ADDRESSING SECONDARY STUDENT MISCONCEPTIONS IN ECOLOGY

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by

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CHAPTER I

MISCONCEPTIONS INTRODUCTION

All students enter school with their own opinions of how the world around them operates. This informal knowledge comes from the child's diverse personal experiences outside of school, including observation of family, friends, and the world; culture and the media; prior teachers' explanations and instructional materials; and the child's own manipulation of the world around them. This type of knowledge comprises the individual's reality, especially before they begin formal education in the classroom. Though these ideas may seem to work well for the child when they are young, they are typically different from the views of the science community. When a student has an idea that is different from what is generally accepted by scientists, it is called a misconception. It is the teacher's job to identify the misconceptions about a topic that students hold and initiate goal-directed formal learning so that the students are able to let go of their old opinions and misconceptions and accept the current scientific explanations.

Literature suggests that simply identifying a misconception in students and teaching with that misconception in mind is not enough to rid students of their previous ideas. Misconceptions tend to be very resistant to change and require specialized approaches in order to be overcome. "Because students have spent considerable time and energy constructing their naïve theories, they have an emotional and intellectual attachment to them" (Cakir, 2008, page 198). Even though most students do well on tests and other assessments in school, they often leave with the same (mis)conceptions they had when they entered school. These conceptions are strongly held and appear to make sense and work well for the student. Unless these beliefs are adequately challenged, the students will not change their ideas about the world and their misconceptions will continue to influence their thinking. It is up to the teacher to confront the misconceptions students bring with them to class and to help the students not only understand the correct scientific views but also incorporate them into their own cognitive scheme. If misconceptions are not tackled, new conceptions will not be fully accepted, and further learning is not likely to occur. Much literature has been done in this regard as many teachers want to know how to address misconceptions efficiently and effectively in order to bring about changes in their students' thinking.

COGNITIVE DEVELOPMENT AND STRUCTURE

Before talking about different ways of student learning, there are some important terms to define as they relate to thinking and education: cognitive, cognitive structure, cognitive ecology, and concepts. "Cognitive means 'of mind, having the power to know, recognize and conceive, concerning personally acquired knowledge,' so cognitive structure concerns an individual's ideas, meanings, concepts, cognitions, and so on. Structure refers to the form, the arrangement of elements or parts of anything, the manner of organization; the emphasis on the way those elements are bound together" (Pines, 1985 in Cakir, 2008, page 197).

Another term for cognitive structure is conceptual ecology. A person's conceptual ecology is the relationship between their existing conceptions and a new conception. This is comprised of many different kinds of knowledge, such as past experiences, formal learning, examples, and images. An individual's conceptual ecology may determine which conditions are satisfied, depending upon whether the new conception is consistent and works with their current understanding and ideas. "A conceptual ecology helps individuals find the deeper structures and commonalities in the world, which allows them to reason causally about the observations they make, and to create knowledge which incorporates and changes conceptions" (Park, 2007, page 218). A student's conceptual structure or conceptual ecology is what will ultimately allow a student to integrate a new conception into their thinking. A teacher must challenge the students' cognitive structures in order to help them become dissatisfied with their current thinking and change their (mis)conceptions to align more closely with what scientists currently accept.

"Concepts are packages of meaning; they capture regularities, patterns, or relationships among objects, events, and other concepts. Each concept is a human invention, a way of 'slicing up' and organizing the world" (Novak, 1996 in Cakir, 2008, page 197). Educators must be careful when introducing and defining concepts to students. Oftentimes in the classroom, separate concepts are given specific definitions and boundaries. Concepts are often taught one at a time without clear linkages given between concepts. This gives students the false notion that concepts are single units. Teachers must make sure to stress the relationships between concepts, and encourage students to consider all concepts within their relationships to other concepts. The acquisition of concepts is a long process and is never complete, as each concept grows and changes when new concepts are added to one's conceptual ecology and are understood by the student.

CONCEPTUAL CHANGE

Conceptual change "describes learning as a process in which a learner changes his/her conceptions by capturing new conceptions or exchanging existing conceptions for new ones" (Cakir, 2008, page 198). The conceptual change model consists of two major components. The first component is the set of conditions that need to be met in order for conceptual change to happen. These conditions center around a concept that the student is learning about. The second component is the student's conceptual ecology or structure, which is the set of experiences and thoughts in a person's mind. The student's conceptual ecology provides the context in which the conceptual change occurs, influences the process, and gives meaning to the change.

There are several important conditions that must be met in order for real change to take place in the minds of the students. First, there must be dissatisfaction with the existing conceptions the students hold. A new conception is unlikely to replace an old one unless the old conception is seen firsthand to encounter difficulties in a situation. "The individual must first view an existing conception with some dissatisfaction before he will seriously consider a new one" (Posner et. al., 1982, page 220). Teachers usually create dissatisfaction in their students' minds with a discrepant event or other way to introduce the concept. A discrepant event is used to puzzle the observers (or students in this case), causing them to wonder why the event occurred as it did. Discrepant events that are contrary to what a person expects and causes him or her to wonder what took place results in cognitive disequilibrium. This disequilibrium causes students to attempt to figure out the discrepancy and search for a suitable explanation for the situation. Teachers must carefully guide their students during this searching phrase of discrepant events, where students are finding explanation for the situation. Educators must make sure to stress why the experimental findings do not agree with previous conceptions in order for students to truly let go of them. When a student arrives at a plausible explanation for the discrepant event, he or she will establish cognitive equilibrium at a new level. However, the students will find the new conception rational only if they have enough reason to believe that their old conceptions no longer work.

Once the students are dissatisfied with their old conceptions, the teacher is able to introduce the new, scientifically correct conception. The new conception must be intelligible and plausible to the student, and should be predicted to work in new situations. In order for the concept to be intelligible, the student must understand what it means and be able to construct a coherent, meaningful representation of the concept in their mind and see it as a possible explanation. The student must know what both the new and old conceptions mean in order for there to be some conflict between them and choosing between the conceptions necessary. "Teachers generally spend most of their time making new conceptions intelligible to their students" (Hewson and Hewson, 1984, page 7). This step does not require that students believe in the new conception, just that they understand what it means.

Plausibility is another important condition that must be met when considering a new conception. The student must believe the new conception to be true and consistent with his or her worldview and also believe that the old and new conceptions are in conflict with each other. The student must also believe that there is reason to be dissatisfied with the old conception, which reduces the plausibility of that conception. "This means that it is reconcilable with the person's present conceptions…Teachers generally assume that students will automatically do this, but we suggest that this assumption is frequently incorrect" (Hewson and Hewson, 1984, page 7). Therefore, teachers must help the students make the connections between their old (mis)conceptions and the new, scientifically acceptable connections being introduced.

Lastly, a new conception must be fruitful. There must be good reason for a person to incorporate a new conception into their conceptual ecology. The student will try out the new conception in different situations and see if it fits in with their worldview. It must solve problems, suggest new approaches, and go farther than the old conception. The individual must be convinced that the new, scientific conception is more useful than their existing alternative conception. This is what will motivate the student to change their ideas about the subject and accept the new conception. "A competing view will be accepted when it appears to have the potential to solve these problems and to generate a fruitful line of further research" (Posner et. al., 1982, page 213). Along these lines, the educator must make sure that the new conception does not sacrifice any of the benefits of the prior conception, or it will not be accepted.

When a new conception is introduced, there are several alternatives that a student must consider. Piaget determined that the first option a student will choose is to use their existing conceptual ecology to deal with the new phenomena. Piaget called this assimilation. If the student's current concepts are not adequate to allow the student to understand the new information, then the student may decide to alter their existing conceptions in order to fit the new conception into their conceptual ecology. Piaget termed this accommodation. If the new conception resolves inconsistencies in the student's conceptual ecology, and appears to be fruitful and lead to new discoveries, then accommodation can take place. But this is the most difficult and, therefore, the most unlikely approach, especially when there are other possibilities: rejection of the observational theory; a lack of concern with experimental findings on the grounds that they are irrelevant to one's current conception; a compartmentalization of knowledge to prevent the new information from conflicting with existing belief ("science doesn't have anything to do with the 'real' world"); and an attempt to assimilate the new information into existing conceptions (Posner et. al., 1982).

Another way a student may resolve the conflict between two conceptions is by compartmentalizing their knowledge, where each conception becomes plausible in different settings. The student may use one conception in certain situations, and another conception in other scenarios. For instance, the student may believe that the scientific views only work in school settings and their own conceptions work in the "real world."

This may lead students to think that science is too hard to understand, and resort to memorizing the answers the teacher wants for a test, without fully understanding them, then reverting back to their old ideas when confronted with situations outside of the classroom.

CONSTRUCTIVIST LEARNING

Conceptual change strategies are rooted in constructivism, which is the idea that knowledge cannot be transmitted but must be built by the learner. Constructivism has been around for many years, and is widely accepted in education, particularly science education. Most educators today believe that learning is not a process of transmitting information to passive students. In order for students to learn, they must be active and construct their own knowledge through engaging assignments and activities. The information and knowledge must be personally valued and interesting to the student in order for real learning to take place.

Constructivist learning takes place when the learner "actively constructs his or her own meaning by looking for regularity and order in the events of the world. On the one hand, learning can happen only by relating the unknown to what is already known, and thus all learning depends on the prior knowledge of the learner, which serves as a format, or schema, into which the new information is fitted" (Hewson and Hewson, 1984, page 5). Educators must plan activities and ways for the students to construct their own knowledge and test the new ideas in order to fit them into their own cognitive frameworks. Students' conceptual knowledge evolves in time, so that when the new ideas are accepted the old ones are pushed out and misconceptions will disintegrate as students gain more knowledge and new information makes more sense.

"Scientists explore their environment, create meaning that is localized, and test that meaning against the observations reported by others. It is no wonder that there has been a push within the science education community to adopt a constructivist method of instruction in the science classroom" (Ruebush et. al., 2009, page 19). The constructivist environment allows students to question what they know and approach problem solving in a manner similar to what scientists do in laboratories everyday. It makes sense that science students should be learning in similar ways to scientists.

THE 5-E LEARNING MODEL

Another constructivist learning model that teachers readily use in the science classroom is the 5-E learning model (Hewson and Hewson, 1984). The 5-E learning model uses five sections of learning in order for students to become more active members of the classroom and encourage conceptual change in students. The first "E" is engage. The engage part of the learning cycle is used to interest students and stimulate their thinking and questioning. It is used to stimulate student thinking and focus their attention on the topic about to be discussed. It also should bring up student misconceptions and challenge students when what happens does not match their original thoughts about a topic. The second "E" of the learning cycle is explore. The explore section of the lesson is a hands-on activity that allows students to experience the subject and collect and interpret data. Oftentimes this is a good time to challenge students with real-world problems. During this time they will test their original thoughts about the topic and find new ways that fit better than their old conceptions. This is the stage where students will do the meaning-making. Ultimately, this section helps students to think, discuss, and form their own opinions about the subject.

The next part of the learning cycle, or the third "E," is explain. This is the time for students to analyze their findings from the explore part of the lesson and is a good time for teachers to clear up any misconceptions that may arise in students. This is where the main concepts of the topic will be taught, vocabulary will be introduced, and where students will be guided to make formal connections between their old conceptions and new conceptions. Here students should be asked to explain and use the new terms and concepts they have just learned. The extend or elaborate phase of the learning cycle comes next. Students should try out their new ideas and apply their new knowledge in a different context. Having students learn these ideas in more than one context helps students to solidify their learning and understand the topics better. The last "E" of the learning cycle is evaluate. Evaluation of students' learning should be taken throughout the learning process and teachers should taken formative and summative assessments of their students' learning. Evaluating students throughout the lesson allows the teacher to know if their students really understand the material and correct misconceptions along the way as they arise. Teachers should assess or evaluate student performance and understanding of concepts, skills, applications, and processes. They should also allow opportunities for self-assessment of their students. The 5-E learning cycle is an effective way for teachers to introduce new concepts to students in a constructivist way.

IMPLICATIONS FOR TEACHING

As many educators know, one must teach science differently than other subjects in order to be effective. As with all subjects, it is crucial that the teacher make the topics personally meaningful to the students in order for true learning to take place. Teachers should introduce the current scientific views and procedures and guide students towards accepting them and including them in their cognitive scheme. This is effectively accomplished by making the ideas and practices meaningful at the individual level. The challenge is for teachers to design instructional strategies that will help students bring their naïve views closer to those of the scientific community.

In order to gain understanding through learning, science teachers must construct hands-on activities that are engaging and challenging to the students. The activities should be minds-on as well, requiring the students to reconsider their current conceptions and reconstruct their personal theories. Individuals best construct meaning from their experiences, so it is important for teachers to create meaningful activities that are derived from authentic contexts. "It is essential to create a classroom environment in which students are free to suggest tentative ideas and then to test them without concern for the rightness or wrongness of these ideas" (Cakir, 2008, page 201).

No idea can function well unless it is internally represented by the student. It is important for teachers to teach students the process of science, rather than just the content, because students will take this knowledge with them further and can use it to learn science on their own. Learning is not just the acquisition of new pieces of information that can be added to the students' conceptual ecology. Learning is the interaction of new information with old conceptions and how they are reconciled in the students' personal conceptual ecology.

Understanding student misconceptions and how to diagnose them has many implications for teaching. An educator must remember that different students not only learn differently, but also come to the classroom with different conceptual ecologies. "A teacher wishing to teach the same new content to two different students may need to use different strategies, because of differences in students' conceptions. What is intelligible, plausible, and fruitful to one student may not automatically be so to another" (Hewson and Hewson, 1984, page 9). While most teachers assume that their students know what they have been taught, or should have been taught, in the grades before them, this is not necessarily true. Even if a student learned and remembers all that he or she should have been taught in school, this information must interact with their previous knowledge and conceptual ecology. Therefore, there is a wide range of knowledge that students come into the class with, depending on the differing amounts of interaction between formal learning and informal learning the students have had.

"Accommodation, particularly for the novice, is best thought of as a gradual adjustment in one's conception, each new adjustment laying the groundwork for further adjustments but where the end result is a substantial reorganization or change to one's central concepts" (Posner, 1982, page 223). Acceptance of new conceptions is rarely quick and easy, they require much work and thought by the student in order to be fit into their conceptual ecologies. Educators must keep in mind that acceptance and understanding of many scientific ideas are gradual and take time and that initial acceptance of a conception may not be included in the students' conceptual ecologies. Frequently assessing student understanding of these theories and continual teaching of them will help students understand the topics better.

TEACHING STRATEGIES

Instructional strategies are an essential component of successful teaching. Teaching strategies start in the planning phase. While planning a lesson, one effective way to include the diagnosis and focus on misconceptions is to use a learning cycle that includes the five essential features of inquiry (the 5-E learning cycle, explained earlier). Studies by Hewson and Hewson show that the strategies of diagnosis, integration, differentiation, and exchange caused a significantly improved acquisition of desired concepts and elimination of misconceptions (Hewson and Hewson, 1984). The first teaching strategy mentioned is the diagnosis of misconceptions, which was discussed earlier.

The second teaching strategy mentioned in their study is integration. Integration could be of new content with a student's existing cognitive framework, or of different conceptions with each other. In this strategy, the teacher assumes the students have learned what they have (or should have) been taught, and plan their teaching accordingly. Teachers assume there is no conflict between conceptions the students hold. This is the dominant teaching strategy in science teaching today (Hewson and Hewson, 1984).

Another teaching strategy Hewson and Hewson outlined was differentiation. Differentiation is important to understand when there are two different, but closely related concepts that students must understand. Students often confuse the two concepts, or hold a single conception, based on too limited a range of examples. It is important for the educator to differentiate between the two concepts, possibly with more examples or more clearly defined examples. Conceptual change is not really a factor in this strategy, as it is possible to reconcile the two conceptions with each other (Hewson and Hewson, 1984).

Exchange is the last teaching strategy mentioned by Hewson and Hewson. Exchange is the case that exists when two different conceptions are irreconcilable with each other, or are thought to be so by the student, so the student accepts one conception at the expense of the other. It is more likely that the new conception will be rejected for the old, unless the teacher uses an effective exchange strategy that increases the plausibility of the new conception and reduces the old one. "In other words, an exchange strategy aims to create conceptual conflict between a student's conceptions, and then to resolve it appropriately" (Hewson and Hewson, 1984, page 11).

OHIO SCIENCE CONTENT STANDARDS AND NATIONAL SCIENCE EDUCATION STANDARDS

The subjects chosen to be examined are food webs, photosynthesis, natural selection, and climate change. These subjects are popular topics in science that students should encounter many times throughout their education. They are prevalent in both the

Ohio Academic Content Standards and the *National Science Education Standards* (Academic Content Standards, 2003; National Science Education Standards, 1996). These four areas are also topics in which students hold numerous misconceptions and that research has shown that college students still hold, therefore implying that teachers are currently not doing enough to rid students of their misconceptions. While these topics are discussed in many grades throughout a students' education, secondary school (grades 7-12) is focused on in this paper. The connections between the topic and the current Ohio State Standards and National Science Education Standards are included in tables one through eight, below.

Food Webs

The standards for food webs are found in several grade levels in secondary education in both the *Ohio Science Content Standards* (Table 1) and the *National Science Education Standards* (Table 2). All of the following indicators for the Ohio Science Content Standards are under the Life Science Standard: Students should be able to demonstrate an understanding of how living systems function and interact within their physical environment, including an understanding of energy flow and matter cycling. An understanding of the dependence and interdependence of life will be understood, including the principles of heredity and biological evolution. The characteristics, structure, and function of cells, organisms, and living systems will also be understood. Above all, students should be able to demonstrate an understanding of different scientific approaches and historical perspectives, as well as emerging scientific issues in the life sciences (Academic Content Standards, 2003).

Table 1: Ohio Science Academic Content Standards for Food Webs
This table includes all of the standards from the Ohio Science Academic Content Standards Guide for grades 7-12 which focus on student knowledge of food webs.

Grade 7	*Diversity and Interdependence of Life* 2. Investigate how organisms or populations may interact with one another through symbiotic relationships and how some species have become so adapted to each other that neither could survive without the other (e.g., predator-prey, parasitism, mutualism and commensalism). 3. Explain how the number of organisms an ecosystem can support depends on adequate biotic (living) resources (e.g., plants, animals) and abiotic (non-living) resources (e.g., light, water and soil). 4. Investigate how overpopulation impacts an ecosystem.
Grade 8	No indicators defined at this level
Grade 9	No indicators defined at this level
Grade 10	*Diversity and Interdependence of Life* 9. Describe how matter cycles and energy flows through different levels of organization in living systems and between living systems and the physical environment. Explain how some energy is stored and much is dissipated into the environment as thermal energy (e.g., food webs and energy pyramids). 15. Explain how living things interact with biotic and abiotic components of the environment (e.g., predation, competition, natural disasters and weather). 16. Relate how distribution and abundance of organisms and populations in ecosystems are limited by the ability of the ecosystem to recycle materials and the availability of matter, space and energy. 17. Conclude that ecosystems tend to have cyclic fluctuations around a state of approximate equilibrium that can change when climate changes, when one or more new species appear as a result of immigration or when one or more species disappear.

Grade 11	*Diversity and Interdependence of Life* 6. Predict some possible impacts on an ecosystem with the introduction of a non-native species. 8. Recognize that populations can reach or temporarily exceed the carrying capacity of a given environment. Show that the limitation is not just the availability of space but the number of organisms in relation to resources and the capacity of earth systems to support life.
Grade 12	*Diversity and Interdependence of Life* 9. Explain why and how living systems require a continuous input of energy to maintain their chemical and physical organization. Explain that with death and the cessation of energy input, living systems rapidly disintegrate toward more disorganized states.

Table 2: National Science Education Standards for Food Webs
This table includes all of the standards from the National Science Education Standards for grades 5-12 which focus on student knowledge of food webs.

Grades 5-8	Life Science Content Standard *Population and Ecosystems* 1. A population consists of all individuals of a species that occur together at a given place and time. All populations living together and the physical factors with which they interact compose an ecosystem. 2. Populations of organisms can be categorized by the function they serve in an ecosystem. Plants and some microorganisms are producers—they make their own food. All animals, including humans, are consumers, which obtain food by eating other organisms. Decomposers, primarily bacteria and fungi, are consumers that use waste materials and dead organisms for food. Food webs identify the relationships among producers, consumers, and decomposers in an ecosystem. 3. For ecosystems, the major source of energy is sunlight. Energy entering ecosystems as sunlight is transferred by producers into chemical energy through photosynthesis. That energy then passes from organism to organism in food webs. 4. The number of organisms an ecosystem can support depends on the

	resources available and abiotic factors, such as quantity of light and water, range of temperatures, and soil composition. Given adequate biotic and abiotic resources and no disease or predators, populations (including humans) increase at rapid rates. Lack of resources and other factors, such as predation and climate, limit the growth of populations in specific niches in the ecosystem.
Grades 9-12	Life Science Content Standard *The Interdependence of Organisms* 2. Energy flows through ecosystems in one direction, from photosynthetic organisms to herbivores to carnivores and decomposers. 3. Organisms both cooperate and compete in ecosystems. The interrelationships and interdependencies of these organisms may generate ecosystems that are stable for hundreds or thousands of years. 4. Living organisms have the capacity to produce populations of infinite size, but environments and resources are finite. This fundamental tension has profound effects on the interactions between organisms. *Matter, Energy, and Organization in Living Systems* 6. As matter and energy flows through different levels of organization of living systems—cells, organs, organisms, communities—and between living systems and the physical environment, chemical elements are recombined in different ways. Each recombination results in storage and dissipation of energy into the environment as heat. Matter and energy are conserved in each change.

Photosynthesis and Respiration

The standards for food webs are found in several grade levels in secondary education in both the *Ohio Science Content Standards* (Table 3) and the *National Science Education Standards* (Table 4). All of the following indicators for the Ohio Science Content Standards are under the Life Science Standard: Students should be able to demonstrate an understanding of how living systems function and interact within their physical environment, including an understanding of energy flow and matter cycling. An understanding of the dependence and interdependence of life will be understood, including the principles of heredity and biological evolution. The characteristics, structure, and function of cells, organisms, and living systems will also be understood. Above all, students should be able to demonstrate an understanding of different scientific approaches and historical perspectives, as well as emerging scientific issues in the life sciences (Academic Content Standards, 2003).

Table 3: Ohio Science Academic Content Standards for Photosynthesis and Respiration
This table includes all of the standards from the Ohio Science Academic Content Standards Guide for grades 7-12 which focus on student knowledge of photosynthesis and respiration.

Grade 7	*Diversity and Interdependence of Life* 7. Explain that photosynthetic cells convert solar energy into chemical energy that is used to carry on life functions or is transferred to consumers and used to carry on their life functions.
Grade 8	No indicators defined at this level
Grade 9	No indicators defined at this level
Grade 10	*Diversity and Interdependence of Life* 3. Explain the characteristics of life as indicated by cellular processes including: a. homeostasis b. energy transfers and transformation c. transportation of molecules d. disposal of wastes e. synthesis of new molecules 4. Summarize the general processes of cell division and differentiation, and explain why specialized cells are useful to organisms and explain that complex multicellular organisms are formed as highly organized arrangements of differentiated cells.
Grade 11	*Diversity and Interdependence of Life* 10. Describe how cells and organisms acquire and release energy (photosynthesis, chemosynthesis, cellular respiration and

	fermentation). 11. Explain that living organisms use matter and energy to synthesize a variety of organic molecules (e.g., proteins, carbohydrates, lipids and nucleic acids) and to drive life processes (e.g., growth, reacting to the environment, reproduction and movement).
Grade 12	*Characteristics and Structure of Life* 3. Explain that the sun is essentially the primary source of energy for life. Plants capture energy by absorbing light and using it to form strong (covalent) chemical bonds between the atoms of carbon-containing (organic) molecules. 4. Explain that carbon-containing molecules can be used to assemble larger molecules with biological activity (including proteins, DNA, sugars and fats). In addition, the energy stored in bonds between the atoms (chemical energy) can be used as sources of energy for life processes. *Diversity and Interdependence of Life* 9. Explain why and how living systems require a continuous input of energy to maintain their chemical and physical organization. Explain that with death and the cessation of energy input, living systems rapidly disintegrate toward more disorganized states.

Table 4: National Science Education Standards for Photosynthesis and Respiration
This table includes all of the standards from the National Science Education Standards for grades 5-12 which focus on student knowledge of photosynthesis and respiration.

Grades 5-8	Life Science Content Standard *Populations and Ecosystems* 2. Populations of organisms can be categorized by the function they serve in an ecosystem. Plants and some microorganisms are producers—they make their own food. All animals, including humans, are consumers, which obtain food by eating other organisms. Decomposers, primarily bacteria and fungi, are consumers that use waste materials and dead organisms for food. Food webs identify the relationships among producers, consumers, and decomposers in an ecosystem.

	3. For ecosystems, the major source of energy is sunlight. Energy entering ecosystems as sunlight is transferred by producers into chemical energy through photosynthesis. That energy then passes from organism to organism in food webs.
Grades 9-12	Life Science Content Standard *The Cell* 5. Plant cells contain chloroplasts, the site of photosynthesis. Plants and many microorganisms use solar energy to combine molecules of carbon dioxide and water into complex, energy rich organic compounds and release oxygen to the environment. This process of photosynthesis provides a vital connection between the sun and the energy needs of living systems. *Matter, Energy, and Organization in Living Systems* 2. The energy for life primarily derives from the sun. Plants capture energy by absorbing light and using it to form strong (covalent) chemical bonds between the atoms of carbon-containing (organic) molecules. These molecules can be used to assemble larger molecules with biological activity (including proteins, DNA, sugars, and fats). In addition, the energy stored in bonds between the atoms (chemical energy) can be used as sources of energy for life processes. 3. The chemical bonds of food molecules contain energy. Energy is released when the bonds of food molecules are broken and new compounds with lower energy bonds are formed. Cells usually store this energy temporarily in phosphate bonds of a small high-energy compound called ATP.

Natural Selection and Evolution

The standards for food webs are found in several grade levels in secondary education in both the *Ohio Science Content Standards* (Table 5) and the *National Science Education Standards* (Table 6). All of the following indicators for the Ohio Science Content Standards are under the Life Science Standard: Students should be able to demonstrate an understanding of how living systems function and interact within their physical environment, including an understanding of energy flow and matter cycling. An understanding of the dependence and interdependence of life will be understood, including the principles of heredity and biological evolution. The characteristics, structure, and function of cells, organisms, and living systems will also be understood. Above all, students should be able to demonstrate an understanding of different scientific approaches and historical perspectives, as well as emerging scientific issues in the life sciences (Academic Content Standards, 2003)

Table 5: Ohio Science Academic Content Standards for Natural Selection and Evolution
This table includes all of the standards from the Ohio Science Academic Content Standards Guide for grades 7-12 which focus on student knowledge of natural selection and evolution.

Grade 7	*Characteristics and Structure of Life* 1. Investigate the great variety of body plans and internal structures found in multicellular organisms. *Evolutionary Theory* 8. Investigate the great diversity among organisms.
Grade 8	*Evolutionary Theory* 3. Explain how variations in structure, behavior or physiology allow some organisms to enhance their reproductive success and survival in a particular environment. 4. Explain that diversity of species is developed through gradual processes over many generations (e.g., fossil record). 5. Investigate how an organism adapted to a particular environment may become extinct if the environment, as shown by the fossil record, changes.
Grade 9	No indicators defined at this level
Grade 10	*Heredity* 7. Describe that spontaneous changes in DNA are mutations, which are a source of genetic variation. When mutations occur in sex cells,

	they may be passed on to future generations; mutations that occur in body cells may affect the functioning of that cell or the organism in which that cell is found. *Diversity and Interdependence of Life* 12. Describe that biological classification represents how organisms are related with species being the most fundamental unit of the classification system. Relate how biologists arrange organisms into a hierarchy of groups and subgroups based on similarities and differences that reflect their evolutionary relationships. 13. Explain that the variation of organisms within a species increases the likelihood that at least some members of a species will survive under gradually changing environmental conditions. 14. Relate diversity and adaptation to structures and their functions in living organisms (e.g., adaptive radiation). *Evolutionary Theory* 20. Recognize that a change in gene frequency (genetic composition) in a population over time is a foundation of biological evolution. 21. Explain that natural selection provides the following mechanism for evolution; undirected variation in inherited characteristics exist within every species. These characteristics may give individuals an advantage or disadvantage compared to others in surviving and reproducing. The advantaged offspring are more likely to survive and reproduce. Therefore, the proportion of individuals that have advantageous characteristics will increase. When an environment changes, the survival value of some inherited characteristics may change. 22. Describe historical scientific developments that occurred in evolutionary thought (e.g., Lamarck and Darwin, Mendelian Genetics and modern synthesis). 24. Analyze how natural selection and other evolutionary mechanisms (e.g. genetic drift, immigration, emigration, mutation) and their consequences provide a scientific explanation for the diversity and unity of past life forms, as depicted in the fossil record, and present life forms.

	25. Explain that life on Earth is thought to have begun as simple, one celled organisms approximately 4 billion years ago. During most of the history of Earth only single celled microorganisms existed, but once cells with nuclei developed about a billion years ago, increasingly complex multicellular organisms evolved.
Grade 11	*Diversity and Interdependence of Life* 10. Explain how environmental factors can influence heredity or development of organisms. *Evolutionary Theory* 12. Recognize that ecosystems change when significant climate changes occur or when one or more new species appear as a result of immigration or speciation. 13. Describe how the process of evolution has changed the physical world over geologic time.
Grade 12	*Diversity and Interdependence of Life* 7. Relate diversity and adaptation to structures and functions of living organisms at various levels of organization. *Evolutionary Theory* 10. Explain additional components of the evolution theory, including genetic drift, immigration, emigration and mutation.

Table 6: National Science Education Standards for Natural Selection and Evolution
This table includes all of the standards from the National Science Education Standards for grades 5-12 which focus on student knowledge of natural selection and evolution.

Grades 5-8	Life Science Content Standard *Reproduction and Heredity* 5. The characteristics of an organism can be described in terms of a combination of traits. Some traits are inherited and other result from interactions with the environment. *Diversity and Adaptations of Organisms*

	1. Millions of species of animals, plants, and microorganisms are alive today. Although different species might look dissimilar, the unity among organisms becomes apparent from an analysis of internal structures, the similarity of their chemical processes, and the evidence of common ancestry. 2. Biological evolution accounts for the diversity of species developed through gradual processes over many generations. Species acquire many of their unique characteristics through biological adaptation, which involves the selection of naturally occurring variations in populations. Biological adaptations include changes in structures, behaviors, or physiology that enhance survival and reproductive success in a particular environment. 3. Extinction of a species occurs when the environment changes and the adaptive characteristics of a species are insufficient to allow its survival. Fossils indicate that many organisms that lived long ago are extinct. Extinction of species is common; most of the species that have lived on the earth no longer exist. Earth and Space Science Content Standard *Earth's History* 2. Fossils provide important evidence of how life and environmental conditions have changed.
Grades 9-12	Life Science Content Standard *The Molecular Basis of Heredity* 3. Changes in DNA (mutations) occur spontaneously at low rates. Some of these changes make no difference to the organism, whereas others can change cells and organisms. Only mutations in germ cells can create the variation that changes an organism's offspring. *Biological Evolution* 1. Species evolve over time. Evolution is the consequence of the interactions of (1) the potential for a species to increase its numbers, (2) the genetic variability of offspring due to mutation and recombination of genes, (3) a finite supply of the resources required for life, and (4) the ensuring selection by the environment of those offspring better able to survive and leave offspring.

	2. The great diversity of organisms is the result of more than 3.5 billion years of evolution that has filled every available niche with life forms. 3. Natural selection and its evolutionary consequences provide a scientific explanation for the fossil record of ancient life forms, as well as for the striking molecular similarities observed among the diverse species of living organisms. 4. The millions of different species of plants, animals, and microorganisms that live on earth today are related by descent from common ancestors. 5. Biological classifications are based on how organisms are related. Organisms are classified into a hierarchy of groups and subgroups based on similarities which reflect their evolutionary relationships. Species is the most fundamental unit of classification.

Climate Change

The standards for climate change are found in several grade levels in secondary education in both the *Ohio Science Content Standards* (Table 7) and the *National Science Education Standards* (Table 8). All of the following indicators for the Ohio Science Content Standards are under the Earth and Space Sciences Standard: Students should be able to demonstrate an understanding of how Earth systems and processes interact in the geosphere, including understanding the composition of the universe, solar system, and Earth. Students should be able to explain the Earth, solar system, and universe in terms of the concepts of energy, matter, motion, and forces and how they shape these systems. Students should understand the properties and interconnected nature of Earth's systems and processes that have shaped Earth and Earth's history, including habitability of Earth. Above all, students should be able to demonstrate an understanding of different scientific approaches and historical perspectives, as well as emerging scientific issues in the earth and space sciences (Academic Content Standards, 2003)

Table 7: Ohio Science Academic Content Standards for Climate Change
This table includes all of the standards from the Ohio Science Academic Content Standards Guide for grades 7-12 which focus on student knowledge of climate change.

Grade 7	*Earth Systems* 8. Describe how temperature and precipitation determine climatic zones (biomes) (e.g., desert, grasslands, forests, tundra and alpine). 9. Describe the connection between the water cycle and weather-related phenomenon (e.g., tornadoes, floods, droughts and hurricanes).
Grade 8	No indicators defined at this level
Grade 9	*Earth Systems* 4. Explain the relationships of the oceans to the lithosphere and atmosphere (e.g., transfer of energy, ocean currents and landforms).
Grade 10	*Earth Systems* 6. Describe ways that human activity can alter biogeochemical cycles (e.g., carbon and nitrogen cycles) as well as food webs and energy pyramids (e.g., pest control, legume rotation crops vs. chemical fertilizers).
Grade 11	*Earth Systems* 3. Explain heat and energy transfers in and out of the atmosphere and its involvement in weather and climate (radiation, conduction, convection and advection). 5. Use appropriate data to analyze and predict upcoming trends in global weather patterns (e.g., el Niño and la Niña, melting glaciers and icecaps and changes in ocean surface temperatures). 7. Describe the effects of particulates and gases in the atmosphere including those originating from volcanic activity. 9. Explain the effects of biomass and human activity on climate (e.g., climatic change and global warming). 10. Interpret weather maps and their symbols to predict changing weather conditions worldwide (e.g., monsoons, hurricanes and

	cyclones). 13. Explain how human behavior affects the basic processes of natural ecosystems and the quality of the atmosphere, hydrosphere and lithosphere.
Grade 12	*Earth Systems* 5. Investigate how thermal energy transfers in the world's oceans impact physical features (e.g., ice caps, oceanic and atmospheric currents) and weather patterns.

Table 8: National Science Education Standards for Climate Change
This table includes all of the standards from the National Science Education Standards for grades 5-12 which focus on student knowledge of climate change.

Grades 5-8	Earth and Space Science Content Standard *Structure of the Earth System* 9. Global patterns of atmospheric movement influence local weather. Oceans have a major effect on climate, because water in the oceans holds a large amount of heat.
Grades 9-12	Earth and Space Science Content Standard *Energy in the Earth System* 4. Global climate is determined by energy transfer from the sun at and near the earth's surface. This energy transfer is influenced by dynamic processes such as cloud cover and the earth's rotation, and static conditions such as the position of mountain ranges and oceans.

CHAPTER II

FOOD WEB MISCONCEPTIONS

INTRODUCTION AND BACKGROUND INFORMATION

The concepts of ecological food chains and food webs are important for students to understand in middle and high school science. Science teachers in the United States identified food chains and food webs as one of the most important topics for students to understand. These teachers also considered these concepts "relatively easy for most students to understand" (Barman and Mayer, 1994, page 160). The concepts of food chains and food webs are included in most national educational curricula and most state standards as well. Research, however, shows that misconceptions about food webs strongly persist, even after school instruction. Although teachers feel that food webs are important for high school students to learn, and though they feel these concepts should be easy for students to understand, this is simply not the case. What's worse, if these misconceptions are not addressed in middle school and high school, they have a "good chance of persisting at university level" (Webb and Boltt, 1990, page 189).

Students tend to show a basic and unsophisticated understanding of food webs. While they can identify and draw simple food webs, they do not understand the complete interaction and dependence of organisms within them. Students are able to predict outcomes of different scenarios if they were simple enough to be answered using strategies based on the food chain concept. However, students have a hard time predicting probable outcomes when the effects of the change in one organism or population affect multiple organisms throughout the web (Webb and Boltt, 1990). When students are asked to explain their food web, they are able to describe the basic feeding relationships between organisms, but do not use the vocabulary associated with these relationships, such as "consumer" and "producer." Student thinking is typically one-way linear, with students interpreting food webs in terms of individual rather than interconnected food chains. This limits the number of steps they trace within food webs and causes them to focus only on direct effects, ignoring indirect effects. Students have great trouble understanding more complicated interrelationships between organisms in the food web and the energy transfer between these organisms.

These results, that students understand the basic concepts about food webs but not the interrelated concepts, are reflective of the compartmentalized teaching that used to be common. Current teaching, however, is moving towards more comprehensive and complex topics and focusing more on the relationships between concepts. "Increased emphasis has been placed on the function, process, and integration of biological knowledge and on the inter-relationships that exist within such knowledge" (Lin and Hu, 2003, page 1540). Due to compartmentalized teaching and the segmentation of concepts in textbooks, students are able to understand individual food chains and simple concepts, but not the level of interrelationship that is required to interpret food webs. It is the teacher's job, then, to emphasize the relationships between concepts so students understand the "wholeness of the world" (Lin and Hu, 2003, page 1541).

The skills needed to understand food webs are typical system-thinking skills. Students must become comfortable in analyzing complex systems and be able to think within the context of the food web. In order to fully comprehend a food web, students need to not only be able to identify the elements of the food web, but also understand the interdependencies between species and identify connections between organisms in the web (Demetriou et. al, 2009). Students also need to understand the concept of causality. Researchers have found that the root of many misconceptions about systems in ecology start with a limited understanding of causality. "[Researchers] found that causally-focused activities, as well as explicit discussions about patterns of causality, did lead to some gains in students' ability to analyse complex, dynamic relationships in ecosystems" (Hogan, 2000, page 28).

Science education research has consistently identified certain misconceptions about food webs. These main misconceptions are: difficulty in providing an accurate explanation of how changes in one population could affect other populations in a food web; believing that a change in one population in a food web could only affect another population if they are related as predator and prey; believing that a population located higher on the food chain within a food web is a predator of all the populations located below them; and believing that a change in the population of a first order consumer would not have any influence on producer populations; and believing that if something happened to one population in a food web, then the same effect will happen to all populations within the web or that if the size of one population in a food web is altered, all other populations in the web will be altered in the same way (Barman and Mayer, 1994, and Griffiths and Grant, 1985). All of these misconceptions have to deal with the relationships among organisms in a food web, which is precisely why teachers need to emphasize the relationships and interdependence within food webs and how food webs are ever dynamic and changing.

IMPLICATIONS FOR TEACHING

Perhaps one of the reasons students do not understand ecological food webs is that teachers may overestimate their students' abilities to understand the concepts. Research shows that teachers in the United States especially tend to assume these concepts are easy and readily understood by their students. The difficulty students have with food webs implies that teachers need to identify way to access students' prior knowledge instead of making assumptions about what their students already know. Ideas that may seem simple or basic to educators are not always perceived the same way by their students. Many teachers tend to overlook basic ideas about a concept because these ideas seem simple and self-evident to the teachers but are actually difficult for students to grasp. (Barman and Mayer, 1994). Teachers need to begin new concepts or units by administering pre-assessments to their students in order to understand their students' prior knowledge. Teachers should never assume students know anything, but instead should assess them in order to meet the students at their current skill level.

The structure of the food web is the easiest for students to comprehend and understand. Therefore, according to Demetriou et al. (2009), this is the "proper" place to start in teaching food webs. This gives students the necessary background they need in order to study the function and behavior of the system. Demetriou et al. (2009) has suggested a three step curriculum for food webs. First, they believe students should identify the elements of the system. Next, students should define the relationships between the elements. Last, the students should construct the food web. This allows students to "transform their image of trophic dynamics from simplistic linear relations to more systemic ones" (Demetriou et al., 2009, page 182). This is known as a bottom-up approach to ecological education. A bottom-up approach focuses on the visible elements of the system first, then moves on to easily understandable relations, then finally moves into the more abstract concepts. This approach focuses on the way that individual parts interact and function in forming a whole system. It "allows students to comprehend how the system as a whole is constructed and how the properties of the system emerge" (Demetriou et al., 2009). This approach will also allow students to better understand the relationships between organisms in a food web.

One of the main problems with student understanding of food webs is that teachers only provide a few examples. Teachers should not assume that by providing information in one context, students will be able to apply it to other situations. Teachers need to provide many examples in order for students to truly understand the concepts and be able to apply them in different contexts. Barman and Mayer (1994) researched how different textbooks address the concepts of food chains and food webs. They found that most of the textbooks provided very brief explanations about food webs and energy transfer and determined that all of the textbooks had inadequate amounts of information about these concepts. Half of the textbooks did not even introduce the terms association with food webs in the same chapter as the descriptions of food webs. It is no wonder that students do not think to include vocabulary, such as "consumer" or "decomposer" in their food webs if their textbook does not even include it. Teachers need to make the connections between the food web diagram and the vocabulary associated with it, especially if the textbook does not.

Another problem that Barman and Mayer (1994) found in textbooks presenting food webs was that several of the books had pictures of food chains, but did not include pictures of food webs. This makes it hard for students to develop a mental image of what a food web would look like, and makes it very difficult for students to understand and interpret them. This means that it is essential for teachers to provide numerous examples and pictures of food webs for their students, to help them understand what food webs are and how to read and interpret them. Teachers should present many different examples of food webs to their students to help them understand what they look like and how they are typically drawn, especially if the textbook students are using does not provide any examples.

"Another criticism concerns the fact that environmental systems are treated by teachers and textbooks alike as static collections of objects and cycles to be memorized, while the focus should be on the dynamic character of those systems" (Demetriou et al, 2009). Students do not face the complexity of a real food web and do not deal personally with the relationships and processes taking place within it. This leads to a simplistic understanding of causality and the systemic nature of interactions taking place within the food web (Demetriou et al, 2009). Students are not able to grasp complex interactions taking place within the web as they do not have the personal manipulation with the web that they should. Therefore, students should be given numerous opportunities to manipulate food webs and see how changing one organism in the system will affect other organisms. This will help them understand that food webs are not static and unchanging, but are flexible and will vary in different situations. Games and hands-on activities would be good ways to give students the opportunity to control food webs themselves and understand the relationships between organisms firsthand.

Rutler et. al. (2005) suggests comparing the food web structure to that of a Jenga game. The simple rules of balance used in the game can compare to the stability of a food web. A Jenga structure is constantly changing and the stability at any moment is dependent on the additions and deletions of the stones. This can be compared to a ecosystem in nature, with additions and deletions of animals instead of stones, and the success of one "stone" dependent on the presence or absence of another "stone." "By realizing that dynamics are key to understanding complex structures, we can see stable food webs not as static entities, but as open and flexible Jenga-like systems that can change in species attributes, composition, and dynamics" (Rutler et. al., 2005). Viewing the features of an ecosystem as flexible enhances student understanding of environmental change and disturbance in nature and allows students to better understand the features of resistance and resilience of animals.

Several teachers have found ways to lesson or eliminate prior conceptions about the animals present in the food webs they are exposing to their students. One teacher used imaginary animals and plants that he made up himself, also making up the names of those plants and animals. He found that, when providing examples of ecosystems to his students, his students would bring in their prior knowledge about the organisms and ecosystem, complicating the assignments. They would be confused when, for example, they knew that a particular animal preyed on another animal but that animal was not included in the example. Real food webs, he found, were also too simplistic or too complicated, and he wished to create his own food webs at the level his students could understand. Hence, the idea of creating his own plants and animals was born. This approach allowed him to control the complexity of the food web, his students had no prior knowledge of the organisms included, and he found he could create animals to illustrate specific concepts (Rockow, 2007). This approach also gives teachers the option to relate the pretend food webs to actual ecosystems or have the students research about similar ecosystems to the pretend ones created. Webb and Boltt (1990) had a similar idea, using letters to represent the animals and plants in their food webs during their research. This requires the students to focus on the principles operating within the food web and reduces the amount of prior knowledge complicating the assignment.

Lessening or eliminating misconceptions about food webs will require creative thinking by teachers. Provision of numerous examples of different types and concepts within food webs is essential for students to understand how they work. This is a complicated topic, and teachers cannot assume that students can transfer information about one food web to the next. Educators must remember that food webs are not static beings to be memorized, but are fluid, changing systems. Comparing a food web to a game of Jenga, or any other game of balance, requires students to visualize the food web as a system where dependence on each organism within the system is essential for the success of the food web. Students need to understand that it is the interrelationship between the organisms that is the most important concept within food webs. Pre-assessments are very useful for identifying prior knowledge, and there are some great ideas for reducing prior knowledge on the organisms present in the food web, such as making up the organisms or to just using letters or numbers instead of names. Sophisticated understanding of ecological food webs will be best accomplished by including all of these ideas, and by giving students the opportunity to manipulate the systems themselves.

CHAPTER III

PHOTOSYNTHESIS AND RESPIRATION MISCONCEPTIONS

INTRODUCTION AND BACKGROUND INFORMATION

The process of photosynthesis is a difficult topic for students to learn, as it is abstract and hard for students to picture and understand. Nevertheless, photosynthesis is taught at all levels of education and is essential in the understanding of the "cycling of matter and energy flow through ecosystems" (Anderson et al., 1990; Eisen and Stavy, 1988, in Yenilmez and Tekkaya, 2006). Photosynthesis should include two aspects: the role in processes such as matter cycling and energy transfer in addition to the biochemical properties and processes (Ray and Beardsley, 2008). The processes of photosynthesis and respiration are important in the understanding of the functioning of an organism, ecosystem, or the biosphere. Students must be able to understand the difference between the two processes as well as the interrelationships between them. "The processes of photosynthesis and respiration play important roles in understanding the many aspects of living systems" and therefore are essential for students to learn and understand (Yenilmez and Tekkaya, 2006, page 82).

Photosynthesis is included in the life science content standards for grades 9-12 in the *National Science Education Standards*, as well as the Ohio State Standards. The standards state that the coverage of the biochemical properties of photosynthesis are mandatory, and that understanding photosynthesis should help students better understand energy transfer and matter cycling in ecosystems (Ray and Beardsley, 2008). Students who understand how photosynthesis operates should be able to describe how plants connect soil and water with the atmosphere and use sunlight, carbon dioxide, nutrients, and water to produce carbohydrates and become biomass (Ray and Beardsley, 2008). They should then be able to trace the effects of photosynthesis through an ecosystem, from plant matter to energy to animals. They should also be able to understand how photosynthesis creates the energy that drives ecosystem processes and how matter is cycled among organisms.

Yenilmez and Tekkaya (2006) conducted research in an eighth grade classroom to identify misconceptions that students commonly hold at this age. They found that approximately a third of students believe that oxygen gas is given out in greater quantities during the day, because plants can only photosynthesize during the day and respire at night (another misconception). To further this misconception, they believe that plants need light energy for photosynthesis and respire in the absence of light energy. Students believe that photosynthesis and respiration are opposites of each other. They believe that photosynthesis is what provides the plant energy for growth. Many students also hold the belief that "the most important benefit to green plants when they photosynthesize is the removal of carbon dioxide from the air" (Yenilmez and Tekkaya, 2006, page 84). Students are also confused as to where photosynthesis and respiration take place, believing that respiration takes place in the cells of the leaves only and photosynthesis takes place in the root of the plant. Many also believe that respiration takes place through holes on the leaves. Different students seem to think these processes occur in different parts of the plant, based on their previous teaching and understanding of the material. Lastly, a common misconception among students is that "plants respire when they cannot obtain enough energy from photosynthesis and animals respire continuously because they cannot photosynthesize" (Yenilmez and Tekkaya, 2006, page 85). Additionally, students believe that plants breathe like animals, taking in and expelling air and will die if they do not respire like people and animals do (Canal, 1999). Many student misconceptions seem to revolve around the differences of respiration and photosynthesis and when plants use each.

Another one of the main misconceptions that students have about plants and photosynthesis is that they do not understand the meaning of the word "food" and what plants "eat." When asked about plants' food, many students will say a mixture of the following: carbon dioxide, water, sunlight, minerals, chlorophyll, water, soil, and fertilizer. They think that the plants take up their food from the soil through their roots and think that plants must take in material from outside the plant as food. Part of the cause of this misconception could be that people typically add fertilizer to plants to help them grow. Parents may tell their children that the fertilizer is extra food for the plant or that the fertilizer helps them grow big and strong. These statements could lead to the idea that fertilizer is an essential component to the diet of plants. Another cause for this misconception could be due to differences in the definition of "food" between scientists and children or the general public. Students generally define food as a substance that is taken in from the environment and apply this definition to both animals and plants. It is important for educators to distinguish between food for animals and food for plants and how scientists define “food” in reference to plants (Yenilmez and Tekkaya, 2006). Teachers should also define the term “nutrition” to their students and state that plant nutrition is not the process by which plants feed themselves, like animals.

It is clear that photosynthesis and respiration are difficult topics for students to grasp and teachers find these topics difficult to learn themselves, much less teach their students. These misconceptions continue to occur throughout primary and secondary school and into the university level, even though these concepts are introduced and explained to students numerous times throughout their schooling. “The most striking aspect of the development of these misconceptions is not the simple presence and persistence of the idea, but rather its development pattern throughout the educational process” (Canal, 1999, page 364). Unfortunately, studies at the university level show that college students hold many of the same misconceptions that grade-school students hold. The problem could be partially due to teachers’ own difficulties understanding and teaching about these processes. It is clear that something needs to change in the teaching of these topics if students are to understand the basics of the two processes of photosynthesis and respiration.

IMPLICATIONS FOR TEACHING

Before teaching about photosynthesis and respiration, educators need to make sure that their students understand some prerequisite content first in order to make the scientific connections that are essential to understanding these processes. Canal (1999) provides several concepts that he believes need to be taught prior to the processes of photosynthesis and respiration in order to minimize the amount of misconceptions believed by students. The first concept that needs to be taught is the difference between the prototypical model of animals and plants, as well as differentiating between the organizational level of the organism and cells. Students need to understand these relationships before they will adequately understand how plants use photosynthesis.

Students also need to understand that nutrition is a "continuous exchange process between the organism's matter and energy (and each of its cells) in the environment in which they live, thus overcoming the identification 'nutrition = feeding'" (Canal, 1999, page 368). The differentiation between organic and inorganic substances and the scientific definition of the word "food" will also help students understand the differences between nutrition and feeding. Students also need to accept that plants obtain the inorganic nutrients they require from both the ground (water and minerals) and the air (carbon dioxide) and use these inorganic nutrients to manufacture the organic nutrients they need in chlorophyll within their cells to synthesize the compounds they need to enable growth and reproduction. Also, the processes of photosynthesis and respiration do not offer any explanation about the role of sunlight for plant nutrition. Students tend to consider light as a kind of nourishment for plants or something healthy for them because they do not understand how light energy comes into play in the process (Canal, 1999). Teachers need to explain to students the role of sunlight in photosynthesis and give their students comparisons to make between the materials plants use for nourishment and those used by animals. Lastly, students need to understand that respiration is a process that is equal in both animals and plants and that this process involves all cells in which organic nutrients are combined with oxygen to fulfill the functions of the cells and the organism (Canal, 1999). Teachers need to stress that plants respire all the time and not just at night or when plants are not photosynthesizing.

One of the problems in understanding how photosynthesis and respiration work in plants could be because a global view of the structure and function of plants and other living beings is not usually introduced (Canal, 1999). Plant respiration tends to be presented as one of the vital needs of all living beings. Young students easily accept that plants breathe the same way as animals do, despite the fact that they do not produce breathing movements like animals or current of air that children can observe. Students, especially young students, are told that respiration is necessary without being given an explanation as to the physiological sense of respiration in the nutrition of human beings. Students accept that plants need to continue breathing to survive, just like animals, but are given no explanation as to why this is the case (Canal, 1999). Older students understand the kinds of gases exchanged in respiration and photosynthesis and may simplify the processes down to gas exchange events, without reference to the complex biochemical processes. This could lead students into believing that photosynthesis is simply the respiration of plants (Amir and Tamir, 1994).

Educators also need to be aware that photosynthesis and respiration are not opposites, and should not present this view to their students. The idea that they are opposites is tempting to consider, because their overall chemical equations are opposite. "However, in actuality they differ in location, energy transformation, enzymes involved and immediate reactions" (Amir and Tamir, 1994). Stating that in respiration oxygen is consumed and in photosynthesis it is produced is correct, as well as other opposites teachers may include, but students do not have the deep understanding scientists and educators do that allow them to understand how these processes are opposite and how they work together within plant cells. Claiming that they are opposites causes students to believe plants photosynthesize when they cannot respire, and vice versa. This leads to the belief that plants photosynthesize during the day when there is sunlight and respire at night when it is dark. The idea of opposites between these two processes can only be used if it is explicitly stated that they are only opposites in the sense that the products of one process are the reactants of the other, or described in terms of the energy flow between the two.

Photosynthesis should also be taught in context and not just as a formula or process that happens in plants. By taking a holistic approach and including photosynthesis in a unit about food webs and energy transfer, students will be able to better understand the exchange of energy and matter among ecosystems. Coupling the processes of photosynthesis, consumption, and decomposition will help illustrate this idea of energy transfer. “A basic knowledge of energy transfer is also necessary for students to develop a useful understanding of dominant patterns in nature, such as energy pyramids” (Ray and Beardsley, 2008, page 17). Many students do not understand how greatly photosynthesis affects their lives, and coupling photosynthesis with other common processes should help bring light to the enormous impact it has on the world. Ray and Beardsley (2008) started their unit on photosynthesis by having their students list ten products that depend on photosynthesis that they interacted with that day. Many students just write down plants they have eaten lately or common plant-derived products, such as cotton. They then add to their students' lists medicines and energy supplies such as coal and oil and place the items into different categories so students can visually see how many different parts of their lives are impacted by plants and photosynthesis.

Teachers need to be sure to teach the processes of photosynthesis and respiration to their students. If students do not understand the processes, they will memorize the information for a test and the learning will not be very meaningful to them. Amir and Tamir (1994) suggest using various formats to teach concepts, as misconceptions are sometimes revealed in one situation and not another. Multiple modes of learning will also help all of an educator's students to understand the concepts. These suggestions work for all topics, not just photosynthesis and respiration.

One fun idea to use to teach students about photosynthesis, or any topic that frequently has misconceptions, is concept cartoons. Concept cartoons are pictures that are not humorous but instead combine visual elements with text written in the form of dialogues to bring light to misconceptions about a topic. These topics must be applied to everyday situation, so that the learners are challenged to make connections between the scientific and the everyday (Ekici et. al., 2007). The students within the concept cartoons portray statements that are false or common misconceptions, along with a single scientifically acceptable explanation. The other statements highlight misconceptions students may have, but must be plausible to students. Learners will see these alternative ideas as reasonable if the misconceptions are based on research. It is also important to make sure that the alternative statements all appear to be equal, so that the learner cannot work out which statement is correct solely based on the context (Ekici et. al., 2007).

Research about concept cartoons shows that they highlight student misconceptions quickly and provide student participation in class discussions as students are eager to defend their choices. Through discussion, teachers are also able to provide the opportunity to talk about where these misconceptions came from and why they are incorrect. Kabapinar (2005, in Ekici et. al., 2007) found that concept cartoons help students' participation in discussion and reduce anxiety about giving the incorrect answer since it is the character in the cartoon that thought of the idea, not the student. This brings the focus off of the student, especially when they are incorrect. Concept cartoons were used in a unit about photosynthesis by Ekici (2007), in which it was found that many students believe that plants get their food from the environment like animals. By having the students discuss their answers as a class and think about their answers individually, many of them were able to change their conceptions about this topic. Investigators during the study talked to students and found that many students with misconceptions realized that their idea was wrong during the discussion and were able to change their ideas (Ekici et. al., 2007). Concept cartoons are relatively easy to make and are a fun exercise that increase student interest about the topic and allow them to revise their conceptions during discussion.

Another way to teach students about photosynthesis is to use the Dual Situated Learning Model. This model pairs students' ontological view of the concept with the attributes of the concept to create dissonance with students' existing knowledge and provide a new mental set with which to construct the new scientific concepts (Akpinar, 2007). This model suggests that there are four mental sets that students must have in order to successfully construct a scientific view of the concepts of photosynthesis and respiration. The four mental sets are:

1. Elements such as water, light, carbon dioxide, and soil are not food for plants.
2. Plants use carbon dioxide, water, and solar energy (light) to photosynthesize and make their own food.
3. Plants and animals respire day and night. Respiration is not the reverse of photosynthesis.
4. Chemical equations of photosynthesis and respiration.

The student must have these four mental sets in order to understand the processes of photosynthesis. Several dual situated learning events were used in Akpinar's study to help students construct these mental sets. These events include experiments, demonstrations, reading a conceptual change article about photosynthesis, group work, and viewing a computer presentation about the relation between animals and plants. The results from Akpinar's study indicated that this dual situated learning model improved student success more than traditional teaching. These types of events, as well as the knowledge that students need to possess these four mental sets in order to adequately understand photosynthesis, will help educators teach their students about photosynthesis.

As with every subject taught in the classroom, it is important to address many different learning styles to engage students with different interests and learning modalities. This will help all students achieve greater success in the classroom overall.

Research has shown that these different activities greatly help students understand photosynthesis better than conventional methods. Concept cartoons can be utilized as a method to increase students' interest and motivation towards science and the topics being taught as well as bringing forth misconceptions that the students may have.

CHAPTER IV

NATURAL SELECTION AND EVOLUTION

INTRODUCTION AND BACKGROUND INFORMATION

Natural selection is an essential component to high school biology classes. It is one of the central mechanisms of evolutionary change and is the process responsible for the evolution of adaptive features of organisms (Gregory, 2009). It is also one of the most commonly misunderstood concepts in the biology classroom (Burton and Dobson, 2009; Nehm and Reilly, 2007). Natural selection is defined as the "non-random difference in reproductive output among replicating entities, often due indirectly to differences in survival in a particular environment, leading to an increase in the proportion of beneficial, heritable characteristics within a population from one generation to the next" (Gregory, 2009, page 156). It is a relatively difficult concept that requires abstract thinking and can cause students to arrive at misconceptions even though they make logical choices and connections (Burton and Dobson, 2009). The difficulty of the topic causes many misconceptions in students at all levels, even including university and medical students.

An understanding of natural selection is becoming increasingly important in many practical fields, such as medicine, agriculture, and resource management (Gregory, 2009). Natural selection results from the basics of ecology and heredity and has direct significance to human health and well-being, which makes them important for students to learn and understand. Unfortunately, textbooks and educators alike tend to simplify natural selection too much or make it too abstract for students to adequately understand the process and students therefore must rely on misconceptions to fill in the blanks. Discrepancies between common and scientific vocabulary just confuse students even more. Also, students have learned most of their information about evolution from non-authoritative sources such as television and their parents, which provide an inaccurate portrayal of the concept. Scientific principles tend to be counterintuitive, which is why inaccurate information from non-educational sources tends to make more sense to students than the scientific information they must learn in school.

It has been suggested that natural selection and evolution are too difficult and abstract for young students to learn and understand. However, the issue does not seem to be a lack of logic in students but biases about the information (Greene, 1990; Settlage, 1994 in Gregory, 2009). Many students develop ideas about how natural selection works early in childhood as they learn about how the world is structured. These ideas tend to be hard to eliminate as they make more sense to students than scientific principles. Therefore the goal of education should be to supplement students' existing conceptual frameworks with more accurate ones. "Helping people to understand evolution…is not a matter of adding on to their existing knowledge, but helping them to revise their previous models of the world to create an entirely new way of seeing" (Sinatra et al., 2008 in Gregory, 2009, page 167).

Burton and Dobson (2009) identified eight misconceptions students hold in response to natural selection. These eight misconceptions are: mutations are detrimental to fitness; changes in traits are a result of need/use/disuse; acquired characteristics are heritable; students do not recognize the importance of genetic variation; environmental conditions are not considered important in causing selective pressures; students do not recognize the role of reproductive success in evolution; evolutionary change is based on gradual modifications in traits, not the changing proportion of individuals with particular alleles; and evolution is deterministic (it works toward some predetermined endpoint). Nehm and Reilly (2007) also found some unanticipated or unusual misconceptions in the students they studied, such as the idea that "survival of the fittest" means survival of the fittest species; "fit" means the dominant allele and "unfit" means the recessive allele; genetic drift is gene flow between different species; drastic climate change or other environmental changes are required for evolution to occur; and heritable "compensation" of one trait occurs when another trait is lost. It is clear from these lists of misconceptions that students are not only having trouble with the concept of natural selection, but also that they are having trouble with genetics. It is important, therefore, for educators to make sure that their students understand the basics of genetics in order to fully understand the concepts of evolution and natural selection.

IMPLICATIONS FOR TEACHING

One of the areas teachers need to focus on when talking about natural selection and evolution is vocabulary. There are many terms in evolution and natural selection that mean very different things in scientific terms and layman's terms. First, teachers need to help students differentiate between evolution as a fact and natural selection as a theory.

Evolution as a fact of nature means that it is empirical data that represents individual events. Scientists have found fossils and other evidence to support the fact of evolution; that features and organisms have changed throughout time. Natural selection as a theory explains how the process of evolution occurs. "Although we have both the fact of evolution and the theory of natural selection, few make the distinction as deliberately as they should" (McComas, 1997, page 494).

Educators also need to understand that the term "fitness," as used in evolutionary biology, does not refer to an organism's physical condition, strength, or stamina as it does in layman's terms (Gregory, 2009). Darwin used the term "fit" to mean "'best suited to a particular environment' rather than 'most physically fit'" (Gregory, 2009, page 159). In this case, the phrase "survival of the fittest" is a poor choice of words and just serves to confuse students into thinking that fitness has to do with physical strength. Teachers need to use the phrases "survival of the fittest" and "only the strong survive" with great caution in the biology classroom in order to help students understand fitness as an evolutionary term. It also appears that many of the figurative and metaphoric language that textbooks and teachers use, and that students find hard to understand, are also used by students, which shows that they do not understand the topic well enough to use their own terms (Geraedts and Boersma, 2006). Cutting down the amount of unfamiliar and figurative language used when teaching any science topic will help students better understand the concept and eliminate misconceptions.

It is also important for teachers to make sure they have thoroughly covered the topics of genetics either before natural selection and evolution are addressed or simultaneously within the unit (Baalmann et al., 1998; Banet and Ayuso, 2003 in Geraedts and Boersma, 2006). Many misconceptions seem to stem from confusions about terms in genetics or how the processes of inheritance work. For example, many students think that all mutations are detrimental to the organism or that the likelihood of occurrence depends on whether the mutation is detrimental or not (Gregory, 2009). Students need to understand that all mutations are random and that mutations and differences among organisms are only relevant if they can be inherited (Gregory, 2009). Also, students tend to think that the dominant alleles are more “fit” because they are passed on more readily to their offspring. The concepts of population and species should also be addressed more fully so students better understand that evolution works at the population level, not the individual or species level (Gregory, 2009; Geraedts and Boersma, 2006). In order to adequately understand natural selection, students must recognize that new traits arise through random changes in genetic material in individuals and that these traits will increase or decrease in frequency in the population under certain environmental conditions (Creedy, 1993).

Geraedts and Boersma (2006) suggest that Darwinian theory should be taught in two separate units, according to the historical development of the theory. They state that natural selection should be introduced in an ecological context by elaborating on predator-prey relationships. Students should answer the question about whether all individuals will have equal chances to survive and reproduce and will conclude that well-adapted individuals will create more offspring than less-adapted individuals and therefore are more “fit.” After the ecological unit of evolution is understood, the genetics of natural selection can be introduced. Genetics should be taught after ecology, including the topic of mutations and how they ascend from the molecular level to the organismal level to the population level. Natural selection can be presented as a theory to describe the evolutionary changes that they saw in the ecological context. Students should be helped to integrate the process of natural selection with genetics to best understand evolution and natural selection.

Another problem that could lead to many misconceptions is that many students do not accept the concepts of evolution and natural selection due to religious and/or personal reasons (Geraedts and Boersma, 2006). It is essential for teachers to be empathetic when discussing these topics with students, but also to let their students know that these are scientifically accepted ideas that the students need to learn and be aware of, at least for the Ohio Graduation Test and other standardized tests. Typically, it is the theory of natural selection that is debated more readily than the fact of evolution. If this is a problem, teachers should emphasize the fact of evolution and the reality of both change in organisms and the relationships between organisms from the fossil record and help students to understand what scientists know about the process of natural selection (McComas, 1997). Though natural selection can be a touchy subject in the classroom, it is important for teachers to address this concept in order to help their students overcome their misconceptions about it.

McComas (1997) suggests that textbooks simplify evolution and natural selection so that it is a story that is both believable and conclusive, which satisfies students and teachers alike. However, he states that the typical textbook story is incomplete and frequently incorrect. McComas suggests that teachers allow their students to explore Darwin's story in much more detail in order to better understand the human dimension of science and also eliminate many misconceptions as they better understand how the theory of natural selection came to be (1997). By reading about Darwin's observations and thinking as he observed evolution and thought about the theory of natural selection, students understand the scientific processes he went through when making his discoveries, allowing them to better understand natural selection as a whole and eliminate some of their misconceptions (McComas, 1997). Geraedts and Boersma (2006) suggest that Darwin's theory is logical and that by allowing students to construct or "reinvent" Darwin's theory of natural selection themselves the students create a better understanding of the topic. Allowing students to read about Darwin's history step-by-step and answer questions about his discoveries while making conclusions themselves seems to be a logical way to combine by McComas and Geraedts and Boersmas' ideas and give students the best chance at eliminating their misconceptions.

Current theories in science education suggest the use of many different activities and strategies to help students overcome misconceptions and understand science topics better. Natural selection is one of the topics that would benefit from this thinking. For example, it may be useful to students to explore natural selection through evolutionary scenarios. This allows students to look at alternative solutions to the process to find which ways work best and make the most sense scientifically. This will also help students better appreciate the explanatory power of natural selection in evolution (Nehm and Reilly, 2007).

Another way to include activities in the classroom when addressing natural selection is to make up scenarios that will help students understand the processes without using too many technological terms and confusing examples. Burton and Dobson (2009) created an evolutionary activity using spoons, forks, and sporks to demonstrate the role of natural selection as a mechanism for evolution. Students choose a spork or a spoon to capture "prey" items (mini marshmallows) to find that spoons capture the prey the least efficiently and diminish quickly, while the number of sporks increases. Bringing in forks to the activity and changing the "prey" to beans changes the results of the evolutionary processes. Students find that certain utensils work best in certain environmental conditions (with different prey) and that the weaker ones will quickly die out while the utensils best suited for the prey will capture the most items and survive. This is an easy way to introduce and explain natural selection to students and is also a memorable and entertaining activity that will keep students engaged and interested (Burton and Dobson, 2009).

Natural selection and evolution are abstract topics that are often confused by students' relatives and the media. It is up to the teacher to help students understand the scientifically accepted principles of natural selection and evolution. These concepts allow teachers to easily incorporate many nature of science elements in the lessons, such as fact vs. theory and that there is not one scientific method or way of doing science that all scientists follow. By including evolutionary scenarios and Darwin's history into the lessons, natural selection can become very hands-on and interesting to the students, causing them to learn the material better and eliminate their misconceptions. As with all topics prone to misconceptions, it is essential that the educator teach with the misconceptions in mind as to make sure their students are addressing and eliminating them adequately.

CHAPTER V

CLIMATE CHANGE MISCONCEPTIONS

INTRODUCTION AND BACKGROUND INFORMATION

Climate change is a sensitive public topic that is becoming increasingly persistent in our world today. It is one of the most serious global environmental problems, and for that reason there has been great interest in educating students about it. For decades, it was of great interest as to whether global warming, or climate change, is actually occurring, and what the human impact is on this phenomenon. The Intergovernmental Panel on Climate Change (IPCC) finally declared in 2007 that atmospheric carbon dioxide levels are rising and that this has caused global climate change. They also stated that human activity has caused some of these changes, that there is already some evidence of biological impacts, and that future levels will be affected by human activity (http://www.ipcc.ch/; Papadimitriou, 2004). Though there was still disagreement about climate change fifteen or twenty years ago, today few scientists would reject the evidence for global warming. Now that climate change is widely accepted to be happening on Earth today, it is essential that young people understand exactly what climate change is, what is causing it, and potential consequences and cures of global warming.

Unfortunately, there seems to be many misconceptions about the causes of climate change in elementary and secondary students today. Many students have ideas regarding the scope and nature of climate change that are incorrect or inconsistent with predominant scientific understandings (Grima et. al., 2010). Some common misconceptions include: that global warming is caused by increased penetration of solar radiation, that it is connected with holes in the ozone layer, and that it would result in increased skin cancer (Grima et. al., 2010; Jeffries et. al., 2001; Kilinc et. al., 2008; Papadimitriou, 2004; Jakobsson et. al., 2009). There appears to be a general confusion between global warming and ozone layer depletion, with many students believing that the hole in the ozone layer is letting in more solar radiation, which warms the Earth and enhances global warming. The confusion between global warming and ozone layer depletion could be due to the rapid switching between topics in the media and inaccurate facts that the media portrays about both topics. Many students also think that global warming will result in increased cases of skin cancer, as they make the connection between warmer weather caused by increased solar radiation and increased sunbathing that can lead to skin cancer.

As for the causes of climate change, most students are aware that an increase in global warming will result in melting of the polar ice, more flooding, and changes in weather patterns, such as Earth getting hotter (Grima et. al., 2010; Jeffries et. al., 2001). They know the concept of the "greenhouse effect" and understand that certain gases in the atmosphere act on the planet like glass in a greenhouse. Most students know that carbon dioxide is a greenhouse gas and that chlorofluorocarbons (CFCs) are also greenhouse gases. Jeffries et. al. (2001) suggests that this link is faulty, in that CFCs are a major agent responsible for ozone layer depletion, and they think that many students are naming it as a greenhouse gas because they know that it damages the ozone layer and falsely believe that ozone layer degradation and global warming are connected.

Many students understand roles that humans play to reduce climate change, such as reducing the use of vehicles, planting trees, and conserving electricity and using renewable energy sources. However, many students seem to think that any habits that are good for the environment will reduce global warming. They consider anything that is environmentally wrong as the cause of any environmental problem (Kilinc et. al., 2008; Papadimitriou, 2004; Jakobsson et. al., 2009). "Furthermore, students consider their actions, as individuals, as having a minimum effect on the environment when compared with what can be done by industries" (Grima et. al., 2010, page 38). It is positive that students are aware of many actions that can be taken to reduce global warming, though these actions will be increased if they understand the reasons behind their actions. An environmentally-educated public will more readily accept governmental action and be more willing to carry out environmentally-friendly actions (Jeffries et. al., 2001; Kilinc et. al., 2008).

While students seem to have the basic views about climate change, they make connections between ozone layer depletion and global warming that are false. They also seem to think that any habits that are good for the environment will reduce global warming and ozone layer degradation. Since most students claim that school has provided most of their information on climate change, it is essential that teachers understand this phenomenon themselves in order to accurately teach it to their students. The claim that school provided students with most of their knowledge about climate change is surprising, as the media tends to use very powerful images to make their information more effective to the public. Teachers, therefore, should remember that they are competing with the media to give students this information and need to plan accordingly.

Student ideas about climate change and other environmental issues are generally fragmented, possibly due to the way the media addresses these issues separately. There are many popular environmental issues today; all of which come and are replaced quickly and the public must accommodate all of them with little concrete evidence. “Perhaps each issue in turn displaces the previous one in the public’s mind as a more immediate problem, so that any learning is not well thought through or consolidated” (Jeffries et. al., 2001).

IMPLICATIONS FOR TEACHING

Many of the issues surrounding climate change are abstract and hard for students to understand. Because climate change is so prevalent in the media today, it is important to think about the pre-existent thinking of the public as well as the individual students when designing educational materials and strategies (Jeffries et. al., 2001). This can be done formally or informally through pre-tests and other ways to gather information about students’ previous knowledge. It is essential that teachers understand the science behind and implications of climate change and that they make sure to teach about the scientific understanding of climate change and not just impose their opinions on the topics.

One of the reasons students have a hard time understanding climate change is because educators have a hard time teaching it. Experiential learning, a powerful form of education, is difficult to apply to abstract topics and therefore difficult to apply to climate change (Jeffries et. al., 2001; Papadimitriou, 2004). Even the aspects of climate change that are more concrete, such as the melting of polar ice, are hard for students to understand because they are predicted or distant. This makes it hard for experimental learning as well. Because these topics are so abstract, traditional ways of teaching, which are based on the transmission of knowledge, are inappropriate as they do not help students use the knowledge learned to understand real issues in everyday life. Engaging students in experiments and other hands-on activities can also be inappropriate because of the abstract nature of the science involved (Papadimitriou, 2004; Kerr and Walz, 2007). Therefore, it is best to use "real-life" issues when teaching students about environmental problems such as climate change.

"Real life" issues should be included wherever possible so that students have practice analyzing problems within social and cultural contexts in order to make valid judgments and conclusions. Students are not effectively transferring their acquired knowledge to the "real world" so giving them "real life" examples will help them to transfer their knowledge to other concepts. The scientific concepts taught in the classroom should have application in the field so that students can make sense of whether their proposed ideas address the cause and have the potential to work in the "real world." Because it has been proven that acceptance of scientific ideas does not lead automatically to the elimination of misconceptions (Kilinc et. al., 2008; Kerr and Walz, 2007), students that are able to apply their new knowledge and ideas should have a better chance at eliminating their misconceptions about climate change.

The student needs to be engaged in active dialogue and translate the information they have learned into their own terms (Jakobsson et. al., 2009). One of the most effective ways of learning is when students are able to discover the principle themselves and construct their own understanding. Constructivist approaches to climate change help students to discover and explain the links between the knowledge they have accumulated in order to build a correct conceptual framework (Grima et. al., 2010). One way to have students take a constructivist approach to this topic is by having them gather information on the issue from many sources. Learners should be encouraged to seek new perspectives and define the topic in their own terms (Grima et. a., 2010; Kerr and Walz, 2007). Students need to be active learners that can reason things out (with educator help) so their knowledge can evolve into a more comprehensive picture.

Another way to help students learn about climate change and other environmental issues is by organizing the curriculum in a spiral manner so that the student continually builds upon what has already been learned (Grima et. al., 2010). Knowledge should be constructed so that it goes from simpler to more complex, with students building on their knowledge and the amount of information they can manipulate. Students should be told to think about how an expert of that particular topic would think in a particular circumstance. Also, since students show confusion between the greenhouse effect, climate change, and ozone depletion, these topics should be presented together so that students have the opportunity to make distinctions between them (Papadimitriou, 2004).

Discussion about environmental issues can be included within many science topics not typically seen as part of the environmental issues, such as biodiversity, energy sources, and life cycle analysis (Summers et. al., 2001). It will also be helpful for teachers to ask whether students have eliminated misconceptions, not just if they understand the material. This can be done by discussion or more formally through post-test materials.

Students may have problems with the concepts of climate change and ozone layer depletion because these are complex scientific topics that require a deeper understanding of the topics. If students do not understand what affects the thinning of the ozone layer and how it affects global warming, their knowledge of the topic will not be complete. The fact that they gave contrasting answers in studies such as by Grima et. al. (2010) and Kilinc et. al. (2008) shows that their knowledge is disjoint. Different aspects pertaining to the same issue are frequently taught in isolation from each other, and this fragmentation inhibits students from visualizing the whole picture. If they do not understand the big picture, they will not be able to apply the knowledge adequately and integrate it with other concepts (Grima et. al., 2010). Currently, students are expected to link concepts on their own, without much guide from the teacher. The educator should be there not to give the students the relations between concepts but to define and cultivate those links so that they are scientifically sound. Students cannot be expected integrate knowledge from various sources on their own, especially when some of that knowledge is filled with incorrect facts. Correct links between concepts and the ability to transfer knowledge from one context to another will create a more complex meaning in a structured manner that will help the student to understand the whole picture of climate change.

Many misconceptions about climate change have been identified as early as in elementary students (Jakobsson et. al., 2009), and unfortunately many of these misconceptions continue on into secondary school and college. It is essential that teachers work to eliminate these misconceptions early so that students can spend their time understanding the concepts behind climate change instead of figuring out their misconceptions. Currently, students are acquiring fragmented knowledge from the media and other sources and having trouble integrating this knowledge into a single framework. Formal science instruction does not currently seem to be effective in changing misconceptions students have about climate change. Including different activities with real-life examples will help students to form their own conclusions about climate change and help them better understand the science behind it. Students need to be aware that climate change is a complex problem with no simple solution (Jakobsson et. al., 2009). These students will be making future decisions about climate change and what people can do to help slow down or eliminate global warming, so it is imperative that they fully understand the underlying causes and consequences of climate change.

CHAPTER VI

DIAGNOSING MISCONCEPTIONS AND WRITING FORMATIVE ASSESSMENTS

In order to effectively teach to change student misconceptions, an educator must first be able to diagnose them. Many times the actual diagnosis of student misconceptions is overlooked by teachers, either because they don't want to spend the time or because they assume the students have learned what they should have been taught, according to the national and/or state standards. Diagnosis is a requirement for any teaching strategy to be effective. Much research has been done over the last thirty years in order to create effective diagnostic materials for teachers to use in the classroom (Clerk and Rutherford, 2000 and Stein et. al., 2007).

There are many variables to consider when creating a formative assessment to use in a classroom. The first to consider is the format; teachers have a few options here. Short answers to questions are ideal for teachers to really understand what the student is thinking, but they are tedious for students to complete and teachers to assess. Multiple choice or true and false questions allow the evaluation to be completed quickly and allow the teacher to control which answers the students have to choose from. It also allows teachers to quickly tally up the answers and see which answers occur the most often, and if that leads to any misconceptions that the students may have. Multiple choice and true and false answers, however, do not really let the educator know what the student was thinking when they answered the question, and if their answer really leads to a misconception.

Researchers have found that it is best to pair multiple choice or true and false questions with space for the student to explain what they were thinking when they answered the question (Stein et. al., 2007). This way, the educator can quickly tally the results, then delve deeper into the students' minds to see if their incorrect answer was really due to a misconception or to another cause. In many cases, for instance, there are ways of thinking about a statement that could make an incorrect answer correct. "There will always be exceptions and ways to think about science that are valid alternatives to the correct answers provided" (Stein, et. al., 2007, page 237). This format also allows teachers to understand the alternative responses the students may give and see the full range of their students' beliefs, including misconceptions. Effective diagnosis of student misconceptions is also useful for students as they allow students to begin thinking about their own ideas, the reasons for those ideas, and how those ideas change as a result of instruction (Stein, et. al., 2007).

Another variable is the length of the assessment. While it may be appealing to try to get in as many questions as one can in order to really assess what the students know, students will likely tire near the end of the evaluation and not give the answers as much thought. As the assessment continues, explanations become shorter and the extent to which ideas are described is lessened. Researchers have found that it is best to keep the assessment short, and to keep the questions focused and make sure they relate to each other (Stein et. al., 2007). It is best, for example, to give an assessment about just the topics of food webs or photosynthesis, than to give an assessment about all of ecology or biology together.

A third variable, not typically considered but important all the same, is that of language. The educator must ensure that the vocabulary is not too advanced for the students he or she are assessing, and that the wording of each question is clear and concise so that all students understand it. In science there are many significant differences in vocabulary usage that many students are not aware of, and this can lead to problems in understanding the question or understanding what answer the teacher is looking for. For example, the word *theory* among scientists has a very different definition than among the mainstream population, almost to have an opposite definition (Clerk and Rutherford, 2000). Students must be able to understand the vocabulary in the assessment well enough to understand what the questions are asking. It is the educator's job to make sure each question is clear and concise with no room for alternative interpretations.

Along the lines of language, if a question or diagram is labeled with words a student is not familiar with, misconceptions may arise, even though the student may understand the concepts. "A misconception does not exist if the tokens are merely mislabeled: for example, somebody who knew very well that there was a force that tended to resist relative motion between two surfaces in contact, but who was not in the habit of calling that force 'friction,' might present the illusion that he or she held a misconception whereas in fact only the label was 'non-standard'" (Clerk and Rutherford, 2000, page 704). It is important that educators understand where these discrepancies lie and not allow language difficulties to mask themselves as misconceptions during an assessment. Students with language problems will not likely respond to traditional conceptual change strategies and not accept different conceptions about a topic into their cognitive scheme (Clerk and Rutherford, 2000).

Included are eight formative assessments (two for each topic examined) that should be used at the beginning and end of a unit in order to assess student misconceptions about a subject and how they have changed after conceptual change measures have been taken. They can also be used throughout a unit as indicators for how student conceptions are changing throughout the unit. The assessments should be used in addition to assessments about the subject matter for the unit. These assessments take into consideration the research that has been done about misconceptions in science and writing for student and teacher understanding.

FOOD WEBS ASSESSMENT I

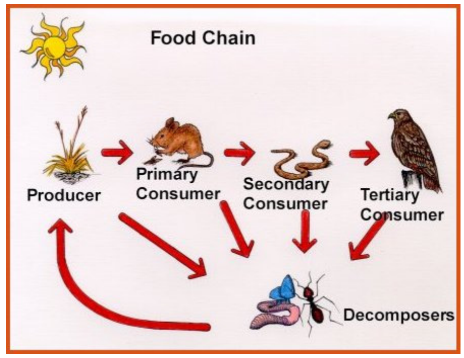

Figure 1: Food Web I

Please answer the following questions, explaining your reasoning for your answers.

1. If the population of secondary consumers in a food web decreases, what will happen to the populations of primary consumers?

2. If the population of secondary consumers in a food web decreases, what will happen to the populations of producers?

3. If the amount of plants, or producers, in a food web decreases, will there be an effect on the primary consumers that eat the plants? If so, what would the effect be?

4. If the amount of plants, or producers, in a food web decreases, will there be an effect on the secondary consumers that eat other animals? If so, what would the effect be?

5. If the amount of primary consumers in a food web increases, will there be an effect on the plants in that food web? If so, what would the effect be?

FOOD WEBS ASSESSMENT II

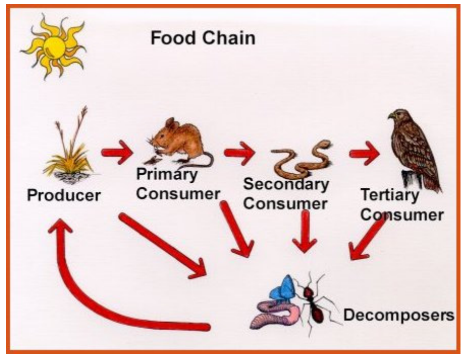

Figure 2: Food Web II

Please circle all correct answers and provide your reasoning for your answers.

1. If the population of secondary consumers in a food web decreases, what will happen to the populations of primary consumers?
   a. they will increase because they will not be eaten by the secondary consumers
   b. they will increase, then decrease as they run out of producers to eat
   c. they will stay about the same

Please explain the reasoning for your answer:

2. If the population of secondary consumers in a food web decreases, what will happen to the populations of producers?
   a. they will decrease because there will be more primary consumers eating them
   b. they will decrease, then increase as the population of primary consumers changes
   c. they will not be affected because the primary consumers were not affected

Please explain the reasoning for your answer:

3. If the amount of plants, or producers, in a food web decreases, will there be an effect on the primary consumers that eat the plants? If so, what would the effect be?

a. the number of primary consumers will increase because there will be less secondary consumers to eat them

b. the number of primary consumers will decrease because there will be less food for them to eat

c. the number of primary consumers will not be affected because it is the secondary consumers that determine how many there are

Please explain the reasoning for your answer:

4. If the amount of plants, or producers, in a food web decreases, will there be an effect on the secondary consumers that eat other animals? If so, what would the effect be?

a. the number of secondary consumers will decrease because there will be less plants for them to eat

b. the number of secondary consumers will decrease because there will be less primary consumers for them to eat

c. the number of secondary consumers will not be affected because it is the primary consumers that determine how many there are

Please explain the reasoning for your answer:

5. If the amount of primary consumers in a food web increases, will there be an effect on the plants in that food web? If so, what would the effect be?

a. there will not be an effect because the number of plants determines the number of consumers, not the other way around

b. there will be less producers because there are more primary consumers eating them

c. there will be more producers because more must grow to be able to feed the primary consumers

Please explain the reasoning for your answer:

PHOTOSYNTHESIS ASSESSMENT I

Please answer the following questions, explaining your reasoning for your answers.

1. Where do plants get their nutrients?

2. When do plants photosynthesize?

3. When do plants respire?

4. What is the most important benefit of photosynthesis?

5. Where do plants get their energy for growth?

6. Is respiration different in plants and in animals? Why or why not?

7. Where in the plant does photosynthesis take place?

8. Where in the plant does respiration take place?

PHOTOSYNTHESIS ASSESSMENT II

Please circle all correct answers and provide your reasoning for your answers.

1. Where do plants get their nutrients?
   a. sunlight
   b. nutrients in the soil
   c. nutrients added to the soil by people or other animals
   d. other

Please explain the reasoning for your answer:

2. When do plants photosynthesize?
   a. during the day only
   b. all the time - during the day and night
   c. only when there is enough sunlight to allow it to happen

Please explain the reasoning for your answer:

3. When do plants respire?
   a. during the day only
   b. all the time – during the day and night
   c. only during the night
   d. only when the plant is not photosynthesizing

Please explain the reasoning for your answer:

4. How is respiration different in plants and in animals?
   a. respiration in plants takes place when plants cannot photosynthesize, while respiration takes place all the time in animals because they cannot photosynthesize
   b. respiration does not take place in plants because they photosynthesize and does in animals because they cannot photosynthesize
   c. respiration is the same in both plants and animals

Please explain the reasoning for your answer:

5. What is the most important benefit of photosynthesis?
    a. photosynthesis removes carbon dioxide from the air
    b. photosynthesis adds oxygen to the air
    c. photosynthesis creates energy for the plant to grow

Please explain the reasoning for your answer:

6. Where do plants get their energy for growth?
    a. sunlight
    b. energy created from photosynthesis
    c. nutrients from the soil and/or other sources

Please explain the reasoning for your answer:

NATURAL SELECTION AND EVOLUTION ASSESSMENT I

Please answer the following questions, explaining your reasoning for your answers.

1. Is an individual organism able to evolve over the course of its life? Why or why not?

2. Are all vestigial structures (such as your appendix) completely useless? Why or why not?

3. Are organisms able to consciously direct the course of their own evolution? Explain.

4. Does evolution occur by chance alone? Why or why not?

5. What does survival of the fittest mean?

6. Does an organism's environment or surrounding habitat affect its evolution? Why or why not?

NATURAL SELECTION AND EVOLUTION ASSESSMENT II

Please circle all correct answers and provide your reasoning for your answers.

1. How does evolution work?
   a. an individual can evolve over the course of its life
   b. a species can evolve over a period of many generations
   c. both types of evolution can happen

Please explain the reasoning for your answer:

2. Are organisms able to consciously direct the course of their own evolution?
   a. yes, they can evolve to meet their eating and living needs
   b. no, but individuals can change their habits to meet their eating and living needs
   c. no, an individual cannot make itself evolve, but evolution can happen over its lifetime
   d. no, an individual cannot make itself evolve, because evolution cannot happen over its lifetime

Please explain the reasoning for your answer:

3. How does evolution occur?
   a. by chance alone
   b. sometimes by chance, sometimes by necessity
   c. by necessity of a species or individual to survive

Please explain the reasoning for your answer:

4. What does survival of the fittest mean?
   a. the animal with the strongest body will be able to fight to survive
   b. the animal with the strongest genes will survive
   c. the animal that is the smartest will survive
   d. the animal with the strongest body will be able to find the most food to survive

Please explain the reasoning for your answer:

CLIMATE CHANGE ASSESSMENT I

Please answer the following questions, explaining your reasoning for your answers.

1. Is there a difference between global warming and climate change?

2. What causes global warming or climate change?

3. What are some consequences of global warming/climate change on the earth?

4. What are some consequences of global warming/climate change on humans?

5. What can people do to decrease global warming/climate change?

6. What can you as an individual do to decrease global warming/climate change?

7. Do chlorofluorocarbons (CFCs) play a role in global warming/climate change? If so, how?

8. Will all parts of the earth be affected equally by global warming/climate change?

CLIMATE CHANGE ASSESSMENT II

Please circle all correct answers and provide your reasoning for your answers.

1. What causes global warming or climate change?
   a. the hole in the ozone layer
   b. increased sun rays coming into the atmosphere
   c. gases in the atmosphere that are causing air particles to hold heat

Please explain the reasoning for your answer:

2. What are some consequences of global warming/climate change on the earth?
   a. melting of glaciers
   b. rising sea levels
   c. changes in weather patterns
   d. hotter temperatures on all areas of Earth

Please explain the reasoning for your answer:

3. What are some consequences of global warming/climate change on humans?
   a. increased rates of skin cancer
   b. people must move due to flooding or hotter temperatures
   c. there will be little to no change on humans

Please explain the reasoning for your answer:

4. What can people do to decrease global warming/climate change?
   a. drive cars less often
   b. decrease the amount of chemicals in the air
   c. decrease the amount of chlorofluorocarbons in the air
   d. there is nothing people can do

Please explain the reasoning for your answer:

CONCLUSION

Through the research of student misconceptions in high school students and effective ways to address student misconceptions in science, much can be gleaned about student learning. First and foremost, it is important to gauge where one's students are coming into the class, both in their knowledge of the content material and of any misconceptions they may hold. This is most commonly done through a pre-assessment of student knowledge. Knowing the base knowledge of one's students will greatly help in teaching these students effectively. Each student is different and has different modes of thinking and learning, so it is essential to address each student on a case-by-case basis as well as teach to the class as a whole to address the most common misconceptions.

The most effective approach to utilize in addressing student misconceptions, or any topic, is constructivism, or having the students construct their own understandings. This approach allows students to think through the processes of science and the topic to make the learning more meaningful to each student and help then integrate the concepts into their conceptual ecology. Other methods, such as the 5-E learning cycle, are also helpful in addressing student misconceptions and helping students to learn effectively in the classroom. Lastly, it is essential to utilize formative and summative assessments to better understand student thinking about the misconceptions during and after the unit is taught, so that new misconceptions may be targeted or stubborn misconceptions dealt with more in depth, as well as alerting students about their changing conceptions.

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