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Identification, Analysis and Instructional Design

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Abstract

Ecology is a unique field of science in which several factors effect the type, variety and number of student misconceptions. Among these factors are: ecology is a relatively new scientific discipline, it is interdisciplinary, and it describes many phenomena with which we have experience. This paper reviews the strategies used to elicit students' understandings of ecology, analysis of several prevalent student misconceptions, and several instructional activities that help address specific misconceptions. The identification of misconceptions through clinical interviews, concept maps and multiple choice questions is reviewed and discussed in relation to what teachers can do to continually identify and monitor student misconceptions. Specific ecological misconceptions related to breathing in aquatic organisms, photosynthesis in marine plants, and the water cycle are concept mapped showing important relationships to related physical and biological science concepts. These concept maps present fundamental topics which must be identified in order to help address student misconceptions Several instructional activities which attempt to address these misconceptions including The Water Circle, Molecules in Motion and Classroom Aquaria are described and discussed in relation to specific instructional design.

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Introduction

"Coral reefs exist throughout the oceans of the world." "If you remove one species in an ecosystem, all of the animals which prey on that species will die." "Fish breathe oxygen that they get from the water molecule" "Some plants live deep in the ocean where there is no light." These statements were made by fourth, eighth and eleventh grade students from the United States of America (USA) in the course of interviews which focused on ocean resources, acid rain and pollution. They represent typical student misconceptions related to the field of ecology and are important to educators because they will effect what children learn in schools. Research on student misconceptions related to ecology is sparse, although several studies of children's understanding of natural phenomena could be interpreted from an ecological perspective.

Ecological Knowledge & Modern Curriculum Reform

The term *ecology*, first proposed by Ernst Haeckel in 1866, comes from the Greek root *oikos*, meaning "home," and *logos* meaning "the study of." Literally, it refers to the study of the home. Ecology is the scientific study of the structure, function and behavior of the natural systems which comprise the biosphere. Ecologists study the relationships of organisms with each other and with their physical environment. Since environmental problems like pollution usually arise from a disturbance of natural systems, ecology is critically important to understanding, solving and preventing environmental problems.

As a discipline, ecology grew out of scientific interest in the natural history of plants and animals, and from the pioneering work of plant geographers. In the 1940s, many biologists urged that a course in ecology be offered for all majors in the biological sciences. The first widely used college text for ecology students, Eugene Odum's *Fundamentals of Ecology*, was published in 1953 and focused attention on understanding the dynamics of the biosphere through the study of its subunits, or ecosystems.

Ecologists attempt to understand ecosystems based on research from the physical and biological sciences. They study nature as a functioning system instead of a collection of distinct unrelated parts. Understanding how the parts function together to form a forest, field, lake or ocean helps ecologists to predict the effects of human induced stress on the environment. Ecological research can help us to understand, for example, how nutrients and energy are transferred from organism to organism, how climate is modified by forest destruction, and how one species affects the population dynamics of another.

As the nature of science evolves, and in particular the evolution of ecology as a discipline, how does the conception of education change in relation to both science and societal needs? The 1990s have seen the emergence of three major curriculum reform movements in science education which could have implication for ecology education.

Among the most recent curriculum reform efforts in the USA are the National Science Teachers Association (NSTA), *Scope, Sequence and Coordination of Secondary School Science (SS&C),* the American Association for the Advancement of Science (AAAS), *Project 2061*, and the National Research Council's (NRC), *Science Standards and Assessment.* Each of these reform efforts includes suggestions about how science should be taught in US schools in order to improve education nation-wide.

According to NSTA's SS&C (1992), there are basically three areas which curriculum reformists need to address: sequencing, coordination and assessment. NSTA's conception of curriculum coordination infers that science topics should link together at any particular time. This linkage is meant to be among various science disciplines and this leads to the analogy of a mini-layer cake approach, that is, 1 quarter physics, chemistry, biology and earth science each year for all children. If NSTA's suggestion that subjects should link together is to be taken seriously, curricula examples based on these principles need to be implemented in real classrooms. A focus on ecology as a basic science subject area is a good example.

The American Association for the Advancement of Science's (AAAS) Project 2061 is based on several principles of learning and teaching. These principles are found in *Science for all Americans* (Rutherford 1990). They are primarily derived from theories of cognition, nature of science and modern learning theory. Implications for teaching are that values are critical in teaching and learning and that both extend beyond the schools. A focus on ecology can help lead to the inclusion of values related to the environment and the application of school learning outside the classroom.

The science standards as proposed by the National Research Council (Coordinating Council, NRC 1992) focus on the content of school science. In particular, they focus on science subject matter, scientific modes of inquiry, scientific habits of mind, decision making, science as a human endeavor and the relation of science to other areas of human thought and activity. Among the most significant of the NRC's recommendations are that science is essential for all Americans, regardless of background, aspiration, or interest, and an understanding of the modes of science based on inquiry are essential. The integration of topics related to ecology (a concern of all people) and inquiry related to both physical and biological sciences into the school curriculum is congruent with these curriculum reform suggestions.

Table 1.

Relationship of Ecology and Science Curriculum Reform

Ecology	Education
"research from physical and biological sciences"	"topics link together"(NSTA)
study of the "home"	"education has value"(AAAS)
environmental problems	"relevance"(AAAS)
how the parts function together	nature of inquiry(NRC)
natural resources	decision-making(NRC)

Identification

People's misconceptions about ecology are particularly important to address because people's understanding has a very real basis in reality. We all experience nature continuously. Ecological misconceptions are based on real life experiences and in many ways our survival as individuals and as a species is a stake. After all, the availability of natural resources for survival such as clean water for drinking or the prevalence of pollution like toxic waste which threatens our health and longevity are among the ideas which pervade our civilization. The relevance and value we associate with ecological concepts necessitates clear understanding based on meaningful learning.

The identification of misconceptions through clinical interviews, student generated materials and multiple choice questions has been documented in the misconceptions literature. Among those studies, which have some relevance for understanding children's conceptions of ecology, are a number of studies which focus on the states of matter, particularly water, ice and steam. These studies, for the most part , involve student explanations of of phenomena related to physical science concepts. There were essentially two techniques used in this area of research. The first interviews about instances asked children to describe a particular label such as plant (Osborne & Gilbert 1980). The second, interview about events asked children to explain their view of everyday phenomena such as light reflection (Osborne 1980).

The results of these types of studies have led to general conclusions about children's understanding of water and the states of matter based primarily on temperature (Osborne & Cosgrove 1983, Straus 1987 & Rafel & Mars 1987) and pressure (Giesse 1987). Osborne & Cosgrove report on the use of interview-about-events techniques to elicit children's views about a number of water related phenomena. In their study concerning the states of water, children were asked a number of questions about evaporation and condensation, such as, "What happens to a wet dish left on the counter top?" Children also observed a jug of water first heating and then boiling. In their oral description of the phenomena, few children gave correct explanations of what was happening. In fact, students from age 8 to 17, presently engaged in science classes gave no indication that what they were being taught about changes in the states of water had anything to do with their explanations of the phenomena. Most of the time they explained the bubbles that form when water is boiling as air, oxygen or hydrogen gases. Bar and Travis (1991) reported on children's conceptions of matter and found that the concept of boiling proceeds the concept of evaporation in the understanding of children. However, as children explained boiling many children described bubbles as containing air and subsequently that in evaporation water vapor becomes air. These results are very similar to those reported by Driver (1985).

A number of researchers have used pencil and paper tests to assess children's understanding and misconceptions. Among those related to ecology, Ringes (1987) reports on a subset of questions from the The Second

International Science Study (SISS) which sampled 1400 fourth graders, 1400 ninth graders and 2400 twelfth grade science students and 2400 twelfth grade non-science students. All students were from Norway. Although there were not any questions reported in this study which dealt exclusively with water, several identified misconceptions are related to the role of water in the hydrologic cycle. Among them are: oxygen is the sole component of air, SO_2 is the formula for sulfuric acid, acid rain consists of powders of sulphur and atoms are not conserved. Ringes concludes that lack of understanding of water in these instances may lead to student misconceptions.

Concept mapping is another technique used by some educational researchers to identify student misconceptions. Hoz et all (19870) report on several misconceptions related to both biology and earth science. In this case, student constructed maps which the researchers evaluated using various cognitive structure dimensions (Hoz 1987). Moreira (1987) also reports the use of concept mapping to detect misconceptions in physics.

Analysis

Ecological science and its related conceptual structure is complex and requires an understanding of both physical and biological sciences as well as their interaction. In the course of most research on children's understanding, investigators have tended to isolate individual concepts, such as, evaporation or food webs. This has led to claims about what the kids know in relation to a specific concept. Although at first glance each topic may appear rather distinct from others, through the course of analyzing ecological research and the construction of concept maps, it is apparent that there are sets of essential concepts and their relationships which must be considered. For example, the water cycle involves a number of related physical and biological concepts and their interaction.

Since the science of ecology is interdisciplinary and based on complex interrelationships most misconception research does not address basic issues related to ecology education. In order to begin thinking about a research agenda in this area the relationships of various concepts must be investigated. In this case, several concepts which have a history of misconception research and are related to aquatic systems will be considered. The purpose is to see how a number of studies can inform us about what children know about ecology.

Three areas that have been researched and are related to aquatic ecology are: the water cycle, primary productivity and respiration.

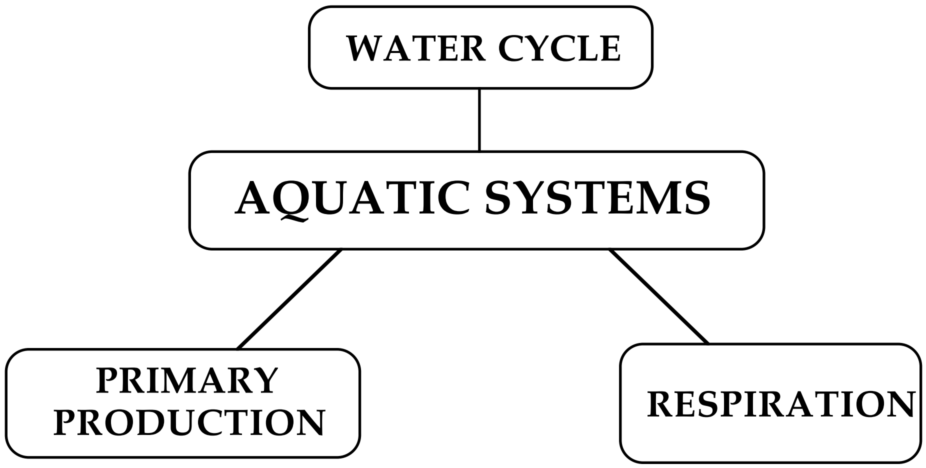

Figure 1. Map of three areas of misconception research which relate to aquatic systems

The Water Cycle

The first set of concepts to address are related to the water cycle and the first question to answer is, "Is there any relevant research related to this area?" According to Bar (1989), the water cycle involves three basic physical science concepts: evaporation, condensation and free fall. In his study of 300 Israeli children ages 5 to 14 he identified several stages of understanding which the children exhibited. In addition there were a number of children's misconceptions. Among them, water disappears, water penetrates solid objects and water remains in some container. The problem of the source of rain was investigated earlier by Piaget (1929) and Z'arour (1976). Piaget found stages of understanding. These included clouds are made by people or God, clouds are made of smoke and clouds are made of water. Z'arour also found teleological beliefs about rain and lack of understanding of evaporation.

From these three studies, we can gather that most children have little understanding about the water cycle and some related misconceptions occur If we generalize, it appears that they explain the water cycle in terms of liquids with no mention of phase changes. There is a clear connection of children's misunderstanding of physical concepts which influences their explanation of natural phenomena.

Although these studies tell us something about children's understanding of the water cycle, what is missing in these studies is an ecological view of the phenomena. By trying to reduce the phenomena to a limited few concepts the authors have missed the interdisciplinary nature of the subject.

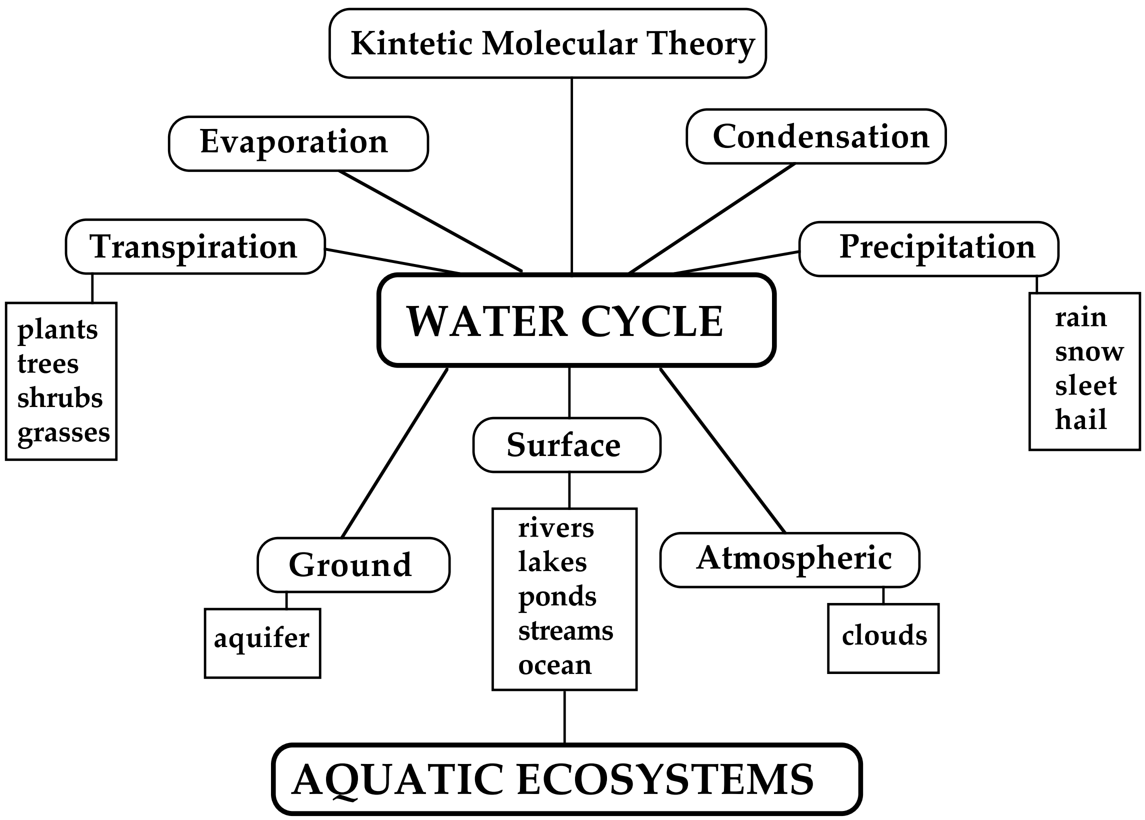

Figure 2. Concept map of topics considered critical to understanding the water cycle.

In the physical science area condensation and precipitation are equally important. Phase changes of water are critical to the water cycle. How these processes occur, including kinetic molecular theory, are also necessary. Although mentioned in some of the research reported above, a fuller treatment of earth science concepts, in particular, atmospheric, surface and groundwater is important. And finally biological science concepts related to transpiration are critical to the water cycle.

Primary Productivity

Photosynthesis has been the focus of a number of studies on children's understandings. In general children don't understand the role of light nutrients, water and carbon dioxide in this process (Brody & Koch 1989-90). A clear misconception related to marine productivity is that some plants live deep in the ocean and do not need light to live. An ecological approach to this misconception could help to better understand children's conceptions.

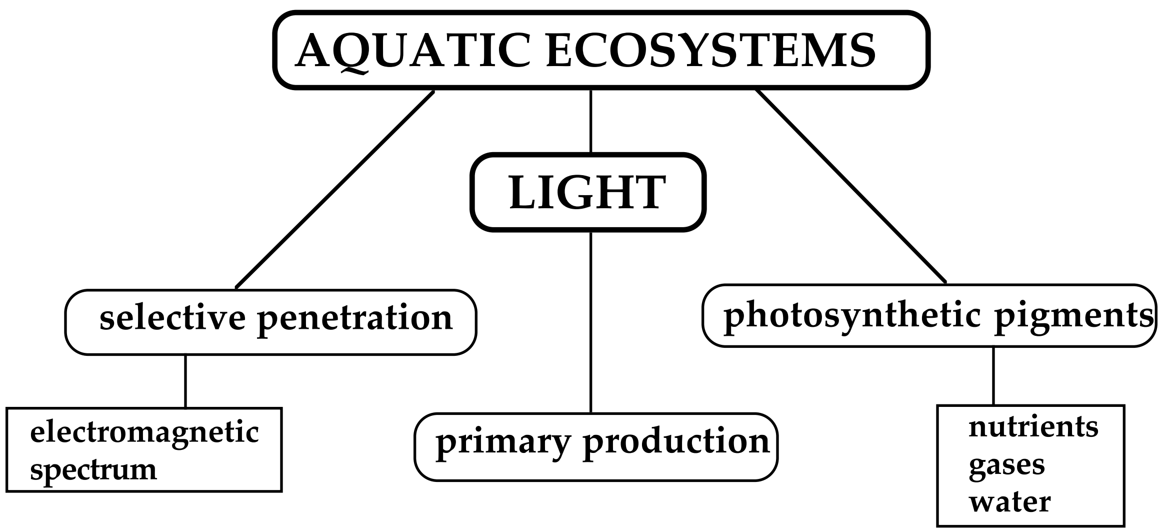

Figure 3. Concept map of topics critical to understanding aquatic primary productivity.

The interaction of both physical and biological subjects is critical in this case. From the physics perspective primary production is dependent on both the depth and selective penetration of light into the water. And from the biological perspective photosynthesis is dependent on the availability of nutrients, dissolved gases, water and light.

Respiration

Respiration has not been a focus of investigations in the misconceptions field. However, a number of studies have involved children's understanding of gases, liquid and solids and a study of marine resource identified the misconception related to fish breathing oxygen from the water molecule (Brody 1992).

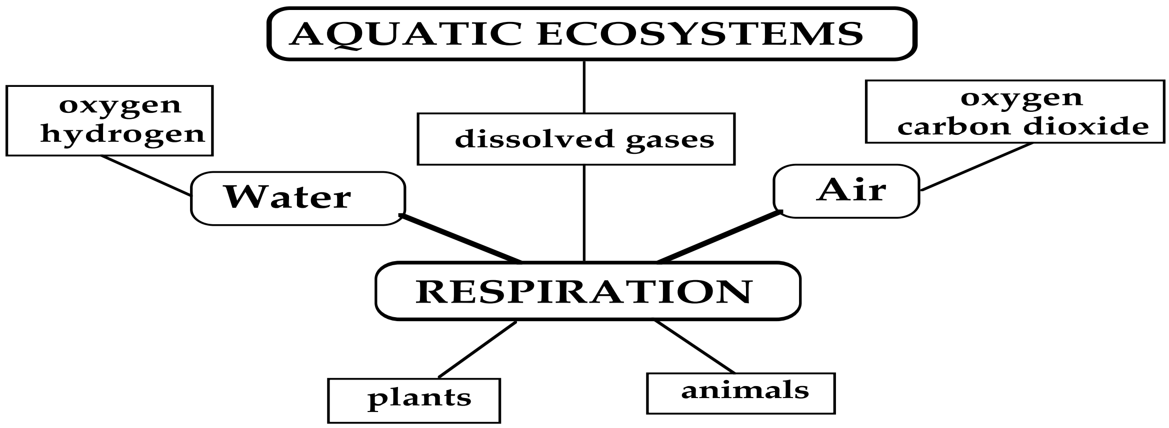

Figure 4. Concept map of topics related to respiration in aquatic systems.

In aquatic systems the physical science concepts related to dissolved gases in critical to understanding aquatic life. Knowledge of dissolved gases assume an understanding of the nature of matter and kinetic molecular theory. On the biological side aquatic life requires breathing and the removal of wastes by organisms.

Instructional Design

Instructional design based on modern conceptions of the field of ecology and student understanding must take into consideration several basic principles:

- ecology is an interdisciplinary discipline based on both physical and natural sciences,
- ecology explains phenomena with which we have extensive experience
- student understanding is an important consideration when planning instruction

- identified misconceptions concerning specific concepts must be addressed directly in terms that are relevant to the learner.

Given the analyses in this paper focusing on the ecological conception of aquatic systems and the related misconception research an instructional design can be developed in a meaningful way. In order to teach this subject the curriculum must include concepts related to the water cycle, primary production and respiration. The concept maps reported above may be combined to form a framework for the scope and sequence of this curriculum.

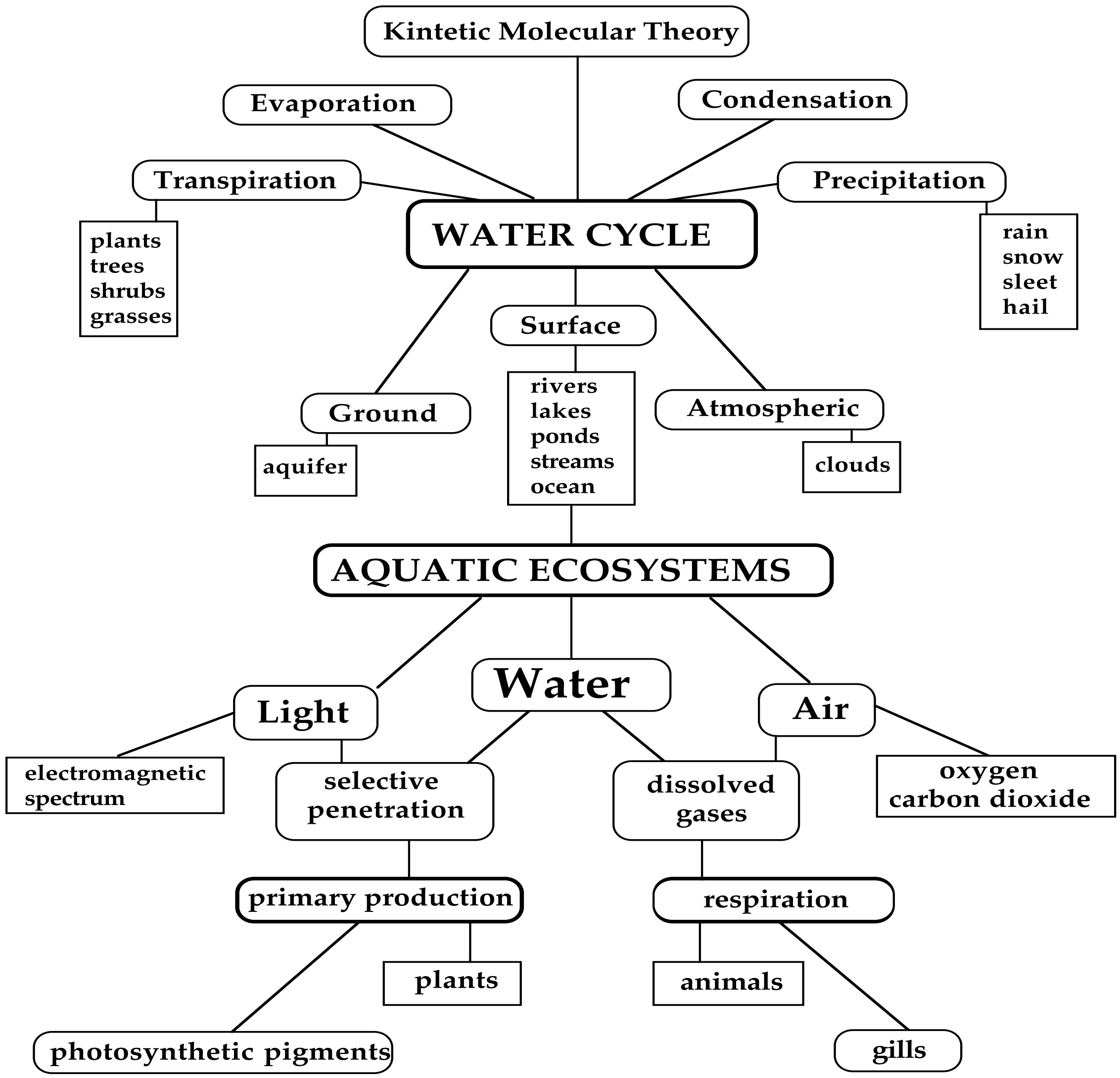

Figure 5. Concept map of those concepts to be included in an aquatic systems unit.

Another way to look at this material is as a list of concepts which are intended for instruction, related misconception research and selected educational activities.

Table 2

Concepts, Misconceptions Research and Selected Activities for Aquatic Ecosystems Instruction		
Concepts	Research	Activities
I Water Cycle		
evaporation	X	water circle
condensation	X	
precipitation	X	
transpiration		
Kinetic Molecular Theory	X	molecules in motion
Types of Water		
Ground		
Surface		aquaria
Atmospheric	X	
Water		
dissolved gases	X	aquaria
penetration of light	X	aquaria
Biological Processes		
primary production	X	aquaria
respiration	X	aquaria

Several instructional activities which attempt to address these misconceptions are <u>The Water Circle</u>, <u>Molecules in Motion</u> <u>Classroom Aquaria</u> and <u>Plant Growth/Nutrients</u>.

The <u>Water Circle</u> is a recommended use of a new metaphor concerning the water cycle. According to all indications, children's understanding of this concept is very limited. A new metaphor is necessary to help children understand the connections of their lives with others and the earth. The circle is a more easily visualized, more relevant in our everyday existence and better understood concept than cycle. From early life our actions are associated with circles. Young children play circle games like "ring around the rosie", musical lyrics often use the circle to indicate connections like "may the circle be unbroken".

The metaphor of a water circle can help illustrate the path of water from the ocean reservoirs through evaporation to the sky. The atmospheric water in clouds traveling to the mountains and the land where cooler temperatures and condensation cause precipitation to fall. And the streams and rivers carrying the water back to the ocean. A circular path exists for water as it travels above, on and below the earth.

The water circle also illustrates the connections of water between living things and the earth. Our bodies are approximately 70% water. Where does that water come from? For many of us who depend on plumbing, we drink water from our faucets which are connected to pipes leading to reservoirs that were filled by precipitation from clouds which contain moisture from distant places. All life is physically connected to the water circle (Brody 1993).

Molecules in Motion is a whole body activity to help children learn about the kinetic molecular theory. All children in the group are asked to be individual molecules. As the teacher raises the light in the room and the "energy" increases the molecules/children become more excited and can move throughout the room. With no prior instruction the movement is random. The teacher may also chose to use a flashlight to transfer energy to individual or groups of molecules which become even more excited. The use of whole body instruction is a powerful way of helping children learn through all of their senses (Project WET 1993).

Classroom Aquaria is a long term hands-on inquiry oriented activity in which the whole class can participate. The establishment of an enclosed aquatic ecosystem is a powerful tool for teaching about the complex relationships of physical and biological sciences. Among the water quality parameters that can be monitored are: temperature, dissolved gases and nutrient levels. Another area for instruction includes the use of different types of light to illuminate the aquarium and stimulate plant growth. All of these have been identified as areas that need to be addressed. The cultivation of both plants and animals helps students address issues related to how physical and biological parameters are related (Brody & Patterson 1992).

Conclusions

Identification, analysis and instructional design related to ecology and student understanding is a constant process. What we have done up to this point has only scratched the surface. New and updated information will be needed for as long as we try to teach children about their world.

Teachers and students must select topics for study which are derived from real world events. These are the ones that will have value in the lives of people and which they will have some relevant understanding. Both correct and incorrect. These topics will need to analyzed from both physical and biological sciences.

Identification of children's understanding is a never ending process since their understanding is derived from the real world and the real world is constantly changing. Which methods are appropriate? All of them. Students need to talk about these subjects, express them in writing as well as in the fine arts. Each vision of their understanding can help us design instruction.

Selection of lesson and activities based on which concepts need to be directly addressed is essential. Teachers and students can always return to concept maps which outline the topics. Where are we on the map? How can we move from here to there? Teaching and learning are long paths with many turns and choices. Which instructional strategy is appropriate? As many strategies as there are children!

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