell High School. This curriculum is aimed at challenging and correcting common student misconceptions that were determined through literature research, student tests, and student interviews. The evaluation suggests that the tutorials were an effective educational tool.

ACKNOWLEDGEMENTS

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DEDICATION

For all teachers. For my family.

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INTRODUCTION

If you visited Harvard University on graduation day and randomly interviewed graduates, faculty, and alumni for their ideas on the cause of Earth's seasonal temperature variations, what would you expect to find? A group of educational researchers did just that, and the results might surprise you. Twenty-one out of 23 individuals interviewed gave explanations that are not consistent with current scientific beliefs. All of these students and former students had background in the sciences in high school, and at least one even studied physics at the university. How is it that these students still hold misconceptions about this topic? In order to demonstrate why students are not learning effectively in the sciences, the researchers examined a nearby high school astronomy class.

Students in the astronomy class had little or no formal background in astronomy, but when interviewed by the researchers, they offered up many explanations for the causes of the seasons. Misconceptions were the norm. After being taught the relevant material in class, the students were interviewed again. At first many students would exhibit a superficially correct understanding of the concepts, but to the teacher's amazement, when questioned further even the brightest student reverted to her old, incorrect theories. The researchers argued that it is the students' strongly held preconceptions and the teacher's lack of awareness of the preconceptions that prevents learning. In order to address this problem, we must look at learning from a new perspective in which students are no longer the receivers of knowledge, but the makers of it.

The idea that knowledge is made by the learner is at the core of what learning theorists call Constructivism: Constructivists believe that each person has a self-constructed model based on past learning experiences. This model is a framework used to understand, predict, and describe aspects of the universe. Learning is simply a process of building and reworking that framework. If the existing framework is to be rebuilt it must first be challenged and shown to be lacking in some way. A cognitive dissonance, or feeling of unease with what is already known, must be created. Once the learner recognizes how his or her existing understanding fails to accurately predict or describe the universe, they are ready for the next step in the process. New information can now be introduced and assimilated with the feeling of dissonance providing the motivation. The result is the construction of a newly shaped framework that predicts and describes the universe better than the previous one (Colburn, 1998; Lord, 1998).

Because of the constructive nature of learning, it would be an oversight to ignore the foundation of knowledge that already exists. Imagine an architect who has the job of designing an addition to a building. If the architect fails to investigate the existing building for measurements, the construction workers will not have a plan they can follow for building on to the existing structure. Furthermore, the architect will never know whether the preexisting structure was fatally flawed in some way. In the same way, a teacher who is unaware of the foundation of knowledge that exists within his or her students will be unable to provide the students with a clear plan for learning, and will never know if the foundation is so flawed as to effectively prevent new learning.

Pre-instructional ideas about a subject have been given many names. They have been referred to as preconceptions, misconceptions, alternative frameworks, prior knowledge (Adeniyi 1985), personal theories, naïve beliefs, and intuitive science (Colburn 1998). Whatever term might be used to describe a student's existing knowledge, the fact is that even before formal instruction a student will often have an existing framework that he or she will bring into the classroom. The student, in response to life experiences and a desire to make sense of the world, constructs this framework. These constructions are often strongly held (Colburn, 1998; Munson, 1984). Prior knowledge can also be constructed from popular culture and current events (Adeniyi, 1985; Brody, 1991).

Students call on their existing framework to solve problems. This framework could be one they have built entirely on their own or it could be constructed with some formal training. Even with formal training, when there is no lack of facts and definitions and no lack of knowledge, there are still the same kinds of misconceptions. The barrier to understanding is not then lack of knowledge, but the *existence* of prior knowledge (Angelo & Cross, 1993).

Because the barrier to learning is not lack of knowledge, simply pouring knowledge into a student is not going to overcome the barrier. Indeed, traditional, teacher-centered modes of education that do not take into account preconceptions have been found ineffective in fostering student understanding. According to many cognitive researchers, the behavioristic model of education has been the dominating approach in science education. This approach is focused on conditioning the student to give the correct response. It does not focus on understanding (Yager, 1991). Studies have shown that even though students may pass the exams, they can still hold misconceptions about the material (Lord 1994). In order to pass these exams, students are often simply parroting back the material that the teacher has given to them. Learning definitions does not provide understanding, nor does recitation of them demonstrate comprehension (Marek, 1986). The constructivist approach dictates that the teacher shift his or her role from that of a knowledge giver, to a facilitator. He or she must question the student's existing framework of knowledge. Students need to be helped to recognize the shortcomings of their preconceptions, and be encouraged to abandon or reevaluate these conceptions in favor of more correct ones. In order to challenge the existing conceptions the teacher must recognize that they exist and find out what they are. The realization that prior knowledge affects knowledge acquisition and that students are active constructors of knowledge is causing many teachers to restructure their classrooms toward a more constructivist style of teaching.

One example of this restructuring in biology education is the 5E model developed by Rodger Bybee of Biological Sciences Curriculum Studies (BSCS). The five E's in this model stand for Engage, Explore, Explain, Elaborate, and Evaluate. Each step in this constructivist approach puts emphasis on student-student interaction and understanding. The *engage* step captures the students' attention and activates prior knowledge. It helps them make connections to what they already know about the world. Through the process of *exploring*, students direct their learning by investigating and discussing a question, or making predictions about and observing a demonstration. During *explain* stage, students reflect on what they have discovered. The teacher is able to easier introduce new knowledge to the students at this time due to student preconceptions having been challenged by the results of the students' exploration. *Elaboration* gives the students a chance to apply the new ideas to different situations and further solidify their understanding. In the final process of *evaluate*, students assess what they have learned and teachers assess how well they have learned it. This five-step process is also referred to as the learning cycle (Colburn, 1998; Lord, 1994). Instruction that incorporates the learning cycle has been shown to foster better understanding in biology students than more traditional lecture-based, teacher-centered instruction. In addition, students maintain a better attitude toward learning throughout the course (Lord 1997).

This method of teaching is most effective when the nature of the prior misconceptions is taken into account. Although the majority of misconception research has been conducted in the physical sciences (Munson 1994), recently there has been more research into the common misconceptions regarding biological concepts. Ecological misconceptions are one such area of research. Studies have found that students of all ages show significant misunderstandings related to the concepts of ecosystem, food web, and the pyramid of energy (Adeniyi, 1985; Griffiths & Grant, 1985; Munson, 1994). See Table 1.

Table 1. Misconceptions discovered through literature research.

Ecological concept	Misconception
Ecosystem	Living things do not interact with non-living things.
	Ecosystem is the relationship between living things.
	A change in population size of one organism may not affect an ecosystem because some organisms are not important.
	All organisms in an ecosystem are equally important.
Food web	Food web misinterpreted as a simple food chain.
	Organisms higher in the web feed on all lower organisms.
	A change in prey population size has no effect on predator population size.
	An alteration in the size of one population in a food web will affect all other populations the same way.
	A change in one population affects only directly connected populations.
Energy	The pyramid of energy is wider at the bottom than at the top because the number of producers is greater than the number of herbivores.
	The top of any food chain within a web receives the greatest amount of energy because energy accumulates up the chain.

PURPOSE

The focus of my thesis project was to research, design and implement a constructivist curriculum that focused on the above ecology-related misconceptions, along with others that I discovered through student tests and interviews. Using a constructivist approach, I designed and implemented a curriculum aimed at correcting student misconceptions in Anne O'Connel's 9th grade wetland ecology class at Creswell High School. The approach involved two major parts. Part one was the administration of a prior knowledge test and the conductance of student interviews, i.e. a determination or at least verification of students' preconceptions. Part two was the implementation of tutorials designed to help the students understand ecology. As a form of assessment, a post-test was administered (re-administration of prior knowledge pretest) and interviews were conducted. To assess student opinion of the tutorials, a written evaluation form was given to each participant.

The prior knowledge test and the student interviews are an especially important part of the constructivist approach because they assess the initial level of student understanding. Knowing this level will help determine the best starting point for a given lesson. Recalling the building analogy, knowing student level is analogous to knowing the shape of the house on which you are to build an addition. By knowing what the students are familiar with, new material can be linked with something they already know, or think they know. The probes are also used to determine more precisely which misconceptions these particular students actually hold about the topics to be covered. Probing for misconceptions is analogous to probing for the faults in the existing foundation of the building. It is these misconceptions that will be the barriers to learning.

For the curriculum to be effective the misconceptions must be known before I begin to design. In addition to supplying this crucial information, the pretest and interviews help the students to activate prior knowledge. It will encourage them to begin linking new material with what they already know (Angelo and Cross, 1993; Wratten & Hodge, 1999).

Armed with an awareness of student knowledge and misconceptions, I designed a series of weekly group problem solving sessions, called tutorials. The model for these tutorials was based on Professor Shawn Kolitch's tutorials for general physics. Tutorials are a special learning tool designed to challenge misconceptions and guide students to a more correct understanding. . In a traditional problem solving session, the instructor solves the problems on the blackboard while the students watch and ostensibly "learn" to imitate the techniques demonstrated. In a tutorial, on the other hand, students engage directly in the process, and are responsible to themselves and to each other for generating the correct reasoning. A tutorial is therefore the active engagement alternative to a traditional problem solving demonstration. A tutorial follows the learning cycle by first making a link to something interesting that the students are familiar with (*engage*). Then, by presenting the students with information and asking questions, the tutorial helps the students evaluate and question what they already know (*explore*). Through student discussion and teacher facilitation, the tutorial guides the students to a newer and deeper understanding of the material (*explain*). Further questions then encourage the students to apply the concepts to new problems (*elaborate*). Throughout the tutorial students are asked to describe their ideas to the teacher in their own words (*evaluate*). The elements of the tutorial that keep it on task are the use of cooperative learning, the assignment of roles, and the use of checkpoints.

Cooperative learning serves many useful purposes in the tutorial. To begin with it takes advantage of the students' propensity for interaction, and it has been shown to encourage more learning than individual experiences (Lundgren, 1994). In order for new understanding to be reached, cognitive energy must be expended on the part of the learner. In a lecture format this energy expenditure usually only lasts for less than 10 to 12 minutes in contrast with a group format where energy is expended for most of the activity (Lord, 1998). In lecture more time ends up being spent off task as the student daydreams or becomes distracted. Constant interaction with the group keeps students engaged and on task. The task of constructing meaning is often more easily accomplished with the help of peers rather than adults (Jones & Carter, 1998). This is because peers are at similar developmental levels. An example of this kind of interaction you may be familiar with is as follows. A teacher is unable to clarify something to a student. A fellow student who is just grasping the concept and can more easily see where the confused student is stuck, steps in and clarifies using terms the confused student can understand.

However, sometimes before agreeing on an idea students will disagree. This disagreement can actually fuel the step in the learning process where misconceptions are challenged. As students discuss their ideas with others and hear the different arguments being made by their peers, cognitive dissonance is created. This dissonance is the precursor to conceptual change. Once new concepts begin to crystallize students act as a team of construction workers, helping each other build their new frameworks of knowledge.

The fact that students are learning as a team does not lessen the importance of individual learning. One measure that is taken to insure that individuals are sharing equally in the learning process is the assignment of roles. At the beginning of each problem one student is chosen to be the interpreter, one the director, and one the scribe. It is the interpreter's role to explain to the group any charts, graphs, or other data presented and to clarify the question. The director acts as the leader of the group, guiding them toward the goal and keeping the group focused on the problem. It is the scribe's job to record the conclusions that the group comes to. At the beginning of the next problem, the students switch roles. This prevents any person from dominating or not participating. The use of roles also isolates problem-solving skills. Role rotation insures that each member of the group will have the chance to approach the problems from different angles, exercising different problem-solving skills each time.

Check points are another measure for maintaining balance in tutorial sessions. At the end of each problem there is a checkpoint that requires the group to discuss its ideas with a teacher. The teacher has a chance to assess each individual's understanding and address any misconceptions that may remain. It is easy to tell which students are just along for the ride and bring them into the tutorial by asking them to explain the ideas for the group. Checkpoints are yet another opportunity for students to explain their ideas in their own words and further strengthen the constructions they have made. They are also an opportunity for further questioning by the teacher to encourage more critical thinking, new applications of the concept, and further connections of the concept to the student's lives. In this way checkpoints serve as both a teaching and an assessment tool.

The ultimate assessment tools employed were the posttests, interviews, and written evaluations. The posttest was simply the re-administration of the pretest. I was able to make comparisons between student's answers on each test in order to assess the tutorial's effectiveness in fostering understanding. The student interviews again probed for level of understanding and surviving or new misconceptions. I also asked for their opinions about the tutorial. Written evaluations will gave the students a chance to give me feedback in a format that is more anonymous. A standardized evaluation also makes it easy to look at class opinion as a whole.

Materials and Methods

Part one: Assessment tools (see appendix A)

Pretest / Post test

The pretest was administered during the first week of classes. Students were told that the pretest would not be graded but that it was important for them to answer the questions to the best of their ability. They were also told that the results would be part of a research study and would help me design tutorials for the class. In order to assess gains in student understanding the test was re-administered after the tutorials had been implemented.

The pretest begins with a brief explanation of how to interpret arrows in food chains and webs. This explanation is given because the goal of the pretest is not to determine if the students understand the arrow convention but if they understand the relationships between organisms in a food web.

Questions 1 through 6 test three different concepts related to food webs. Each of the three concepts is tested twice. In food webs effects are referred to as top-down if they come from a change in a predator population and affect populations lower in the web. Bottom-up effects are experienced by populations higher in the food web due to changes in a prey population lower in the web. By testing the students on the same concept twice (from the top-down and from the bottom-up) I can get an idea for how well they understand the concept by seeing if they are consistent in their interpretation. Questions 7 and 8 are essentially a pair as well, though 8 incorporates ideas from all of the preceding questions. Questions 9 and 10 test students on the concept of pyramid of energy (that there is less and less energy contained in each level of the food chain as you go up). Question 11 tests students for misconceptions regarding the source of energy for plants. The format and goal of each question is outlined in table 2a – k.

<u>Table 2a – k. Format and Goals of Multiple Choice Test.</u>

Table 2a.

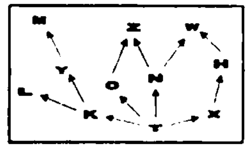
1. Population W a) Feeds on populations H, X, N, and T. b) Feeds on populations H and N only. c) Is fed on by populations H, X, N and T. d) Is fed on by populations H and N only. 	**Purpose:** Tests for misconceptions regarding arrow convention. Tests for misconception that a population high in the food web feeds on all lower populations not just the adjacent populations.

Table 2b.

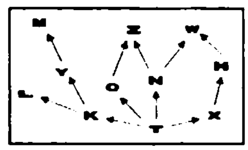
2. Population T a) Feeds on all populations. b) Feeds on populations K, O, N, and X only. c) Is fed on by all populations. d) Is fed on by populations K, O, N, and X only. 	**Purpose:** Tests for misconceptions regarding arrow convention. Tests for misconception that a population high in the food web feeds on all lower populations not just the adjacent populations.

Table 2c.

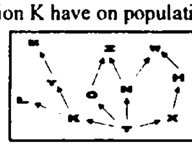
3. What effect would a sudden decrease in population K have on population L? a) Population L will increase. b) Population L will decrease. c) Population L will not be affected. 	**Purpose:** Tests for understanding of predator-prey relationships from the bottom-up.

Table 2d.

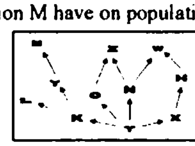
4. What effect would a sudden increase in population M have on population Y? a) Population Y will increase. b) Population Y will decrease. c) Population Y will not be affected. 	**Purpose:** Tests for understanding of predator-prey relationships from the top-down.

Table 2e.

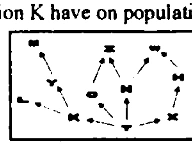
5. What effect would a sudden decrease in population K have on population M? a) Population M will increase. b) Population M will decrease. c) Population M will not be affected. 	**Purpose:** Tests for the misconception that a change in one population only affects adjacent populations. In this case it asks for the effects on a population separated by one link in the food chain. Approached from the bottom-up.

Table 2f.

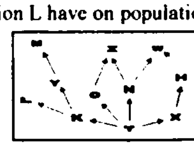
6. What effect would a sudden increase in population L have on population T? a) Population T will increase. b) Population T will decrease. c) Population T will not be affected. 	**Purpose:** Tests for the misconception that a change in one population only affects adjacent populations. In this case it asks for the effects on a population separated by one link in the food chain. Approached from the top-down.

Table 2g.

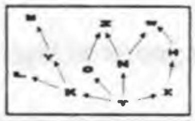
7. What effect would a sudden increase in population L have on population Y? a) Population Y will increase. b) Population Y will decrease. c) Population Y will not be affected. 	**Purpose:** Tests for the misconception that a change in one predator population will not affect another predator population sharing a common prey item. This relationship links two food chains.

Table 2h.

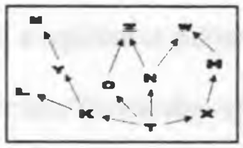
8. Circle the populations through which a change in population T can be passed on to population W. 	**Purpose:** Tests for the misconception that a change in one predator population will not affect another predator population sharing a common prey item (link Z-H-W). In addition tests concepts from questions 1-6.

Table 2i.

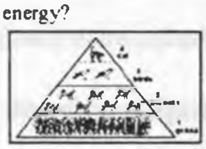
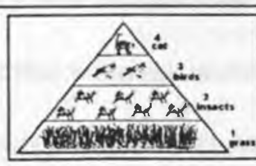
9. Which level in the pyramid contains the greatest total energy? a) Level 1 b) Level 2 c) Level 3 d) Level 4 e) They all contain equal amounts of total energy. 	**Purpose:** Tests for the misconception that energy accumulates up the food chain.

Table 2j.

10. Each level in the pyramid of energy a) Contains an amount of energy equivalent to all lower levels added together. b) Contains more energy than the level just beneath it. c) Contains the same amount of energy as all other levels d) Contains only a fraction of the energy found at the level just beneath it.	**Purpose:** Tests for possible misconceptions regarding pyramids of energy by giving students more specific choices.

Table 2k.

11. Level 1 a) Gets its energy from the soil. b) Gets its energy from the sun. c) Gets its energy from the air. d) Makes its own energy. 	**Purpose:** Tests for misconceptions regarding the source of energy for plants.

Interviews

Students were seated in front of a video camera and made to feel comfortable. They were told that there were no right or wrong answers but rather I was only investigating their ideas on the subject of ecology. The initial interviews probed eight students. After the tutorials four of those eight were legitimate candidates for the post interview. In order to be considered a legitimate subject a student had to have attended at least two tutorials and be present in class for the day of the interview (attendance seemed to be a challenge for many of them).

Students were shown an illustration of a river ecosystem that included rocks, water, plants, and many animals. Students were asked what parts of this picture make up an ecosystem. This question tests for the misconception that an ecosystem is only the relationships between the living things. This picture and question were only used in the initial interview as students showed a clear understanding for the concept of ecosystem.

Next the students were shown a picture of a forest food web. Students were asked to identify a primary producer, consumer, and decomposer. This question tests their knowledge and possible misconceptions regarding important ecology terms. A scenario was described which caused a near disappearance of foxes from the food web. In order to test for the misconception that a change in one population only affects directly connected populations students were asked to name all of the populations that could be affected by the dramatic decrease in foxes.

To further test the students' understanding of relationships within food webs they were shown an arctic food web that had a similar structure to the food web on the pretest. Questions 1 through 8 from the pretest were restated with reference to organisms in the arctic food web. By asking these questions again in person and with a less abstract food web, it can be determined whether the results of the pretest reflect actual student understanding or simply problems with the test itself. These questions were not asked during the initial interviews but were added a week later as an improvement. After conducting the first round of interviews it was clear that the single question asking what would happen if foxes disappeared was not enough to determine how well students understood relationships in a food web. Four students were questioned and recorded on audio tape.

Finally, students were shown a food chain with pictures (shown as names in the appendix) representing the four trophic levels. To test their idea of what the arrows in a food chain or food web represent students were asked to explain the meaning of the arrows. They were then asked where the plants get their energy. This question is an elaboration on question 11 from the pretest. Students were then asked to explain why there is so much more plant material than grasshopper, grasshopper than mouse, and mouse than owl. This question is related to energy flow and was included in order to uncover misconceptions students might have about the reasons for a pyramid of biomass.

Student evaluations

Students were encouraged to be honest in their evaluations of the tutorials and told that their opinions would be an important part of my research project. The evaluations were filled out and handed in while I was out of the room.

The first question on the evaluation asks the student how many tutorials he or she was able to attend. This question was included so that the opinions of those who were able to attend the majority of the tutorials could be given more weight.

Students were then asked to rank several characteristics on a standardized scale. Difficulty level was evaluated to insure that the tutorials were in the right range for this particular grade level. Because the tutorial style is meant to be engaging and interesting, students were asked to rate how enjoyable this particular approach to learning ecology was for them. In order to determine the tutorials' effectiveness in achieving its main goal students were asked how helpful the tutorials were in clearing up misconceptions. They were also asked to evaluate the effectiveness of the tutorials as a learning tool. The helpfulness of the group-oriented, discussion-based format of the tutorial was also evaluated, as it is a key component as well.

Finally, students were given an opportunity to write in a response to three questions. They were asked to list the aspects of the tutorial they enjoyed the most, the aspects they enjoyed the least, and any way in which the tutorials could be improved. These questions made room for more personal comments regarding the tutorials.

Group record sheets

Group record sheets were handed out to each group at the beginning of the tutorial. Students recorded their names and facilitators initialed each checkpoint that the students passed. A section was included for "work in progress" if some parts of a problem were checked off before a checkpoint. This insures that when another facilitator arrives to help the group he or she knows how far the group has progressed.

Peer evaluations

A system of peer evaluations was implemented to encourage equal participation by all group members. The students were given the forms after tutorials so that they could rank each group member in terms of effort. Scores for each person were averaged and factored into their grade for the class.

Part two: Tutorials (see appendix B)

Pre-tutorial reading assignments and discussions

Prior to tutorials in which there would be a great deal of new material for the students an appropriate reading assignment was assigned. The purpose of the reading assignment was to introduce the students to the concepts to be covered in the pre-tutorial discussion and in the tutorial. After assigning reading, but before tutorial, a discussion-oriented lesson covering the relevant topics was given. This insures that students are up to speed on some basic concepts and terminology before tackling the tutorial. It is also a key time to begin establishing links with what the students already know to what will be discussed in tutorial. By adhering to an outline for the topics needing to be covered but at the same time posing open ended questions, the discussions allowed students to make connections to concepts or situations they were already familiar with. The high level of student involvement in these lessons insured that the examples given and the specific details were relevant to them.

Vocabulary

As part of the class format students were required to learn ten vocabulary words each week. Definitions were gathered from the context of the reading rather than from a dictionary. For the four-week duration of the tutorials the vocabulary words came from pre-tutorial readings and from the tutorials themselves. Any vocabulary words were printed in boldface in the tutorial. The students made a word-search each week and were quizzed each Friday. This approach proved to be useful in familiarizing them with some important terminology.

Tutorial 1

The goal of tutorial 1 is to give the students a foundation to work with for later tutorials dealing with food chains, food webs, and energy flow. It covers the concepts of biomass and primary productivity. Because biomass is the currency of energy in food chains and primary producers are at the base of many food chains, it is important that the students have a good understanding of both.

The tutorial begins with a broad approach to primary production designed to engage the students' interest and relate the lesson to their lives. In order to capture their interest plants and the process of photosynthesis is presented as a life support system or "green solar panels" that send a current of energy into the biological world. An interesting fact about the absence of oxygen in the atmosphere before photosynthesis is also included. The students are then asked to think of other ways, besides providing food and oxygen, that plants benefit us. A possible list might include lumber, medicine, beauty, shade, soil stability, and wildlife habitat. By encouraging the students to think about the ways primary producers are important in their lives this preliminary question helps give real-life relevance to the lessons that will follow.

In order to solidify student understanding of some key terms part A of problem 1 asks them to define *primary producer* and *biomass* in their own words. Since the students have had a pre-tutorial lesson on these concepts it is a chance for them to put into words their current understanding of these concepts. The first checkpoint follows these definitions so that tutorial facilitators can check for existing misconceptions about these concepts. Students are asked to put forward their ideas and facilitators can then help them to see what parts of their definitions are incorrect or lacking. In Kolitch's physics tutorial, the model that these tutorials are based on, defining terms sometimes takes as much as half of the tutorial period. Students and facilitators work out the basic conceptual understanding that is necessary to grasp the lesson to come. A great deal of work is done on this conceptual level to make sure that each student can define the terms correctly for themselves. "Primary productivity" and "biomass" are such important concepts that if not fully understood would prevent a student from learning much from the rest of the tutorials.

After grasping biomass and primary productivity the next step is to expand on these concepts by discussing real life examples. Parts B-D begin with an explanation of the way scientists measure biomass. The terms "standing crop," "wet weight," and "dry weight" are defined. The subject is given immediacy by asking the students to estimate the standing crop of biomass in the classroom. Checkpoint questions expand on these concepts by addressing wet weight vs. dry weight biomass, above ground to below ground biomass ratios, and how biomass is related to productivity. Facilitators have a list of real-life examples to illustrate these concepts. For example, when discussing the inaccuracies of wet weight estimates facilitators can share the varying percent water composition of humans in the different age groups or genders. They can also bring up an example of how percent water composition varies from species to species by pointing out that a jellyfish is 97% water while an average adult male human is 64% water. All of these examples and discussions give the students more chances to solidify their ideas and make links between the new material and real life.

Further expansions and linkages in tutorial 1 focus on the factors affecting productivity as measured by biomass. In problem 2 students are given a table of the annual rates of biomass production of different ecosystems. By analyzing production rates the students can come up with a list of factors that affect productivity. The question is open-ended and requires that the students be independent thinkers. Discussion at the checkpoint is designed to highlight some of the key factors by comparing different ecosystems. For example, students are asked why an evergreen forest has a higher rate of biomass production than a deciduous forest. This is an example that can easily be related to the student's lives as they have all seen deciduous trees lose their leaves in the winter. They can make the connection that evergreen trees keep producing food by photosynthesizing year-round, thus producing more biomass.

Problem 3 provides a final expansion on the concepts by allowing the students to apply what they have learned about productivity and biomass to variations in biomass production rates in wetland ecosystems. Students must interpret tables and graphs showing the relationships between different wetland characteristics and productivity. Checkpoint questions focus on the differences in productivity depending on vegetation type. This problem broadens their understanding and continues to add relevance to the lesson by linking it to a nearby ecosystem that is the focus of class study.

Tutorial 2

The goal of tutorial 2 is to clear up misconceptions associated with food chains. Misconceptions about the direction of arrow convention in food chains, and predator-prey feeding relationships are dealt with. Understanding food chains is an important step in reaching an understanding of food webs, as they are really just many overlapping, intertwined food chains.

The tutorial seeks to gain the student's interest by beginning with the powerful statement from the book of Isaiah, "All flesh is grass." It asks the student the seemingly wacky question, "Did you eat grass for lunch today?" Problem one asks the students to make a list of the food items they ate and remember that "you they are what they eat." In this way, the students are personally involved in the lesson and have connected the concepts with their lives. The concept that plants are the beginning of energy flow into food chains and that biomass is built from biomass are both being dealt with as the students are asked to explain the quote, "All flesh is grass." Problem 1 continues along this vein by asking the students to explain the "green pact," a fictional contract stating that animals will forever be bound to plants for energy. So that students can make the connection that all energy ultimately comes from the sun, they are asked to explain what kind of pact plants have signed. A checkpoint question asks what would happen if there were suddenly no plants on earth. This question highlights student understanding that plants are the first, vital link in the food chain.

Problem 2 gives the students a chance to work through their understandings of some key vocabulary words associated with food chains. The concepts that they are asked to define – "food chain," "primary producer," "consumer," and "trophic level" were all part of the pre-tutorial discussion. Again, defining the words allows for students to solidify their understanding of the concepts and for facilitators to make sure that there is satisfactory understanding before continuing. As a checkpoint question students were also asked to define "decomposer." The decomposers are the third major ecological group and will be important when we discuss the detrital food chain that begins with a decomposer eating decaying organic matter.

Problem 3 begins with an explanation of how the arrows in food chains are always drawn to represent energy flow. It presents a food chain and asks that students fill in the arrows while keeping in mind that they must show the direction of energy flow. This problem is followed by a checkpoint to insure that students understand this convention, as it is essential for the interpretation of food chains and webs.

In order to apply their understanding for the vocabulary and to develop their understanding of food chains, students are asked to construct their own food chain on poster paper, labeling each trophic level and the producer and consumer levels. To begin linking their understanding to the next problem dealing with predator-prey relationships students are asked to think of as many predator prey relationships in the food chain as they can. In order to make the concept more personal students are asked to think of a food chain that includes a human if the have not already. Checkpoint questions elaborate on the concept of trophic level by asking what trophic level a decomposer would occupy and how a human could possibly occupy more than one trophic level.

Problem 4 is designed to clear up the misconceptions that a change in predator population does not affect the prey population and that a change in prey population does not affect the predator population. Those misconceptions were tested by problem two and three in the pretest. The students are given a graph of population versus time showing the classic predator-prey oscillation. They are then asked to explain why the prey and predator population numbers are rising or falling at certain points. The points cover all the possibilities: rise in prey = rise in predator, fall in prey = fall in predator, rise in predator = fall in prey, and fall in predator = rise in prey. A final question gives the students a chance to synthesize what they have learned by asking them to explain the pattern that they see. Because the populations do not line up with one another but instead shadow one another, students are asked to explain possible causes for the delay. This question is asked to deepen their understanding for the predator-prey relationship. By talking about the biology of the animals the problem becomes more than just a graph on the sheet of paper. The students can make connections to real life.

Problem 5 continues to elaborate on the idea of a food chain by introducing the detrital food chain that begins with an animal eating dead plant and animal material and contrasting it with the grazing food chain that begins with animals eating living plants. Students are given another graph to interpret that shows the increasing edibility of marsh plants as they are decomposed by bacteria. It connects the concept of the detrital food chain to wetlands and to a particular wetland environment that we would be visiting soon thus making the material directly relevant to their lives and linking it to situations outside the classroom.

Tutorial 3

Tutorial 3 continues to focus on misconceptions associated with food chains and then moves into food webs. The misconception that a change in one population only affects populations directly-connected (adjacent) to it is the focus of this tutorial.

Problem 1 involves a case study of Lake Mendota in Madison, Wisconsin. It is designed to be an interesting and engaging, real-life example illustrating the trophic cascade through an example of biomanipulation. The trophic cascade is the concept that a change in one population in a food chain will be passed through the food chain to all other populations – not just the adjacent populations. Biomanipulation is the shaping of the environment through biological means. This question works with the misconception tested for by questions 5 and 6 in the pretest.

In Lake Mendota algae blooms were a real problem until scientists introduced a fish predator. Students are given the existing food chain in the lake and then told that the introduction of a top predator affected the population at the base of the food chain, causing a decrease in the algae population. Part A asks, "How could the introduction of a piscivore solve the algae problem?" After being able to explain how the trophic cascade works in part A, the students expand on the idea in part B by predicting the outcome if a human was added to the top of the food chain. In addition to giving the students more practice it also makes the concept more relevant by relating it to a past time they themselves might enjoy – fishing. Finally, the students are told that the phenomenon they have been describing is termed the trophic cascade. In order to solidify their understanding for how populations are affected in a food chain, part C asks them define trophic cascade in their own words.

A checkpoint question is to ask if students can think of any other examples of biomanipulation. Pest control using predatory insects is one example (aphids and ladybugs). This checkpoint expands on the idea of biological control and food chains (a increase in ladybugs leads to an increase in garden plants). It also serves to further link the material to relevant situations outside the classroom that the students are familiar with.

Part A of problem 2 introduces the idea of a food web and focuses on defining what a food web is. It also asks students to discuss how food webs are different from food chains and how food webs are related to food chains. Part B of problem 2 asks students to draw a food web and explain their answers to part A. The act of drawing a food web is included so that students have a more tangible example of the similarities and differences between food webs and food chains. They are encouraged to see how chains interlock and overlap to form webs.

Problem 3 introduces a source web (a food web that begins from a common food source). It is designed to correct the misconception that a change in a predator population will not affect another predator population sharing the same food source. This is the misconception tested by question seven in the pretest. The students are given a scenario that is of some interest to many of them as hunters or animal enthusiasts. The mountain lion was chosen as one of the predators because of its recent appearance in local news. Students are given a graph of predator and prey oscillations similar to the one found in problem four of tutorial 2 and asked to predict the result of an increase in mountain lion population on a predator that shares the same food source. Students are instructed to draw into the graph a line that plots the second predator's population size. This encourages them to think about what would happen and translate their answer into a graphical form. It is yet another angle from which to approach the problem and gives the students additional opportunities to explain their answer.

Problem 4 continues to test this misconception that a change in one population can not be passed on to another population in the web that is in a separate food chain. The problem here is presented using the same animals in the previous problem but introduces a new prey item. The problem asks what effect a change in that particular prey item would have on all other populations in the web. The goal is for students to have more practice thinking about how all populations can be affected. Because there are many possible interpretations of the outcomes checkpoint discussion focuses on other possible interpretations. The key is for the students to come to the understanding that all populations are affected – not just the adjacent one.

Problem five expands on food webs by presenting the students with a new concept – the keystone predator. The students are introduced to a sink web (a web showing the feeding interactions leading to a top predator) from the Oregon coast. The hope is that the students will be familiar with some of the animals and will connect the material to their lives. This problem gives the students a food web that is less straight forward by introducing feeding preference and competition into the interactions, thus elaborating on their food web interpretation skills. In order to bring forward their existing ideas students are asked to make a prediction. Finally, the students are asked to think about the term keystone and come up with a biological definition. Checkpoint questions encourage students to think about the difference between a dominant species and a keystone species.

Tutorial 4

Tutorial 4 focuses on energy flow through food chains in order to deal with the misconception that energy accumulates up the food chain. Its other goal is to have the students make the connection that pyramids of biomass exist because there is increasingly less energy available at higher trophic levels. This is to say that there is less living material as you go up a food chain because energy is being "lost" out of the chain. This is why there is so little biomass of top predators and so much biomass at the producer level of plants.

Problem 1 jumps right into a discussion of energy by stating the first law of thermodynamics, that energy can neither be created nor destroyed. Part A asks students to think of examples of each of three types of energy (mechanical, chemical, and electrical) and explain how that energy can be used to do work. The goal of this thought question is to have them make the connection that energy is found in many forms and that they are familiar with it from their everyday lives. Part B asks the students to rub their hands together very fast. They are told that they are using chemical energy to do work and asked the question, "If energy is neither created nor destroyed where is it going?" The purpose of this exercise is for the students to actually experience the phenomenon that we will be discussing throughout the tutorial – that useful chemical energy is being turned into less useful forms through the transformation of energy into heat. They will feel the warmth in their hands as they rub them together.

Problem 2 moves into a discussion of the energy unit the calorie. The concept is made more tangible to the students by discussing food calories and describing the sun as a source of calories. They are reminded that when they stand outside on a hot day that they can feel the sun's energy. This links the concept to a tangible experience. The annual incident solar energy striking a field is then put in terms of Snickers bars. They are reminded that it is this energy that plants are capturing for photosynthesis.

After a discussion of the amount of energy actually being captured by plants problem three looks at respiration. The students are encouraged to look at respiration as slow combustion since combustion is a process that they are undoubtedly familiar with. They are presented with the idea that they are in a sense, slow burning fires. Part B asks, "What element must be present for a fire to burn? For animals to respire?" Part C asks, "Where do you think the energy from respiration ultimately goes?" These questions take what the students already know about the process of burning and link it to the process of respiration. After identifying the type of energy transformation that is taking place the students are asked to think about the second law of thermodynamics. This is an important step as it is part of the explanation why there is less and less energy available at higher trophic levels. The energy is being converted to more disorderly and less useful forms.

Problem 4 asks the students to predict what percentage of the energy contained in the biomass of a lower trophic level will make it into the next trophic level. This bringss forward any misconceptions that they might have before being presented with the actual numbers. The next step is to calculate what percentage of the energy found in biomass is being incorporated into biomass at the next higher level. After finding that it is roughly ten percent the students are asked where all the energy is going if not into biomass. So that they have an opportunity to recognize the trend students are asked to predict the number of calories found in a fourth trophic level. The concept is then presented graphically in a pyramid of energy and students must draw in the fourth trophic level. The key question asked in part G is, "Why wouldn't there be a fifth trophic level?" As the boxes representing energy get smaller and smaller it becomes clear that the reason there can not be a fifth trophic level is because there is so little available energy. The use of a graph helps connect this idea to the visual image of a pyramid.

Problem 5 approaches the concept of ecological efficiency from a different angle. It asks the students to think about a food chain that they are part of (grain – cow – human). The students are given a rule of thumb for ecological efficiency and asked to calculate the number of pounds of human biomass that could be produced off the same amount of grain if it is first fed to a cow or if it is consumed directly. This final problem approaches the issue of inefficiency in food chains from another angle, giving the students more practice and also linking it to a food chain they are familiar with. Possible checkpoint questions address the benefits of eating lower on the food chain and the issue of accumulation of toxins in higher trophic levels.

RESULTS AND DISCUSSION

Pretest and posttest

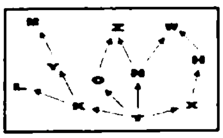
The average score on the pretest was 51 percent. This average improved to 57 percent on the post-test. From these numbers it would appear that the tutorial yielded a small return in student learning (fortunately the result of the interviews show a reasonable gain in student understanding). The sample size for the pre and posttests was limited to nine students. This is because some students joined the class too late, others left the class, and still others were not able to attend tutorial. Of the students counted in the average the majority were able to attend at least three of the tutorials. This small sample size can in no way yield statistically significant information, but it is part of the fun to analyze the results anyway.

Of the nine students in the sample five improved their score on the posttest, one maintained the same score, and three had scores that declined. An analysis of how each of the questions was answered on the pretest as compared to the posttest is as follows. A star indicates the correct choice. Normalized gain is given for each question. Normalized gain is the actual improvement divided by the total possible improvement and multiplied by one hundred.

Table 3a – j. Multiple Choice Test Results.

Table 3a.

1. Population W
   a) Feeds on populations H, X, N, and T.
   b) Feeds on populations H and N only.
   c) Is fed on by populations H, X, N and T.
   d) Is fed on by populations H and N only.



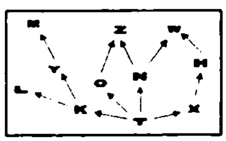
Choice:	a	b*	c	d	e
Pretest	4	3	1	1	N/A
Posttest	4	2	0	2	N/A

Question 1 showed a normalized gain of negative 16.6% (ouch). A significant number of students were drawn to distractor a of question one in both the pretest and the posttest. This choice has organism "W" feeding on all organisms lower than it in the food chain. This misconception was never directly addressed in the tutorials, as it seemed from interviews that students grasped this concept. There was clearly a need for a clarification, however. It could also be that students simply had difficulty with the abstract nature of the food web. During interviews students were shown food webs that had organisms rather than letters and had little trouble correctly interpreting many of the relationships.

Students choosing answers c or d interpreted the meaning of the direction of the arrows incorrectly. This is a misconception that is fairly well rooted. Students have a tendency to revert back to their view that an arrow shows a kind of action, as in a predator capturing its prey. It is especially easy for this reversion to take place when the organisms are abstract letters as is the case in the pretest.

Table 3b.

2. Population T
   a) Feeds on all populations.
   b) Feeds on populations K, O, N, and X only.
   c) Is fed on by all populations.
   d) Is fed on by populations K, O, N, and X only.

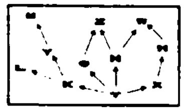


Choice:	a	b	c	d*	e
Pretest	2	1	2	4	N/A
Posttest	1	1	2	4	N/A

A normalized gain of zero percent for question 2 shows that students are consistently having trouble with the concepts tested by questions 1 and 2. Roughly half the students are getting the right idea on this question with the rest being confused about feeding relationships (choice c), the meaning of the direction of the arrows (choice b), or both (choice a). I am inclined to say that the fact that there is no improvement in this problem due partly to the difficulty of interpreting an abstract food web. The students do not have a problem with these concepts when they look at a food web with real organisms.

Table 3c.

3. What effect would a sudden decrease in population K have on population L?
   a) Population L will increase.
   b) Population L will decrease.
   c) Population L will not be affected.

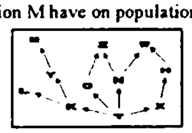


Choice:	a	b*	c	d	e
Pretest	0	8	0	N/A	N/A
Posttest	2	7	0	N/A	N/A

Most students are getting this problem right in both the pretest and the posttest, but here the normalized gain is works out to be a negative 100%. It is impossible to tell if the students answering with choice a are doing so because they misinterpreted the meaning of the direction of the arrow between the predator and prey. One of the two students left the preceding questions blank and the other was inconsistent between the two. This concept was covered in tutorial and was easily grasped by all students in the pre and post interviews when real animals were used instead of letters.

Table 3d.

4. What effect would a sudden increase in population M have on population Y?
   a) Population Y will increase.
   b) Population Y will decrease.
   c) Population Y will not be affected.

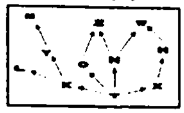


Choice:	a	b*	c	d	e
Pretest	2	4	3	N/A	N/A
Posttest	2	6	1	N/A	N/A

Question 4 tests the same concept as question 3 but from the top down so it is surprising to see that students had less understanding initially. The normalized gain was 40% so there was some improvement. Problem 4, tutorial 2 approached the predator-prey relationship from both top and bottom so in that sense it was probably useful in helping to increase student understanding.

Table 3e.

5. What effect would a sudden decrease in population K have on population M?
   a) Population M will increase.
   b) Population M will decrease.
   c) Population M will not be affected.

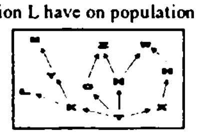


Choice:	a	b*	c	d	e
Pretest	1	6	2	N/A	N/A
Posttest	0	8	1	N/A	N/A

Normalized gain for question 5 was 66%. Students showed a fairly good initial understanding of the concept that a change in one population affects a population not directly adjacent in the food web. Only one student misinterpreted the nature of the affect while two students thought there would be no effect. Problem 1, tutorial 3 addressed this misconception and it appears that it was effective as no students misinterpreted the effect and only one still believed that there was no effect (she hung on to that belief!).

Table 3f.

6. What effect would a sudden increase in population L have on population T?
   a) Population T will increase.
   b) Population T will decrease.
   c) Population T will not be affected.

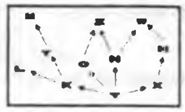


Choice:	a*	b	c	d	e
Pretest	2	4	3	N/A	N/A
Posttest	2	6	1	N/A	N/A

Question 6 dealt with the same misconception but from the top down. Again when the concept was approached from the top down the students showed less initial understanding. Only two of the nine students answered correctly initially. It is surprising that only two students answered correctly on the posttest because the problem (mentioned above) designed to educate the students approached the concept from the top down. The majority of students ended up being confused about the nature of the effect (whether it was an increase or decrease). Looking on the bright side it is good that an increasing number of students realized that there was at least an effect! The number of students selecting the "no effect" option decreased, if only to increase the number selecting the wrong effect. The normalized gain ended up being zero percent after all.

Table 3g.

7. What effect would a sudden increase in population L have on population Y?
   a) Population Y will increase.
   b) Population Y will decrease.
   c) Population Y will not be affected.



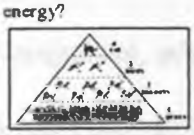
Choice:	a	b*	c	d	e
Pretest	3	2	4	N/A	N/A
Posttest	1	6	1	N/A	N/A

Question 7 showed a normalized gain of 57.1%, the highest yet. While student answers ranged the gamut, most initially selected choice c ("no effect"). This misconception that a change in one population will not affect another predator sharing the same prey item was common among the students. Tutorial 3 dealt with this misconception in problems three and four both and it seems that it was effective in increasing student understanding. The posttest only showed two students split between the distractors while all the others selected the correct answer.

Question 8 proved to be very challenging for the students and was left blank by many of them on both pre and post assessments. It is notable that of the students who did answer, all but one failed to recognize the less direct T-O-Z-N-W pathway.

Table 3h.

9. Which level in the pyramid contains the greatest total energy?
   a) Level 1
   b) Level 2
   c) Level 3
   d) Level 4
   e) They all contain equal amounts of total energy.



Choice:	a*	b	c	d	e
Pretest	4	0	0	3	2
Posttest	7	0	0	0	2

Another successful approach to misconceptions occurred in tutorial 4 dealing with energy flow in food chains. Students showed marked improvement in their understanding of this concept as tested by question 9 with a normalized gain of 60%. Distractor e (that all levels in a pyramid of energy contain equivalent amounts of energy) was able to draw students in both pre and posttests. It is noteworthy that no students selected the previously common distractor that the highest level in the food chain contained the most energy. Tutorial 4 seems to have been effective in helping students to understand the pyramid of energy.

Table 3i.

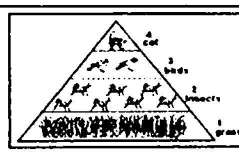
10. Each level in the pyramid of energy
    a) Contains an amount of energy equivalent to all lower levels added together
    b) Contains more energy than the level just beneath it.
    c) Contains the same amount of energy as all other levels
    d) Contains only a fraction of the energy found at the level just beneath it.

Choice:	a	b	c	d*	e
Pretest	0	3	3	3	N/A
Posttest	0	2	2	5	N/A

Question 10 continues to deal with the concept of energy flow through a food chain. Students were evenly split between two distractors. One was that each level in a pyramid of energy contains more energy than the level beneath it (same as d above) and the other was that each level in the pyramid contains equivalent amounts of energy (same as e above). A normalized gain of 33.3% showed that students were fairly consistent in their improving understanding of the concept of energy flow in food chains.

Table 3j.

11. Level 1
    a) Gets its energy from the soil.
    b) Gets its energy from the sun.
    c) Gets its energy from the air.
    d) Makes its own energy.



Choice:	a	b*	c	d	e
Pretest	1	2	2	4	N/A
Posttest	0	7	0	2	N/A

By far the most dramatically successful correction of a misconception, the normalized gain for this question dealing with the source of energy for plants was 71.4%! Initially, the majority of students were misguided, selecting from three distractors. The most popular distractor was that plants make their own energy (choice d) and the second most popular was that plants get their energy from the air (choice c). One student said that plants get their energy from the soil. Perhaps the reason that so many of the students were able to correct this misconception was that it was dealt with in every tutorial. In tutorials 1, 2, and 3 it was a major focus. Repetition seems to be helpful in improving student understanding. In all questions that had the highest normalized gain (5, 7, 9, and 11) the concepts were dealt with at multiple points within the same tutorial or even in more than one tutorial.

Interviews

Initial interviews revealed that no students had any misconceptions regarding the concept of ecosystem. All of the students were able to identify the ecosystem as made up of all the living and non-living things. Each student was also able to easily recognize which animal was eating which other animal in a food web. This was not so easily done in the pretest as evidenced by the scores on problems one and two. Students who were asked the pretest questions using the arctic food web as a reference were all able to answer correctly questions that asked them to predict the result in a change in one population on its predator or prey. All but one of them were also able to explain the effect a change in one population would have on non-adjacent populations. These questions, corresponding to numbers 3 through 6 on the pretest, were asked from the top-down and bottom-up, just as they were on the pretest. The difference here was that the students had no difficulty answering correctly. The ability of the students to understand the feeding relationships in a food web with pictures of animals suggests that much of the difficulty with the pretest was due to its abstract nature.

Other concepts that were tested for were not so well understood. There were several questions for which students had no answer. Questions that were particularly difficult for them to answer asked for them to identify a primary producer and to explain why there is a pyramid of biomass. A lack of background in the subject was most likely the cause of their inability to form an answer to these questions.

When the students did have an answer, misconceptions were common. Table 2 lists the misconceptions that were discovered and the frequency with which they appeared in the pre-interviews. Frequency is listed as number of students having misconception / number questioned.

Table 4. Misconceptions discovered through student interviews.

Concept	Misconception	Frequency
Primary productivity	Plants get their energy from a source other than the sun.	5 / 8
	A primary producer is any organism.	2 / 8
	Primary producers are invertebrates such as worms or insects.	1 / 8
Food web	A change in one population only affects directly connected populations.	2 / 8
	A change in one population has no effect on a non-adjacent population separated by one link in the food chain.	1 / 4
	A change in one population has no effect on a population that shares the same prey item.	4 / 4
	A change in one population in the food web can only be transmitted through unidirectional chain-like pathways in the food web.	4 / 4
Energy	A pyramid of biomass exists because of human impacts on organisms higher in the food chain.	2 / 8
	A pyramid of biomass exists because of decreased feeding lower in the food chain.	1 / 8
	A pyramid of biomass exists because animals lower in the food chain produce more offspring.	1 / 8

That plants get their energy from a source other than the sun was a very common misconception among the students. This was also clear from the results to pretest question 11. Sources of energy listed by students in interviews included water, air, and soil. This concept was dealt with on many levels in all of the tutorials. I think it was the repeated discussion of this concept that helped the students clear up this misconception. In post interviews all five students correctly identified the sun as the source of a plant's energy.

Students were also well educated on the concept of primary producer. Again, this was a concept that was dealt with throughout the tutorials. In the pre-interviews there were some students who did not know what a primary producer was and some that had misconceptions about the term. The post-interviews showed that none of the four students had any misconceptions or any difficulty identifying a primary producer.

As far as food webs were concerned the students had considerable difficulty recognizing any affects that were not immediate. Initially, students were not able to identify many organisms not directly connected that would be affected if the fox were removed from the food web. In the post interviews students were able to move past directly connected populations, following cascading effects through the food web. After being asked the question one student immediately exclaimed, "They'd all be affected!" and proceeded to explain how changes could be passed on throughout the food web. Of the four students interviewed three of them easily recognized effects reaching beyond directly connected populations, and two of the three them made the connection that most organisms would be effected to some extent.

The pretest-like questions accompanying the arctic food web confirmed that indeed students were having a difficult time with some of the less direct effects. While one in four students failed to recognize an affect on non-adjacent populations separated by one link in a food chain, all four students interviewed failed to recognize that a change in one population could be passed on to another population sharing the same prey item. This misconception was twice accompanied by the explanation that there were no arrows connecting the two animals in question. The post interview showed a dramatic improvement with three of the four students correctly explaining the effect. The fourth student also recognized the effect with a bit of extra questioning on my part.

One of the more challenging applications of the concepts of the food web is for students to recognize the pathways through which a change in a certain population at the bottom of the food web can be passed on to certain other population at the top. Initially, all four of the students only recognized the direct routes that followed up two different food chains. The third, unrecognized pathway included a step in which the effect had to be passed through a common prey item. Though it was still difficult for them to recognize this third pathway, they were able to explain it after reasoning it out. The improvement in student understanding regarding less direct effects in food web dynamics suggests that tutorial three was effective in helping students clear up their misconceptions.

The initial reactions of the students to questions about the pyramid of biomass revealed that they had little background in the subject to help them form an opinion. Those that were able to form an answer gave reasons that did not agree with the scientific explanation for pyramids of biomass. This question showed a fantastic increase in student understanding in the post-interview. Only one of the four students was unable to correctly explain why there is a pyramid of biomass and she was not in attendance for the fourth tutorial designed to educate students on this concept. Students gave eloquent explanations. Student one explained that the reason there was less biomass at the level of primary consumers (grasshoppers) than at the level of primary producers was that grasshoppers are "getting less energy than the plant has. It [the energy] gets smaller each time it goes through a trophic level." Other explanations included the figure for average ecological efficiency.

Student 2: Only ten percent is passed along. The rest of it is just wasted or turned to heat. Only ten percent of the energy in grass gets into grasshoppers.

Student 3: Ten percent gets turned into biomass. It gets lower and lower until it can't get any lower.

These three students were able to identify and explain how ecological efficiency was the reason for the pyramid of biomass. It appears that tutorial 4 was effective not only in dispelling misconceptions but also in educating the students that had no prior notions about the subject.

All four students interviewed showed a dramatic increase in their level of understanding from the pre-interview to the post-interview. They were able to correctly explain the concepts in their own words. Unlike the results of the posttest, the results of the post-interview suggest that students truly made a great improvement. It appears that the tutorials had a much larger return than indicated by the posttest. The fact that the results from the written test and interviews were so different is evidence in support of the importance of interviews to further investigate understanding.

Evaluations

Student opinion showed that, for the most part, the tutorials were on target. Students found it fairly easy to agree with the four positive statements about the tutorial (see table 5). Though there was a small to medium group of neutral parties there was usually only one student who ever disagreed with any of the statements. The majority of students (7/11) agreed that tutorials were an enjoyable way to learn and that the tutorials were an effective learning tool. Students were less agreeable about the tutorial achieving its main goals as being useful in clearing up misconceptions that they had. This lower level of agreement might be due to one or more of several factors. It could be that tutorials were not as directly confronting misconceptions as they could have been, students were less conscious of their misconceptions, or they had little prior knowledge about many of the subjects. The cooperative learning style is an integral part of the tutorials and the hope was that students would benefit from this. The majority of students felt that discussion with peers and tutorial facilitators was helpful.

Table 5.
Student evaluation results.

Students ranked their level of agreement with four statements. A fifth statement asked students to evaluate the overall difficulty level of the tutorials.

The tutorials were an enjoyable way to learn about ecology.

Level of agreement	*strongly agree*	*agree somewhat*	*neutral*	*disagree somewhat*	*strongly disagree*
# of students out of 11	3	4	3	1	0

The tutorials were useful in clearing up any misconceptions that I had.

Level of agreement	*strongly agree*	*agree somewhat*	*neutral*	*disagree somewhat*	*strongly disagree*
# of students out of 11	4	2	4	1	0

The tutorials were an effective learning tool for me.

Level of agreement	*strongly agree*	*agree somewhat*	*neutral*	*disagree somewhat*	*strongly disagree*
# of students out of 11	4	3	3	1	0

I found group-work and discussion helpful.

Level of agreement	*strongly agree*	*agree somewhat*	*neutral*	*disagree somewhat*	*strongly disagree*
# of students out of 11	3	5	1	2	0

How would you rank the difficulty level of the tutorials overall?

Difficulty ranking	*too easy*	*a little easy*	*just right*	*a little difficult*	*Too difficult*
# of students out of 11	0	5	6	0	0

Indeed, working in groups was the most common answer to the short response question, "What aspects of the tutorial did you enjoy the most?" It was clear from working with the students on tutorial day that the part they liked about working in groups was talking with each other and the tutorial facilitators (not always about ecology). Students had a great curiosity for the social life of the college-aged tutorial facilitators and many were very excited about the prospect of cute college girls and boys visiting their class. In fact one student wrote that the best part of tutorial was "having Kellie come around and help." Another interesting response was, "I just like B.S. with the groups." There was however one student who modeled the ideal response when he or she said that the best part was, "Getting to work with different people and learning what they knew compared to what I knew!" This type of peer interaction and comparison was precisely one of the goals tutorials strove to achieve.

The part students seemed to enjoy least was writing down the group's ideas. Students were very reluctant to write down complete, accurate answers for the tutorial problems. Some of the students listed not being required to write anything down as an improvement that could be made to the tutorial. Another problem that was identified and suggested as an area that could be improved was role enforcement. I agree with this evaluation. In my experience, role enforcement took a back seat to enforcement of general involvement. Before roles could be enforced something would have to be done to involve the students more in general.

General involvement might be increased by following the advice that two of the students gave in their evaluation forms. One of the recommendations was that the tutorials be more interesting. The other was that the tutorials should be more hands-on.

Interesting is certainly a quality that is in the eye of the beholder. I thought I had designed tutorials that were interesting, but in many cases they did fail to maintain student interest. Making the tutorials more hands-on could be a way to increase interest. Trying to make the tutorials more hands-on was one of the greatest challenges in writing them. After tutorial 1 I recognized that the tutorials needed to be more hands-on. Attempts to address this were made by adding in poster-making to tutorial 2, and having a tangible example of energy transformation in tutorial 4 (students rubbed their hands together very fast, converting chemical energy into heat). Within the framework of the tutorials it is hard to imagine demonstrations or activities related to primary productivity or food web dynamics. I know it is possible, though and with more time and creativity I could improve this aspect of the tutorial.

The difficulty level of the tutorials should also be adjusted. Students were split between the tutorials being slightly too easy and just right. One student recommended that the tutorials be made more challenging and in-depth. The first tutorial was in-depth and challenging. Its many subtleties very difficult for the students. In fact, it even challenged college-aged biology students and biology professors! The difficulty level was toned down for tutorial 2. Though I picked up a number of students who had been less involved before, I also lost those that were bored by the less challenging material of T2. Tutorials 3 and 4 straddled the target difficulty level, but I think the more challenging nature of tutorial 4 stimulated better discussion. With more practice the tutorials could be fine-tuned to a variety of ability levels.

CONCLUSIONS

I believe that the tutorials were a success overall, though I experienced a great deal of frustration at times due to a seeming lack of results. In talking with students during post-interviews I saw dramatic increases in each individual's understanding of the material that made me proud of their progress. Though not as often as I would have liked, there were times during discussion when students were making real connections and I could tell the light bulbs were on in their heads.

One of the more valuable parts was pre-tutorial discussion. I expected to connect with the students more during tutorial, but it was during the class discussions that I felt like I was most engaged with them. With a general outline in mind I could allow for students to provide the examples and illustrations of the concepts we were discussing. It seemed that this made it very relevant and interesting to them and many of them were active participants. They seemed to enjoy adding their perspective on the topic at hand. Many times their curiosity would be inspired and the topic of our discussion would roam into other subjects in biology or even other disciplines in science, but there always seemed to be a way to tie it all together into the framework of the lesson plan. I believe that this is a very constructivist approach to lecture in that it directly engages students' prior knowledge by letting them provide examples and control some of the direction of discussion. It also insures immediate relevance to their lives as the examples that we talk about are things that they are familiar with. By allowing a free exploration of the topic it insures that the concepts discussed are linked to more than just the particular subject of ecology. The students get practice applying their knowledge to new situations. This exploration is key in building the new framework of knowledge that is the goal of a constructivist approach.

It seems strange that discussion would be at its best in a class format rather than in tutorial groups. Then again, when you consider some of the students it is not so surprising. When I first began this project I received many warnings about hormone levels in young high school students. I had no idea! When broken into groups many of them could not be trusted to stay on task or even not to draw blood (no joke). Ideally the tutorial groups work as autonomous units working toward a checkpoint. Facilitators would only get involved when the group reached a checkpoint or if the students were stuck somehow. With a class full of raging hormones, little could be left to chance. As a facilitator I found myself taking on the role of a taskmaster and disciplinarian. Keeping the students on track was very difficult when they wanted to joke and tell stories to each other, or even worse – carve their initials into the tabletop and play with the water faucets. In addition, many students were unwilling to spend the mental energy necessary for the tutorial problems. A few of them were quite blatant about that fact, simply telling a facilitator that they did not care to learn today (but not in such polite terms!). Enforcing the roles of director, interpreter, and scribe became secondary to enforcing simple involvement in the tutorial.

I am still uncertain as to how this problem can best be tackled. One thing that helped was hand selecting the groups at the beginning of each tutorial to avoid certain negative interactions. Limiting the group size to three is also imperative. Groups of four are unmanageable and should be broken into two's if groups of three are not possible. Holding the students more accountable for the work that they do could help focus them more. As it was we had weekly quizzes on tutorial vocabulary and peer evaluations that both went toward their grade in the class. There was even a test on the material covered in tutorial. It might be better to have each student play the role of scribe in the future while the role of director and interpreter could rotate. This would insure that each student would have a written copy of his or her work in tutorial that could be handed in for a grade each week.

Another area needing work was the pretest. I am convinced that the test was too abstract for the students and therefore a poor way of assessing their true understanding of the concepts. The food web provided with the pretest would need to at least have organism names if not actual pictures. The fact that students did poorly on the posttest but were able to easily articulate the correct ideas orally is strong evidence that the pretest was a flawed assessment tool. In addition, when analyzing multiple-choice answers it is not known if the student was confused, guessing, or even expending any effort. The very nature of multiple-choice is limited in that students can choose only from a limited number of answers. If I use a multiple-choice test again a space for write-in answers will be included on many of the problems.

The interviews were invaluable as an assessment tool and could have been utilized more heavily. In the future I would develop interview questions and channel most, if not all of my investigation through this route. It is a much more efficient and accurate way to assess student understanding. There can be effective clear communication between the interviewer and subject. You can also be sure that you will be testing exactly what you set out to test. In addition to developing more questions I would increase the number of students being interviewed. Developing the interviews as an assessment and research tool would provide a more accurate and in-depth profile of student knowledge and understanding.

The initial literature research that I conducted into existing misconceptions in ecology identified misconceptions with food chains, food webs, and energy flow. If I were to take this approach to curriculum design again I would not feel limited by what the literature has identified as existing misconceptions. I am sure that misconceptions exist in all areas of ecology and that if enough study were done into the subject before designing interview questions, many misconceptions could be uncovered.

The tutorials themselves could be improved by having more problems that asked students to make predictions. The shock of having a prediction be completely wrong is a catalyst in the learning process. It provides the cognitive dissonance that is the precursor to a change in beliefs. The more students can be challenged this way, the better.

The difficulty level of the tutorials needs to be more finely tuned, but it will need to vary with any class. Tutorial 1 was too difficult, tutorials 2 and 3 too easy, and tutorial 4 just about right. One way to adjust difficulty level is through the use of checkpoints. When students were having a tough time with tutorial 1 I would skip certain checkpoints that complicated the issues. On the other hand, if students are easily grasping a problem it can be taken to the next level with a challenging checkpoint question. A possibility would be to have supplemental checkpoint material prepared such as charts and graphs that could challenge students. One of the strengths of the tutorial model is its flexibility.

Another improvement could be made if the tutorials were made more hands-on. Tutorials could benefit from the use of models that represent concepts that are being discussed. With some ingenuity a hands-on way to model food web dynamics and energy flow could be created. Another possibility would be to increase associated curriculum. For example, to accompany the tutorial on primary productivity students could have conducted an experiment growing plants under different conditions and measuring the results – possibly using biomass as a measure. Though this would not make the tutorial itself hands on the ideas being learned could be linked to a tangible experience.

On a personally level, the experience that I gained from this entire project has been invaluable. One of the most enjoyable parts was simply in designing the tutorials. Not only was it a chance for me to assimilate and synthesize a lot of interesting ecology, but it was highly creative. Planning and leading discussions with the class was the most rewarding part of my in-class experience. Capturing student interest and facilitating unexpected and interesting responses was another creative outlet that I found invigorating.

One of the greatest moments that I shared with the students occurred during our field trip to the coast to visit the salt marshes of the South Slough Estuary Reserve in Charleston. Arriving early I directed our driver, Fred out Cape Arago highway to the tide pools that were my classroom during a summer at the Oregon Institute of Marine Biology. I never imagined that I would one day be leading a school bus full of high school students to the rocky intertidal that I had come to know and love so well. Many of the students were groggy as we descended the trail to the ocean below. But in the next fort-five minutes I was to witness a transformation in all of them. Students came alive as we began to make discoveries. They wondered at everything that they saw – from a fragment of a shell or a kelp holdfast found on the beach, to the tiny crabs that scuttled for cover when a rock was lifted. The students who had been grumpy and uninterested in the classroom were now the most enthusiastic about learning. They were so eager to learn that I could barely keep up with their questions. It was a rewarding experience for all of us. For me, seeing the students so passionate was a confirmation that learning truly is a natural process for all of us and can be a source of inspiration.

APPENDIX A
ASSESSMENT TOOLS

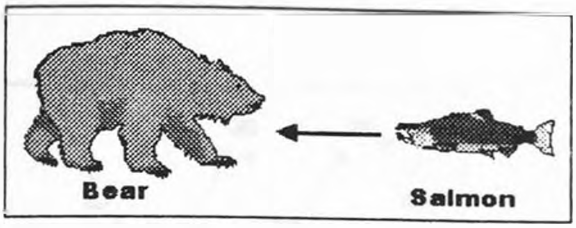


Figure 1. A feeding interaction between two organisms you are familiar with. The arrow signifies the direction of energy flow. It shows that the bear eats the salmon and gets energy by doing so.

NAME: ____________________

In a particular habitat there are many bears that make up a population of bears and many salmon that make up a population of salmon. The population of bears feeds on the population of salmon.

Consider a diagram showing the feeding interactions of *all* the different populations within a habitat. This is called a food web.

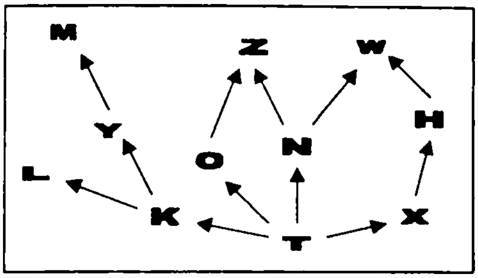


Figure 2. A Food Web.
Letters represent different populations in the web. Arrows represent energy flow.

Adapted from Griffiths & Grant (1985).

Questions 1-8 refer to Figure 2.

1. Population W
   a) Feeds on populations H, X, N, and T.
   b) Feeds on populations H and N only.
   c) Is fed on by populations H, X, N and T.
   d) Is fed on by populations H and N only.

2. Population T
   a) Feeds on all populations.
   b) Feeds on populations K, O, N, and X only.
   c) Is fed on by all populations.
   d) Is fed on by populations K, O, N, and X only.

3. What effect would a sudden decrease in population K have on population L?
   a) Population L will increase.
   b) Population L will decrease.
   c) Population L will not be affected.

4. What effect would a sudden increase in population M have on population Y?
   a) Population Y will increase.
   b) Population Y will decrease.
   c) Population Y will not be affected.

5. What effect would a sudden decrease in population K have on population M?
   a) Population M will increase.
   b) Population M will decrease.
   c) Population M will not be affected.

6. What effect would a sudden increase in population L have on population T?
   a) Population T will increase.
   b) Population T will decrease.
   c) Population T will not be affected.

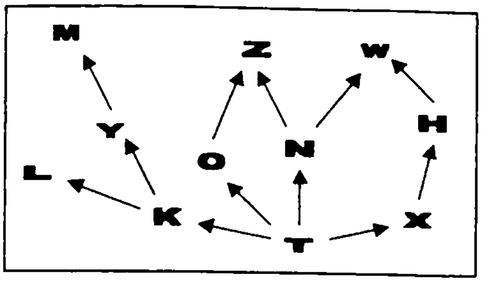


Figure 2. A Food Web.
Letters represent different populations in the web.
Arrows represent energy flow.

7. What effect would a sudden increase in population L have on population Y?
   a) Population Y will increase.
   b) Population Y will decrease.
   c) Population Y will not be affected.

8. Circle the letters of the populations through which a change in population T can be passed on to population W.

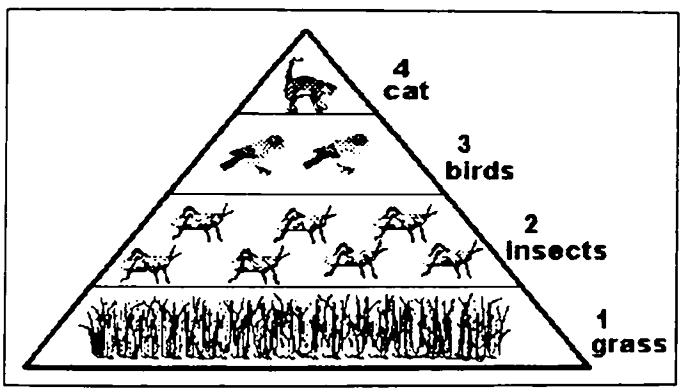


Figure 3. A Pyramid of Energy for a food chain with which you are familiar.

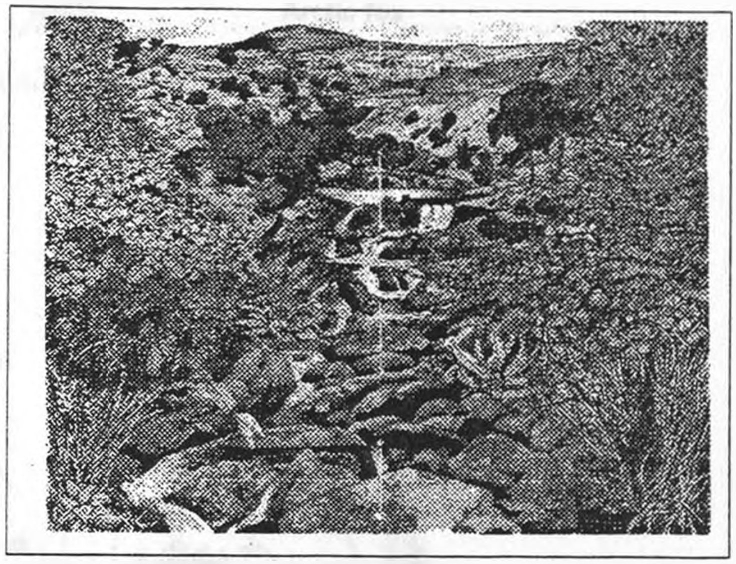
Questions 9-11 refer to Figure 3.

9. Which level in the pyramid contains the greatest total energy?
   a) Level 1
   b) Level 2
   c) Level 3
   d) Level 4
   e) They all contain equal amounts of total energy.

10. Each level in the pyramid of energy
    a) Contains an amount of energy equivalent to all lower levels added together.
    b) Contains more energy than the level just beneath it.
    c) Contains the same amount of energy as all other levels
    d) Contains only a fraction of the energy found at the level just beneath it.

11. Level 1
    a) Gets its energy from the soil.
    b) Gets its energy from the sun.
    c) Gets its energy from the air.
    d) Makes its own energy.

What parts of this picture represent an ecosystem?

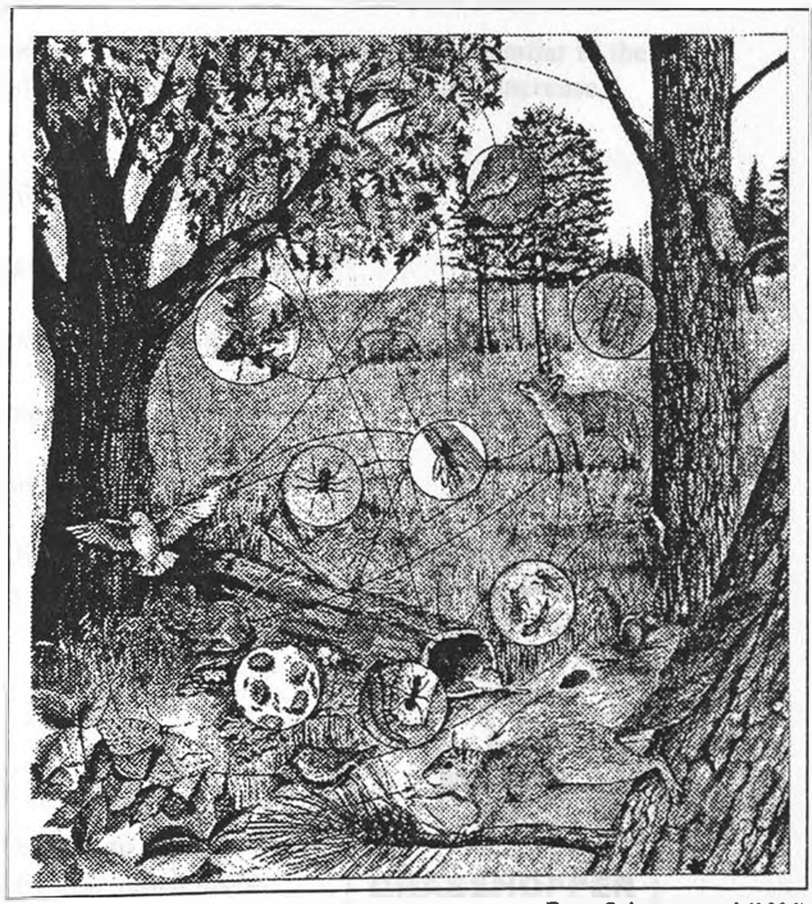


From *Nature: Day and Night*

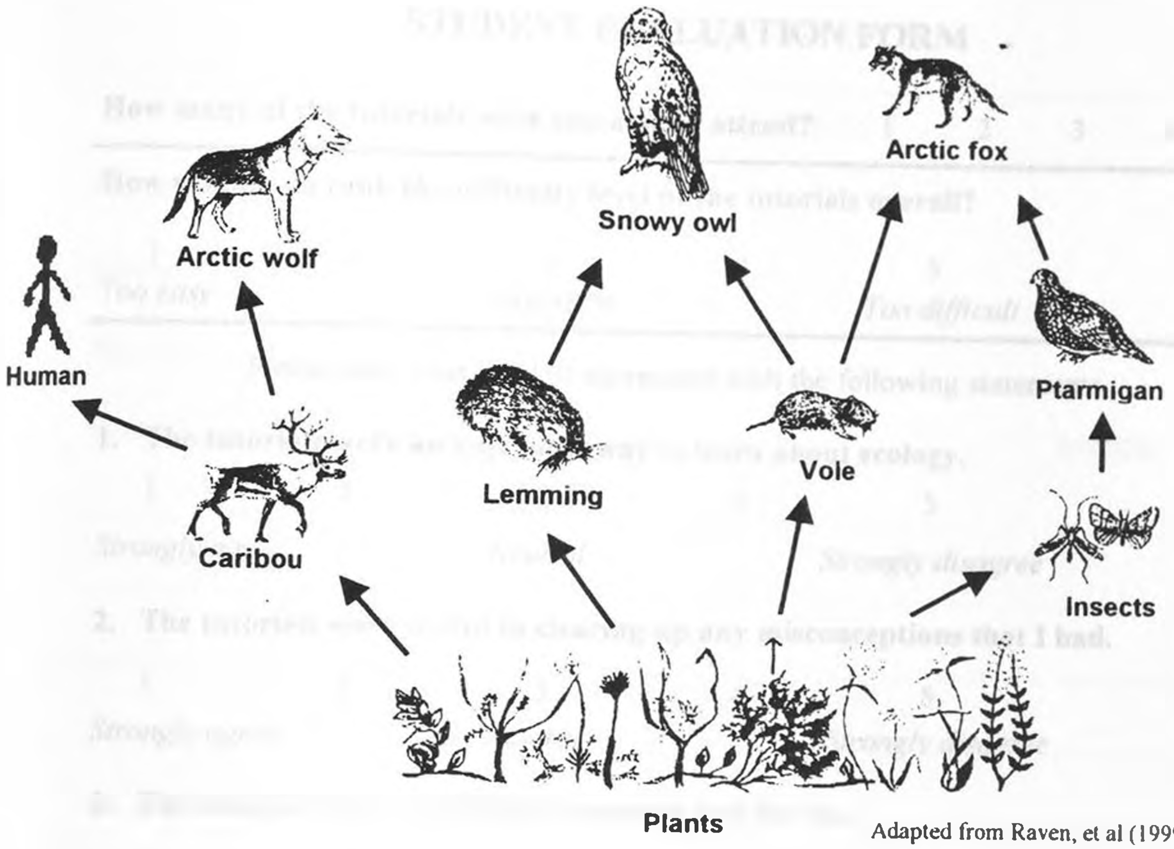
Can you identify a primary producer? A consumer? A decomposer?

Imagine that there are several farms nearby. Foxes are breaking into chicken coops and eating many of the farmers' chickens. The farmers start shooting foxes whenever they see them. Soon the foxes all but disappear from this food web.

What are all the organisms you can think of that would be affected by the disappearance of foxes?



From Solomon, et al (1996).



Adapted from Raven, et al (1999).

This is a picture of an arctic food web. I am going to ask you questions similar to the ones on the pretest. You will basically have three options for an answer: increase, decrease, or no effect.

What effect would a decrease in caribou have on wolves?

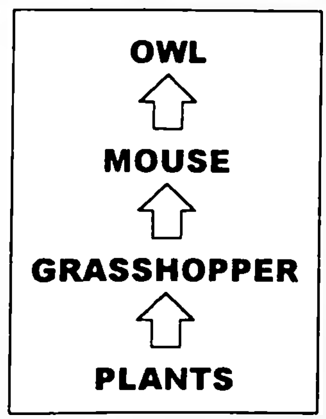
What effect would an increase in ptarmigan have on insects?

What effect would a decrease in grass have on owls?

What effect would an increase in foxes have on insects?

What effect would an increase in humans have on wolves?

Through what populations could a change in plant population size be passed on to foxes?



What do the arrows mean to you?

Where do the plants get their energy?

Why is it that in nature we see that there is so much more mice biomass (living material) than owl, so much more grasshopper than mice, and so much more plant than grasshopper?

STUDENT EVALUATION FORM

How many of the tutorials were you able to attend? 1 2 3 4

How would you rank the difficulty level of the tutorials overall?

1	2	3	4	5
Too easy		*Just right*		*Too difficult*

Please rank your level of agreement with the following statements.

1. The tutorials were an enjoyable way to learn about ecology.

1	2	3	4	5
Strongly agree		*Neutral*		*Strongly disagree*

2. The tutorials were useful in clearing up any misconceptions that I had.

1	2	3	4	5
Strongly agree		*Neutral*		*Strongly disagree*

3. The tutorials were an effective learning tool for me.

1	2	3	4	5
Strongly agree		*Neutral*		*Strongly disagree*

4. I found group-work and discussion with classmates / tutorial assistants helpful.

1	2	3	4	5
Strongly agree		*Neutral*		*Strongly disagree*

What aspects of the tutorial did you enjoy the most?

What aspects of the tutorial did you enjoy the least?

How could the tutorials be improved?

GROUP RECORD SHEET

Name: ______________________________

Name: ______________________________

Name: ______________________________

Checkpoints #	Work in progress	Initials
______	__________________________________	______
______	__________________________________	______
______	__________________________________	______
______	__________________________________	______
______	__________________________________	______
______	__________________________________	______

PEER EVALUATION SHEET

Evaluate each group member (including yourself) on a scale of 1 – 10. Take into account each group member's performance as INTERPRETER, DIRECTOR, and SCRIBE.

Name: ______________________ Score: _______

Name: ______________________ Score: _______

Name: ______________________ Score: _______

APPENDIX B
TUTORIALS

GUIDELINES FOR WETLAND ECOLOGY TUTORIALS

1. Tutorials are group problem solving sessions. Each group will consist of three members working as a team to progress through "checkpoints."

2. When your group reaches a checkpoint you will stop and discuss your answers with a teacher.

3. As you work through the tutorial each member will assume the role of interpreter, director, and scribe. These roles rotate on a regular basis.

4. The **interpreter** reads and explains any tables, graphs, or figures that accompany a problem. He or she is responsible for putting the graphical information into a verbal form.

5. The **director** guides the group toward a solution. He or she is responsible for focusing the group and homing in on the question at hand.

6. The **scribe** records the group's ideas and writes all of the answers in complete sentences that are easy to read. He or she is responsible for creating the sheet of answers that the group will share.

7. All group members are responsible for helping come up with answers and making sure their teammates understand.

8. Read each problem carefully. They contain the clues that you will need to solve them.

9. Don't get discouraged if the answer does not present itself right away. Take your time to think about the problem.

10. Be creative and have fun!

TUTORIAL 1

Topics to be covered in pre-tutorial discussion:

- **Primary productivity**

  How does this term apply to plants?

  What are they producing?

  How are they first?

- **Plant essentials**

  What do plants need to live?

  What is photosynthesis?

  What happens to the carbohydrate produced through photosynthesis?

- **Biomass**

  What is biomass?

Pre-discussion reading assignment:

Begon, M., Harper, J.L., & Colin, R.T. (1986). *Ecology*. Sunderland, MA: Sinauer Associates, Inc. p 629.

Solomon, E.P., Berg, L.R., Martin, D.W., & Villee, C. (1996). *Biology*. Fort Worth, TX: Saunders College Publishing. p 1200.

Plants are like green solar panels collecting the sun's radiant energy. Through the process of photosynthesis they convert solar energy into sugar (chemical energy). This sugar is the life-providing substance not only for the plants themselves but for <u>all</u> life on Earth. Plants are our life support system, keeping a current of usable energy flowing into our world. In addition to sugar another product of photosynthesis is oxygen. Originally, Earth's atmosphere did not contain oxygen! Over 2.5 billion years ago the ancestors of today's plants began changing the atmosphere, making it hospitable to life as we know it. **Besides food what other important things do plants provide for the world today?**

1. a) Define the following in your own words:
   - **Primary productivity**
   - **Biomass**

Check Point

Biomass can be used to estimate the productivity of an ecosystem. When scientists measure biomass they measure the **standing crop**. Standing crop is the amount of biomass contained within a volume of water or area of land at a given point in time. It is a snapshot of biomass. Biomass can be determined by weighing organisms in alive/near-alive condition (wet weight) or it can be determined by weighing organisms after complete dehydration (dry weight).

(b) Estimate the standing crop in this classroom. Are you using wet weight or dry weight? Which is a more accurate measure of biomass? Why?

(c) Describe the procedure you would use to estimate the standing crop of a mature cornfield. How would this procedure be different if you were measuring a mature potato field?

(d) How is the standing crop of plants a good indicator of the <u>overall</u> productivity of an ecosystem? When might it not be?

Check Point

2. Compare the annual primary production of some ecosystems. (measured in terms of biomass)

ECOSYSTEM TYPE	MEAN NET PRIMARY PRODUCTIVITY ($g / m^2 / yr$)
Tropical rain forest	2,200
Tropical seasonal forest	1,600
Temperate evergreen forest	1,300
Temperate deciduous forest	1,200
Boreal forest	800
Woodlands and shrubland	700
Savanna	1,500
Temperate grassland	600
Tundra and alpine	140
Desert and semidesert scrub	90
Extreme desert, rock, sand, ice	3
Cultivated land	650
Swamp and marsh	2,000
Lake and stream	250
Estuaries	1,500
Open ocean	125

a) What are some factors you can think of that affect primary productivity?

b) How do wetlands rank in terms of productivity? Why might this be?

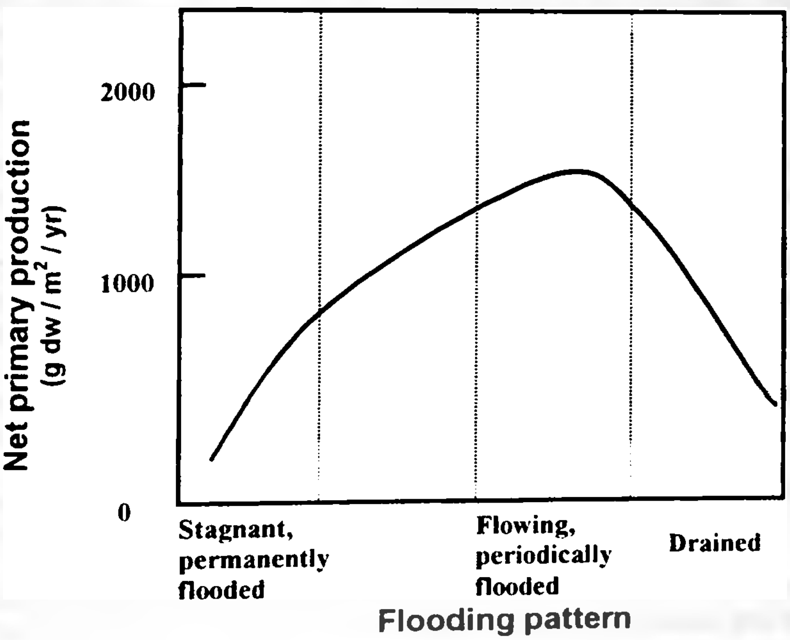
Check Point

3. There are four main types of wetlands: marshes, swamps, bogs, and fens. They each have different rates of average primary productivity. One of the main factors affecting productivity is the **hydrology** (water flow pattern). Depending on the water's source its inflow can provide important nutrients. It can also replenish the oxygen supply that becomes depleted by organisms living in stagnant or very slow flowing waters. O_2 depleted or **anoxic** conditions persist in permanently flooded soil and stagnant water. The presence of oxygen is important to plant and animal life and for the decomposition of plant material into usable nutrients.

Consider the following table of the hydrology of wetland types and the graph showing the rough relationship of primary productivity to flooding pattern.

Wetland type	Water source	Hydraulic residence time* (days)
Marsh and swamp	River	0.4 – 4
Bog	Rain	70
Fen	Groundwater	5

* the average amount of time a water molecule spends in the wetland



a) Rank the wetland types from most productive to least productive. Justify your ranking scheme.

b) Which would be more productive: a **seasonal wetland** with alternating flooded and dry periods or a wetland that is always flooded? Why?

Check Point

In the above examples the wetland types marshes and swamps are grouped together but they are actually very different. **Marshes** are filled with herbaceous (non-woody) plants that often die each year. **Swamps** are composed of large, long-living woody plants such as trees that invest a large portion of biomass in non-photosynthetic support material (trunks/branches).

c) In general marshes are twice as productive as swamps. How can this be explained in light of their different plant compositions?

Check Point

TUTORIAL 1 CHECKPOINT QUESTIONS

1. b) What if we were to weigh the class and a particular student had just consumed a lot of water? How would this throw off an estimate of standing crop?

   How would you expect % composition of water to be different from young to old? From male to female?

   What if you were to compare the wet weights of jellyfish vs. humans?

1. c) Below ground biomass often gets ignored. How could this cause an estimate of productivity to be off?

1. d) What is the difference (in terms of actual productive material) between 100 kg of grassland biomass and 100 kg of tree forest biomass?

   The standing crop is just a snapshot of biomass at a given point in time. What would happen if there was a high reproductive rate (turnover rate) coupled with heavy grazing as we see in many aquatic ecosystems? How would an inverted pyramid make sense in this case and how would looking at just the standing crop of the producers be misleading?

   How would your estimate be thrown off if you were looking at many different plants that have peaks in production during different parts of the year?

2. In light of the factors affecting primary productivity, why are deserts so unproductive? Tropical rainforests so productive? Open ocean so unproductive?

   How would you explain the difference between deciduous and evergreen forests?

3. a) How do the nutrient contents of river water, rainwater, and groundwater compare?

   At first, an increase in flow rate increases productivity. What could be the reason for the decrease in productivity as we continue to increase the flow rate?

   Why are drained wetlands less productive?

3. c) Why is it important to consider what the plants are made of?

   Why is it important to consider the life span of the plants?

TUTORIAL 1 ANSWER KEY

Medicine (taxol anti cancer drug from bark of pacific yew), lumber for buildings and furniture, fuel, paper, recreation (football field), filtration (wetland plants filter out toxins), shade, habitats for many organisms, soil stability (prevent erosion), some chemicals that are addictive, aesthetic purposes (gardens, flowers).

1. a) Rate of assimilation (gross primary production) or accumulation (net primary production) of energy and nutrients by green plants and other autotrophs.

   The weight of living material. Usually expressed as weight per unit area or volume. Can be all or part of an organism, population, or community

   b) Students should find an average weight and multiply it by the number of people. This would provide a reasonable estimate. This is wet weight. Dry weight is a more accurate measure. Wet weight varies not only in the same organism from hour to hour, but from organism to organism within the same species, and most dramatically from species to species.

   c) Students should describe the procedure in detail. What tools they would use, which parts they would cut, etc. A potato field would require measurement of below ground biomass. In fact, a complete estimate of corn biomass would also require measurement of below ground biomass. Below ground biomass can account for 40 to 80% of total biomass.

   d) Since plants are the primary producers the standing crop represents the energy available to consumers at the moment. It is the energy available to be passed up the chain. It is not a good measure when the ratio of productivity to biomass is low. An example of this would be a forest versus a grassland. The ratio of productive material to total material in grass is higher. This is because more of the material in grass is living, photosynthetic material. The ratio of productive material to total material in a forest is low. This is because there is a lot of dead support material counted into the total biomass of a tree.

   It is also not a good measure when turnover rate is high. When turnover rate is high we get an inverted pyramid for standing crop. Recall that standing crop is a snapshot of biomass at a given time. Aquatic food chains are often supported by rapidly multiplying algae, but the grazers keep the actual algae numbers low. If we were to look only at the standing crop of algae we would assume that it could not support very many grazers. But because the algae are reproducing so quickly they can actually support a standing crop of consumers larger than their own standing crop.

2. a) Water availability, nutrient availability, sunlight, length of the growing season.

   b) Wetlands rank 2nd, right behind tropical forest. In general this is due to nutrient and water availability because of flooding – Analogous to fertilization and irrigation in a farming situation. It is a subsidy. It is important to note that not all wetlands are very productive. The ones listed in the table (marsh and swamp) are the most productive.

3. a) Marsh and swamp > fen > bog. This is all because of available nutrient levels. Available nutrient levels depend on available oxygen and the water source. Available oxygen has to do with the water source and flooding pattern.

   Faster flow = shorter hydraulic residence time. This is associated with rivers. Lower hydraulic residence time means that there will be less time for oxygen to become depleted before it is refreshed. Rivers also bring in nutrients. This is why we can rank swamps and marshes above fens. Fens, though they have a short hydraulic residence time, do not get the inflow of nutrients that a river would provide. Fens are groundwater fed.

   Slower flow = longer hydraulic residence time (stagnation). Oxygen is depleted. Plant material is not broken down because of the lack of oxygen to fuel decomposition. The material is accumulated (as peat) rather than being turned into available nutrients. The only source of nutrient input that a bog has is the rainwater. Rain has a low nutrient content.

   b) Between two wetlands of the same class the seasonal one will always be more productive. This is because a dry(er) period allows for oxygen to be present and decomposition to take place. Decomposition increases the available nutrient levels.

   c) The Productivity to biomass ratios are higher in marshes. Herbaceous plants have a higher percentage of actual productive photosynthetic material than large woody trees. The other key is in the lifespan of the plants. The marsh plants die off each year allowing for the potential use of the energy stored in their biomass. Large woody trees have a long lifespan. They trap energy and nutrients and lock them away in the form of wood for decades or even centuries.

TUTORIAL 1 SOURCES

Horne, A.J. & Goldman, C.R. (1994). *Limnology*. New York, NY: McGraw Hill, Inc.
This book has an excellent chapter on wetlands that was very helpful in providing me with information for problem 3. Information for the hydrology table came from this source. The graph of productivity versus flooding pattern was also adapted from Horne and Goldman's text.

Krohne, D.T. (1998). *General ecology*. Belmont, CA: Wadsworth Publishing Company.
Problem 1c and 1d deal with the subtleties of biomass as an indicator of primary productivity. The information about above ground versus below ground productivity helped me to write part c. It also presents productivity to biomass ratios for many ecosystems which, along with some other factors, inspired me to include part d.

Mitsch, W.J. & Gosselink, J.G. (1993). *Wetlands*. New York, NY: Van Norstrand Reinhold.
Another excellent source for information about wetlands, this book provided me with information used in problem 3. Much of the information in Horne and Goldman comes from Mitsch and Gosselink.

Raven, P.H., Evert, R.F., & Susan E.E. (1999). *Biology of Plants*. New York, NY: W.H. Freeman and Company/Worth Publishers.
This was a source of information about plants for constructing the introduction to the tutorial.

Stiling, P. (1999). *Ecology: Theories and applications*. Upper Saddle River, NJ: Prentice Hall.
This book is an easy to understand approach to ecology that I found very useful. The table showing primary productivity by ecosystem type that is found in problem 2 was adapted from this text.

Estuary Teacher's Guide.
Celeste Carlisle at The South Slough National Estuarine Reserve sent this to me so that I could prepare for our field trip to the salt marsh. It has some good ecology curriculum in it. Problem 1b is taken directly from one of the labs.

TUTORIAL 2

Topics to be covered in pre-tutorial discussion:

- **Food chains**

  Construct a food chain with three members on the board.

  What direction should we draw arrows if they are to represent energy flow?

  Discuss definitions of primary producer (autotroph) and consumer (heterotroph).

  Discuss definition of trophic level (feeding position).

  Label the producer, consumers, and trophic levels of the constructed food chain.

- **Grazing food chain vs. detrital food chain**

  What is a grazing food chain?

  Discuss definition of detritus.

  Construct a detrital food chain on the board.

  Student prediction: Which is more prevalent in nature, the grazing or the detrital food chain?

- **The nutritional nature of plants**

  Discuss the difficulty of digesting plants due to high fiber content.

  Discuss the importance of bacteria and fungi; examples of animal adaptations for cellulose digestion (rumination in cows)

Pre-discussion reading assignment:

Beeby, A. & Brennan, A. (1997). *First ecology*. London, England: Chapman and Hall. pp 123-124, 126.

ALL FLESH IS GRASS.

1. Did you eat grass for lunch today? I bet that you did! Make a list of all the food items you had for lunch – and remember…*you are what you eat.*
   a) In what ways did you eat grass (or other plants) for lunch today? Think of all the ways you can. Include both the direct and the indirect ways you ate plants.
   b) Read the above quote. How is this ancient bit of wisdom true?

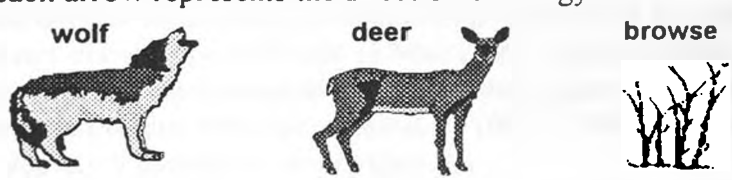
   It has been said that all animals have signed a "green pact." A pact is a contract.
   c) In what way are animals bound to a lifetime contract or "green pact" with plants?
   d) If animals have signed a green pact what kind of pact have plants signed?
   e) A professor of biology once said, "biology is the study of plants and their parasites." In a sense this is true. How so?

Check Point

2. Define the following terms in your own words:
   - **Food chain**
   - **Primary producer**
   - **Consumer**
   - **Trophic level**

Check Point

3. When biologists draw food chains they use arrows to show the direction of energy flow between the organisms. One organism makes a meal of another and gets energy by doing so. Another way to think of this is that the arrows show whose stomach an organism will end up in. Draw arrows into the food chain below. Make sure that the direction of each arrow represents the direction of energy flow.



Check Point

   Now construct a food chain of your own using animals you are familiar with. Draw this food chain with markers on the poster paper provided to your group. *Be sure to keep drawing your arrows so that they represent energy flow!*
   a) How many trophic levels does your food chain have? Label each trophic level.

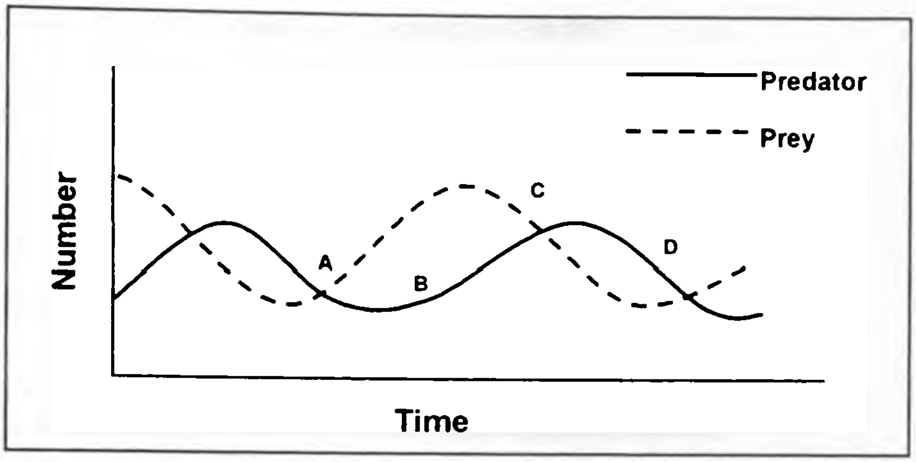
   Organisms are given titles according to their place in a food chain.

   - **producer**
   - **primary (1st) consumer**
   - **secondary (2nd) consumer**
   - **tertiary (3rd) consumer**
   - **quaternary (4th) consumer**

   b) Label each trophic level in your food chain with the appropriate title from above.
   c) List as many predator-prey relationships as you can think of.
   d) If your food chain does not contain a human think of one that does. If your food chain already contains a human think of one that does not.

Check Point

4. The figure below shows the variation in population size of a predator population and a prey population through time.



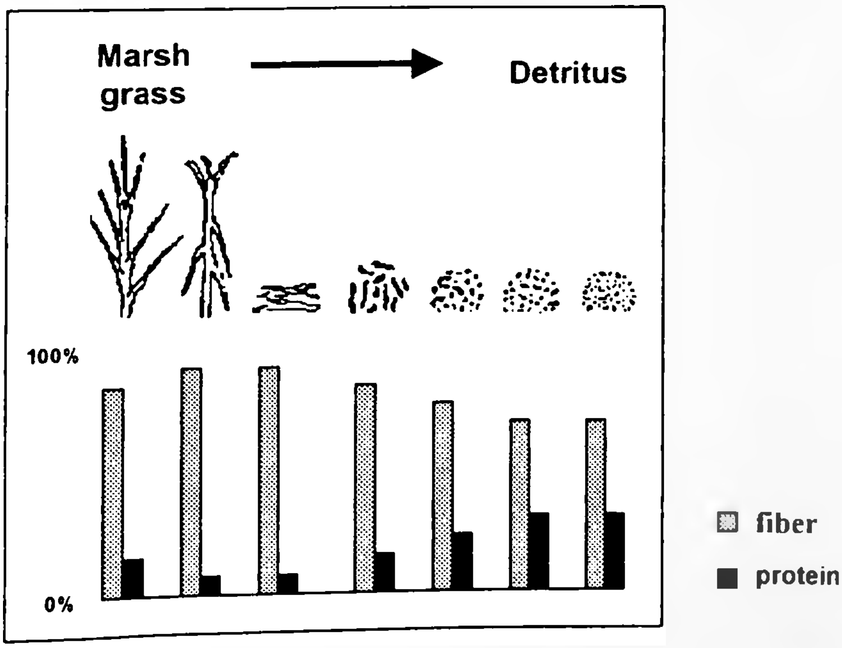
a) Why is the prey population rising at point A?
b) Why is the predator population rising at point B?
c) Why is the prey population falling at point C?
d) Why is the predator population falling at point D?
e) What pattern do you see in this predator-prey relationship?

Check Point

5. As you know plants make up the base of the food chain. A food chain that begins with an animal eating a living plant is called a **grazing food chain**. It is important to note that there is another kind of food chain that in general is more important than the grazing food chain. This is the **detrital food chain** and it begins with a decomposer eating **detritus**. Detritus is the dead organic matter or other plant and animal waste existing in an ecosystem. Fallen leaves on the forest floor are an example of detritus.
a) Think of a kind of detritus and build a food chain that begins with it as the source.

In wetlands the detrital food chain dominates over the grazing food chain. In the South Slough salt marshes we will visit in May there is some grazing of plants by animals but most of the plant material enters the food chain as detritus. Recall that plants contain little protein and a lot of cellulose (fiber). This fiber is impossible to digest unless you are a bacterium or a fungus.

Consider this graph showing how the % composition of protein and fiber per pound of material change as the marsh grass is degraded into finer and finer detritus.



b) What is causing the marsh grass to degrade?
c) What advantage do animals stand to gain by consuming detritus rather than living plant meterial?

Check Point

TUTORIAL 2 CHECKPOINT QUESTIONS

1. What would happen if there were suddenly no plants on Earth?

2. What is a decomposer?

3. What trophic level does a decomposer occupy?

   How could a human occupy more that one trophic level?

4. Why don't the two population cycles line up? What causes the delay?

5. In the last tutorial we learned that oxygen is essential for decomposition. Without oxygen bacteria and fungus can not break down plant material.

   What will happen to the plant material if there is no oxygen?

   In what way will this affect productivity?

   How have humans exploited this kind of situation? (fossil fuels)

TUTORIAL 2 ANSWER KEY

1. a) Directly or indirectly, all that we eat comes from plants. If it is an animal food then that animal ate plants or another animal that ate plants.

   b) All flesh is grass because in order to make flesh we must eat grass (plants) – or the flesh of something that eats plants, or the flesh of something that ate the flesh of something that ate plants…and so on.

   c) Animals depend on plants to bring energy into the system of living things. They depend on plants to form the base of the food chain. This is the "contract" we signed.

   d) Plants have signed a "sun pact." They are dependent on the sun for energy.

   e) You could think of all plant matter as a single organism finding its energy in the sun and animals as a single organism parasitizing the plant organism for energy.

2. <u>Food chain</u>: The trophic relationships between a series of organisms.

   <u>Primary producer</u>: An autotroph. Organisms that make their own food. (Plants and chemosynthetic bacteria.)

   <u>Consumer</u>. Heterotrophs. Any organism that does not make its own food.

3. Arrows should be drawn from browse to deer and from deer to wolf. There are three trophic levels in this food chain. The browse is the primary producer, the deer is the primary consumer, and the wolf is the secondary consumer. There are two different predator-prey relationships.

4. a) The prey population is rising at point A because the predator population is low.

   b) The predators are rising at B because the prey population is high.

   c) The prey population is falling at point C because predators have increased.

   d) The predator population is falling because the prey population has decreased.

   e) The pattern is that the predator population shadows the prey population.

5. a) Dead leaves on the forest floor are eaten by slugs. A small bird eats the slug. A fox eats the bird.

   b) If animals let bacteria and fungi go to work on plant material the result is that the plant material that is left has a lower percentage of difficult to digest fiber. The relative protein content has increased as well. The partially decayed detritus is more nutritious pound for pound than living plant material. Bacteria and fungi themselves can also be nutritional.

TUTORIAL 2 SOURCES

Beeby, A. & Brennan, A. (1997). ***First ecology.*** **London, England: Chapman and Hall.**
The quote at the top of the page comes originally from the Bible but I discovered it at the beginning of the chapter on ecosystems in Beeby and Brennans text. This book ended up being my favorite general ecology text because of the interesting perspectives found in its pages. The information is presented in a unique way and it also takes the human animal into consideration. This source also had useful information on the detrital food chain. In addition it aided me in designing problem 4. The graph of population size versus time was adapted from a section on predator-prey relationships.

Mitsch, W.J. & Gosselink, J.G. (1993). ***Wetlands.*** **New York, NY: Van Norstrand Reinhold.**
An excellent source for wetland information this book provided me with information about the detrital food chain in salt marshes. The graph for problem 5 was adapted from here.

Oregon State University Sea Grant College. ***Estuary: An ecosystem and a resource.***
Celeste Carlisle at The South Slough National Estuarine Reserve sent this to me so that I could prepare for our field trip to the salt marsh. It has useful information about the detrital food chain in salt marshes that helped me to write problem 5.

Rosenthal, Fran.
Fran is the education coordinator at the Mt. Pisgah Arboretum. During nature guide training she taught me that asking kids the question, "Did you eat grass today?" can get an interested response. It is a fun and educational question to ask kids when we are on the trail so I thought I would apply it to tutorial. Everybody eats grass!

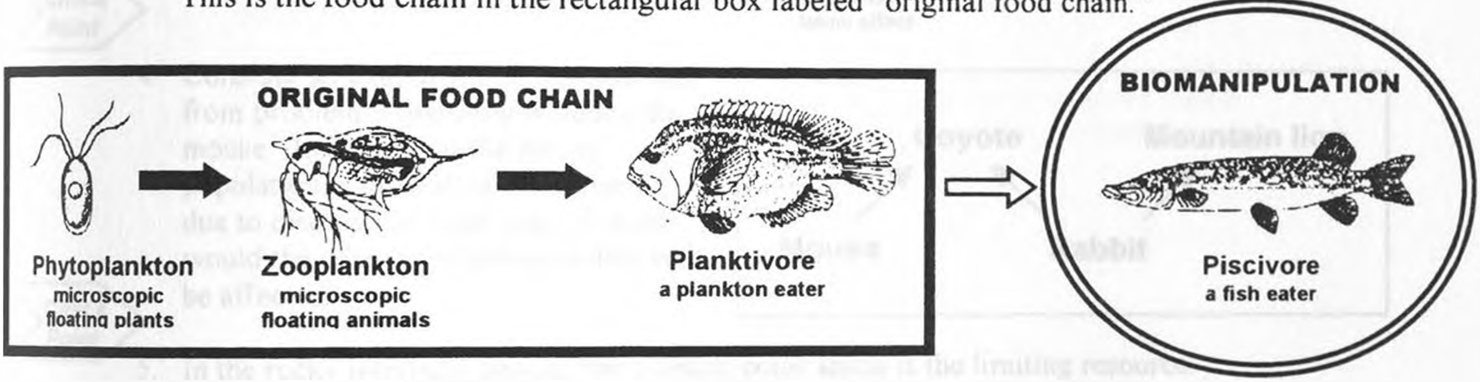
1. Case study: *Lake Mendota, Madison, Wisconsin*

Recall from tutorial one that an increase in nutrients often leads to an increase in plant production. If a farmer fertilizes his field he will get his plants to produce more. Likewise, an ecosystem that has nutrients added to it will produce more plant material. This is exactly what happened in Lake Mendota – but not on purpose.

Manure from nearby farms and soil nutrients from construction sites was carried into the lake by runoff when it rained. All of this nutrient input led to great blooms of algae within the lake. Sometimes these blooms were so dense that you could not see past the surface of the water. As the oxygen supply became depleted by the large amounts of decomposing algae the health of the lake began to suffer.

Everyone agreed that something would have to be done. But what? Filtering out algae would help but it would be impossibly laborious. Plant poison would kill algae but it would also harm other life in the lake. How could they save the lake?

Consider the following diagram of the pre-existing Lake Mendota food chain. This is the food chain in the rectangular box labeled "original food chain."



After a great deal of study, scientists decided to try the risky tactic of **biomanipulation**...and it worked! Biomanipulation is the shaping of the environment through biological means. In this case stocking the lake with a piscivore changed the environment in such a way that there was no longer an algae problem.

The circle to the right of the original food chain represents the biomanipulation.

a) How could the introduction of a fish predator solve the algae problem?
b) What would happen to the algae population if another fish-eater (a two legged piscivore with a fish-catching tool) were tacked on the top of this food chain?

Check Point

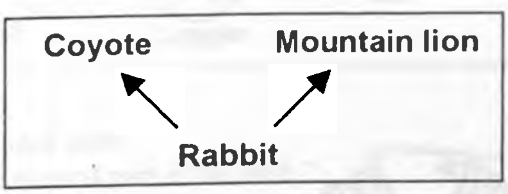
The phenomenon that occurred in Lake Mendota is called the **trophic cascade.**

c) Explain the term trophic cascade in your own words.

2. a) What is a food web? How is it different from a food chain? How is it related?
   b) Draw an example of a food web and explain your answers to part a.

Check Point

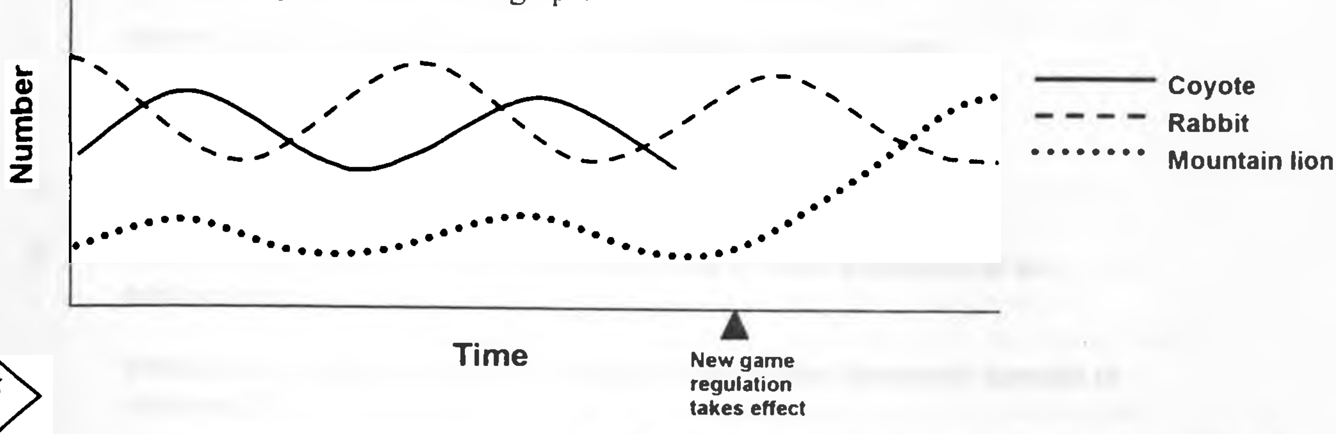
3. Consider the food web to the right. A food web like this is called a **source web**.
   a) Why do you think this is called a source web?
   b) Is this a complete food web?



Recall from tutorial 2 that predator and prey populations are closely linked and that a change in one population leads to a change in the other. (Continued on page 2)

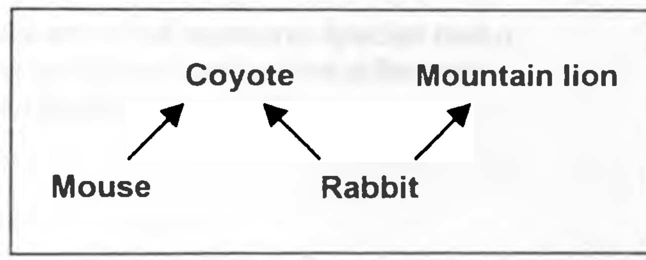
Imagine that at a certain time the mountain lion population increases due to a new game regulation that makes it illegal for them to be hunted. Consider the graph below showing how the populations of the three animals vary through time.

c) What will happen to the coyote population? Why?
Draw your prediction on the graph.



Check Point

4. Consider an expansion of the food web from problem 3 that now includes the mouse. Imagine that the mouse population is dramatically decreased due to disease. In what way, if at all, would the other populations in this web be affected?



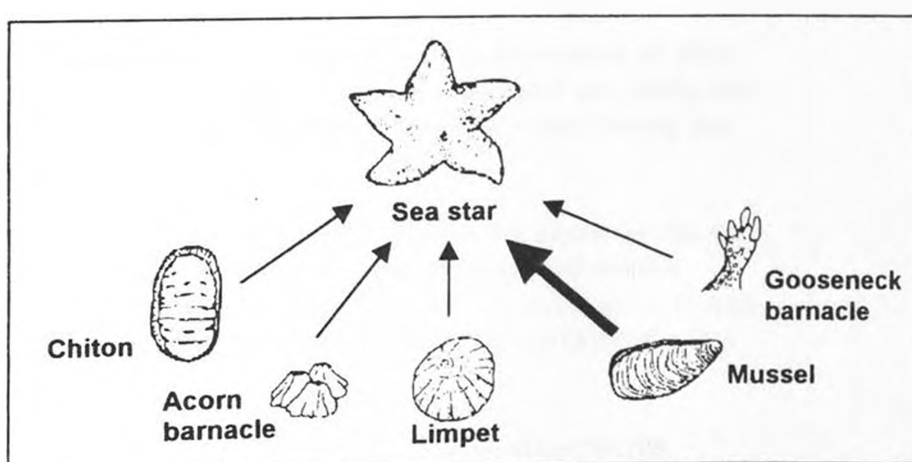
Check Point

5. In the rocky intertidal zone of the Oregon coast space is the limiting resource. Organisms compete fiercely with one another to determine who will get to settle down on the rock. It turns out that the mussel (a little black shellfish that looks like a long skinny clam) is the best competitor by far. If their growth goes unchecked they will easily crowd out all other organisms by covering the rock like a crunchy carpet.

Consider this **sink web**.

a) Why do you think this is called a sink web?

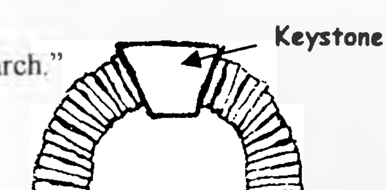
b) With sea stars removed how would you expect the prey populations to change?
Note: the weight of the arrow shows the feeding preference.



Check Point

The sea star is a **keystone species** in the intertidal zone.
The dictionary definition of a keystone is "the central part of an arch."

c) How is the term keystone fittingly applied to the sea star?
d) Come up with a biological definition for keystone species.



Check Point

TUTORIAL 3 CHECKPOINT QUESTIONS

1. Can you think of any other examples of biomanipulation?
   Pest control using insects (aphids and ladybugs)

   Identify the primary producer and name the trophic levels.

   Who is the grazer?

3. What other possible outcomes can you think of?

5. The dominant species is the species that is most abundant in an ecosystem.

   What sort of effect would you expect to see if the dominant species is removed?

   Removal of either the dominant species or the keystone species has a great effect on an ecosystem. How would you explain the difference between a dominant species and a keystone species?

TUTORIAL 3 ANSWER KEY

1. a) The introduction of a piscivore will cause a trophic cascade. A reduction in planktovores will lead to decreased predation on zooplankton which will lead to an increase in zooplankton populations which will lead to increased grazing on algae which will lead to lower concentrations of algae in the lake.

   b) The resulting trophic cascade would lead to an increase in algae.

2. a) A food chain shows the linear feeding interactions between some organisms. A food web shows the feeding interactions between all the organisms in a community (or at least many of them). It is made up of many interlocking and overlapping food chains. Sometimes food webs will only highlight certain features of a community's feeding interactions. Examples of this are the sink web or the source web. A sink web shows all the feeding interactions that lead to a single top predator (the sink). A source web shows all the feeding interactions that arise from a single food source. Any drawing of a food chain should be branching and non-linear.

3. The population of coyotes should fall as the population of mountain lions rises. The two animals share a common food source. If predation on the food source by one predator increases there will be less food available to support the other predator.

4. All other populations. A decrease in mouse means less food for coyotes. This could lead to two outcomes. Decreased coyotes so less coyote predation on rabbits leading to more food for mountain lions and an increase in lions.
   Or an increase in coyote predation on rabbits as they shift their diet. This would lead to a decrease in rabbits available to mountain lions and a decrease in lion numbers.

5. a) There will be a dramatic increase in mussels and a dramatic decrease in all other populations. With the sea star gone the mussels go unchecked and can easily out-compete other organisms for space. The weighted arrow shows that the sea star feeds selectively on the mussel.

   b) The term keystone makes sense here because if you remove the keystone, the arch collapses. If you remove any one of the smaller stones the arch will remain standing. Likewise, removing the keystone species results in a collapse or at least dramatic change in the ecosystem – A change greater than if you removed a less important species.

   c) The biological definition is: A species that if removed, has an effect on the ecosystem out of proportion with its biomass. If an organism is highly abundant sure, its going to be devastating to remove them. This is the dominant species. But the keystone species has effects larger than you would expect for the biomass present.

TUTORIAL 3 SOURCES

Begon, M., Harper, J.L., & Colin, R.T. (1986). *Ecology*. Sunderland, MA: Sinauer Associates, Inc.
The graphics for problem 5 were adapted from this text.

Carpenter, S.R., Kitchell, J.F., & Hodgson J.R. (1985). Cascading trophic interactions and lake productivity. *Readings in ecology*. England: Oxford University Press.
Last summer I attended a presentation by James Kitchell where he explained much of the theory and research behind the trophic cascade. When I began thinking about designing food web problems this article stood out as a perfect case study. The case study presented in problem 1 of is based on the work done by these researchers in Lake Mendota.

Krebs, C.J. (1994). *Ecology*. New York, NY: HarperCollins College Publishers.
The individual organism graphics in problem 1 were adapted from this book.

Stiling, P. (1999). *Ecology: Theories and applications*. Upper Saddle River, NJ: Prentice Hall.
Returning to this nice general text, I found a nice comparison between the concepts of dominant and keystone species. After my experiences at the coast and my newfound understanding for the keystone species concept I was inspired to write problem 5.

TUTORIAL 4

Topics to be covered in pre-tutorial discussion:

- **Energy**

  What is it?

  Discuss definition according to physicists.

  Discuss first law of thermodynamics focusing on the energy transformation occurring in a burning log. How did the energy get in the log in the first place?

  Discuss second law of thermodynamics in light of the burning log.

  Discuss chemical potential energy and how breaking bonds releases energy.

  Demonstrate energy transformations and stored energy with large rubber band.

- **Photosynthesis and respiration**

  Discuss photosynthesis and respiration in light of energy storage and release.

  What are the pathways for carbohydrate in an organism? (respiration and growth)

- **Other reasons why energy transfers are inneficient**

  Discuss utilization, egestion, and assimilation.

Pre-discussion reading assignment:

Beeby, A., Brennan, A. (1997). *First Ecology*. London, England: Chapman and Hall. pp 123-124, 126.

1. Physicists define energy as the ability to do work. The **first law of thermodynamics** states that energy can be neither created nor destroyed – merely transformed.
   (a) Energy exists in many forms. Some examples are mechanical, chemical, and electrical. Give an example of each of these forms of energy and state how this energy could be used to do work.

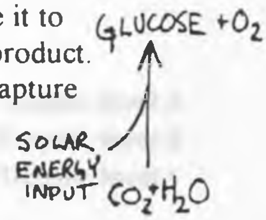
   (b) Rub your hands together very fast for several seconds. You are using chemical energy to do work. If energy is neither created nor destroyed where is it going?

Check Point

2. Energy is measured in many ways. A unit of energy that you are familiar with is the calorie. A calorie is the amount of energy it takes to raise 1 gram of water 1 degree Celsius. Note: Calories listed on food labels are actually kilocalories (1000 cal).

   When we stand in direct sunlight on a warm day on Earth we quickly become aware that the sun is sending calories our way. In fact, one square meter of a field in Michigan was measured to have received 471 million calories of solar radiation in a year. This is the same amount of calories contained in 2,770 king size snickers bars!

   Through the process of **photosynthesis** plants capture the sun's energy and use it to manufacture glucose (sugar) out of carbon dioxide and water. Oxygen is a byproduct.

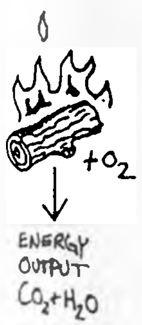


   (a) What percentage of the incoming light do you predict plants will actually capture and turn into food?
   (b) What kind of energy transformation is taking place in photosynthesis?

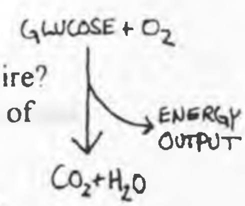
   The actual number of calories **assimilated** (captured as energy) is only one percent.
   (c) If the plants only capture one percent of the incoming solar radiation where does the rest of it go?

Check Point

3. Let us now consider just the energy that is actually assimilated by the plant – solar energy captured and stored in the form of glucose (chemical energy).
   (a) This energy has two possible pathways within the plant. What are they? Hint: think about how you use the food you eat.



   Recall that breaking chemical bonds releases the potential energy that was stored in them. When you burn a log you are breaking the chemical bonds and releasing the energy stored in those bonds. This same process of burning happens in plants and animals – only very slowly! It is called **respiration**. The process of respiration uses oxygen to break down organic compounds (glucose) and release the chemical energy stored in them. The byproducts of both respiration and combustion are carbon dioxide and water. You are a slow burning fire!



   (b) What element must be present in order for a fire to burn? For animals to respire?
   (c) Where do you think the energy from respiration ultimately goes? What kind of energy transformation is taking place?

   The **second law of thermodynamics** states that energy tends to be transformed into less useful forms.
   (d) How does the second law of thermodynamics hold true for the process of combustion or respiration?

Check Point

4. The energy leftover after respiration can be incorporated into growth of biomass. Recall that the biomass of plants represents the energy available to primary consumers (herbivores).

   (a) What percentage of the energy that is found in plant biomass do you think is assimilated into herbivores?

Check Point

Consider these calorie figures for a food chain.

Trophic level	Caloric content (calories)
3 : small birds	6500
2 : insects	65000
1 : plants	643000

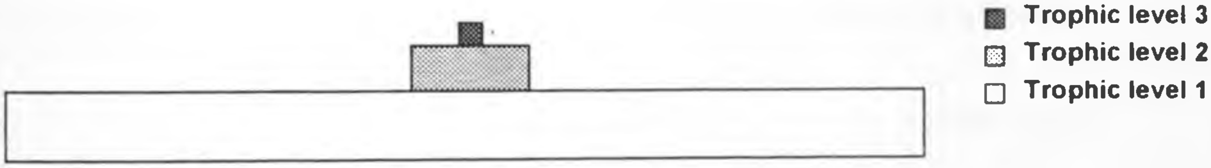
BIRDS
↑
INSECTS
↑
PLANTS

   (b) About what percentage of the energy found in biomass from a lower level gets turned into biomass at the next higher level? Where is all the other energy going if it is not going into biomass?

   (c) Keeping in mind the pathways energy has taken so far, about how many calories would you expect to find in a fourth trophic level occupied by a hawk?

Check Point

Consider the following pyramid of energy. Each block represents the energy contained in a particular trophic level.



   (d) Why does the pyramid look the way it does?
   (e) Draw in a block representing the energy content found in the fourth trophic level occupied by the hawks.
   (f) Why wouldn't there be a fifth trophic level?

Check Point

5. A good rule of thumb is that only 10% of the energy found at a given trophic level will be assimilated into the next trophic level. The percentage of energy found in the biomass of one trophic level that is incorporated into the next is called the **ecological efficiency**. Another way to say that the average ecological efficiency is 10% is that it takes 100 lbs. of grain to make 10 lbs. of beef to make one lb. of human. Ecological efficiency is actually quite inefficient!
   (a) Say that in two years a growing human eats 100 lbs. of beef. How many pounds of biomass from beef can that human add to his or her body?
   (b) How many pounds of grain had to be grown to supply him or her with that biomass?
   (c) How many pounds of human biomass could have been made off this same amount of grain had the human eaten the grain directly?

Check Point

TUTORIAL 4 CHECKPOINT QUESTIONS

1-3. How did it all begin?

What is the purpose of life?

4. b) Have you ever heard of buffalo chips? Dung beetles? Human waste referred to instead as human "resource?" Keeping in mind energy, how is poop useful?

5. As a result of human activities, the environment contains many toxins (such as DDT) that accumulate in the flesh of animals. In light of what you know about ecological efficiency, how can you explain the fact that the toxins are doing the most biological damage at the highest trophic levels?

What advantages do we stand to gain by eating lower on the food chain?

TUTORIAL 4 ANSWER KEY

1. a) An example of mechanical energy is the energy in a rubber band when it is stretched (potential) and released (kinetic). You could do work with this by launching a projectile. An example of chemical energy is gasoline. You can do work with this by burning it in an engine. An example of electrical energy would be the energy captured at a power plant and sent into your home. You can do work with this energy by running an electric motor.

   b) The chemical energy is being transformed into heat.

2. a) Student prediction.

   b) Solar energy is being transformed into chemical energy.

   c) The rest of the radiation is mostly reflected. Some of it goes into heating up the plant.

3. a) The two possible pathways are respiration and growth of biomass.

   b) Elemental oxygen must be present in order for a fire to burn and for animals to respire.

   c) The energy from respiration ultimately goes into heat. This is a transformation from chemical energy to heat. Heat is simply kinetic energy.

   d) As combustion or respiration takes place the energy found in wood or glucose is released ultimately as heat. This heat quickly dissipates into the universe where it is no longer a concentrated, ordered form of energy like it was in the wood or glucose.

4. a) Student prediction.

   b) About 10% of the energy found in biomass at lower levels is being turned into biomass at the next higher level. Some of the energy is not eaten, of what is eaten some is not assimilated but it is egested. Of what is assimilated some is respired. Of all the energy found in a lower trophic level only the energy that is eaten, assimilated, and not respired is incorporated into biomass.

   c) With an average ecological efficiency of 10% we should see approximately 650 calories in the fourth trophic level.

   d) The pyramid looks like it does because there is less and less energy as we travel up the food chain. Because of the inefficiencies of utilization, assimilation, and respiration energy is being wasted or "lost." Only a fraction makes it into the next trophic level, thus the block representing the energy found in a trophic level is only a fraction of the size of the block beneath it.

e) The block should be very small, one-tenth the size of the block representing trophic level three.

f) There would not be a fifth trophic level because there is not enough energy available to support another predator.

5. a) That human could add 10 lbs. of biomass to his or her body from eating 100 lbs. of beef.

   b) One thousand lbs. of grain had to be grown to supply that human with that 10 lbs. of biomass.

   c) Had the human eaten grain instead, 100 lbs. of biomass could have been made instead of 10. All of these figures are completely hypothetical but serve to convey the general idea.

TUTORIAL 4 SOURCES

Ricklefs, R.E. (1997). ***The economy of nature.*** **New York, NY: W.H. Freeman and Company.**
This source was my stand by for general ecology knowledge. Anytime I needed to consult a definition this was the text I went to. It was especially useful for tutorial 4 because it has an excellent explanation of ecological efficiency and the factors that affect it.

Kormondy, E. J. (1996). ***Concepts of ecology.*** **Upper Saddle River, NJ: Prentice-Hall, Inc.**
This book was a rich source of information on energy flow in ecosystems. The numbers for incident solar radiation in problem 2 came from this text. The pyramid for problem 4 was based on pyramids of energy found here as well.

Giancoli, D.C. (1998). ***Physics.*** **Upper Saddle River, NJ: Prentice-Hall, Inc.**
Giancoli kept me straight on the first and second laws of thermodynamics, calories, and heat. It also provided me with the definition for energy given at the beginning of tutorial.

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