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ABSTRACT

This paper reviews the educational research related to student understanding of water and water resources. The literature is drawn primarily from science and environmental education literature and is divided into student knowledge of: physical and chemical properties, biology, earth systems and water resources. The majority of work has been in the area of physics and chemistry and indicates: very low levels of student comprehension, a direct relationship to atomic and kinetic molecular theory and a large number of misconceptions. Children's biological knowledge related to water, although studies are limited to diffusion, osmosis and circulation, appears similarly incomplete with numerous misconceptions. Earth systems knowledge related to water centers around the concept of the water cycle which is poorly understood by all students. The least amount of student knowledge in any area is related to water resources and may reflect the complex interdisciplinary nature of this subject. Finally, multiple studies have drawn the conclusion that older students who have taken science courses have similar level of knowledge as elementary students and they possess more misconceptions about water and water resources. Contains 51 references. (Author)

Student Understanding of Water and Water Resources: a review of the literature*

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Student Understanding of Water and Water Resources: a review of the literature*

Abstract

This paper reviews the educational research related to student understanding of water and water resources. The literature is drawn primarily from science and environmental education literature and is divided into student knowledge of: physical and chemical properties, biology, earth systems and water resources. The majority of work has been in the area of physics and chemistry and indicates: very low levels of student comprehension, a direct relationship to atomic and kinetic molecular theory and a large number of misconceptions. Children's biological knowledge related to water, although studies are limited to diffusion, osmosis and circulation, appears similarly incomplete with numerous misconceptions. Earth systems knowledge related to water centers around the concept of the water cycle which is poorly understood by all students. The least amount of student knowledge in any area is related to water resources and may reflect the complex interdisciplinary nature of this subject. Finally, multiple studies have drawn the conclusion that older students who have taken science courses have similar level of knowledge as elementary students and they possess more misconceptions about water and water resources.

Student Understanding of Water and Water Resources: a review of the literature

Introduction

The environment and associated natural resource issues are an increasingly important topic for teachers to consider in light of the future of civilization and the earth. In particular, water and water resources are critical for people to understand since we all share the need for this precious resource. Given the prevalence in mass media of scientific concepts related to everyday events, it is imperative to have societies which understand the role of science in the real world (Hively 1988, Gore 1992). The incorporation of environmental issues such as groundwater depletion, water pollution or endangered aquatic species in the school curriculum can help make apparent to the student the relevance of both science and social studies and help answer the often asked student question, "What do we need to know this for, anyway?"

Among the modern curriculum models which have emphasized the interrelatedness of v ıous disciplines and real world applications are the Human Ecological Perspective and Science Technology and Society (STS). The National Science Teachers Association (NSTA 1982) recognized the need for interaction of the various disciplines and the interrelatedness of subjects in their position statement which acknowledged a commitment to useful science education for all students. The National Association of Biology Teachers (NABT) published *Human Ecology: A Perspective for Biology Education, Monograph Series II* (1984) which focused on a framework for reconceptualizing the biology curriculum based on human interactions with the environment. In that publication there is a report on a survey conducted at Carleton College, United State of America (U.S.A.) which describes the extent of public commitment to environmental issues and their role in public education (Bybee, 1984). Results indicated a large percentage of adults would like to see such topics as air quality, world hunger, water resources and population growth included in the K-12 curriculum. According to the study; 89.5% of the sample felt environmental issues should be taught in elementary school, 97.7% in middle school, 97.8% in high school and 97.1% in college. If we are to proceed in the interest of the general public with the design of multidisciplinary curriculum models, given the general attention to environmental issues, research towards a better understanding of students' knowledge concerning specific social and natural science concepts is necessary.

Among some of 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 science 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 linkageis meant to be among various science disciplines and this leads to the analogy of a min-layer cake approach, that is, 1 quarter physics, chemistry, biology and earth science each year for all children. The NSTA guidelines also infer that, "Less is More." That is, there should be fewer topics treated more deeply. If NSTA's suggestions that subjects should link together and that "less is more" are to be taken seriously, curricula examples based on these principles need to be implemented in real classrooms. A focus on the environment and water as a curricula theme is appropriate.

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 water and water resources 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 scien 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 water (a concern of all people) and inquiry related to water resource management into the school curriculum is congruent with these curriculum reform suggestions.

There are a number of curriculum efforts in the USA which address water and water resources. Among some of the existing curriculum materials related to water are: Project Learning Tree (1988) and Project Wild (1986) which provide elaborate frameworks which include general environmental education goals. Several states and regional curriculum efforts in the USA have water related education programs which contributed key ideas to our thinking about water and water resource education (Arizona's Governor's Task Force on Environmental Education 1992, Fortner 1992, GEMS 1991, Minnesota Office of Environmental Education 1990, Picker et al 1984).

We all understand that environmental issues related to water appear in the popular media with tremendous frequency. It is not uncommon for newspapers to have front page stories concerning issues of both water quality and quantity. Editorials related to scenic rivers, water pollution, water rights and access to water based recreation are prevalent. Television is an important source of information concerning topics related to the environment and it is expected that much of the world wide political agenda for the 1990s and beyond will focus on ecological issues. Newspapers and television have been found to have some impact on both specific and general environmental knowledge (Ostman & Parker, 1987) and people's attitudes (Fortner 1985). Most of the general public, including students, have been exposed to a large number of ideas and opinions concerning our ecological fate. When students' existing conceptions of current ecological crises are taken into account they can help form the basis for effective curriculum design based on principles of meaningful learning. Knowledge of students' understanding of the environment can help educators construct a variety of meaningful classroom experiences concerning water and water resources. These topics can be incorporated into an existing curriculum and help integrate natural and social sciences with current natural resource events.

Nature of Knowledge about Water

The concept of water (which in its totality may be called the hydrosphere) may be the most integral of all concepts related to life and the earth and thus is critical to achieving an understanding of the complexity and interrelatedness of earth systems. Without water, life would not exist as we know it. Some life on earth does exist without air (oxygen) but there is no life on earth which can exist without water. From the molecular to the global level, it is what makes the earth unique and it is the connection between all living and non-living forms that make up the earth.

Ancient civilizations considered water to be one of the four elements: the earth, the wind, the fire and the water. The Greek scholar Thales of Miletus in the beginning of the sixth century claimed water to be the primordial substance, that from which all life arose and will eventually return. Today we know that people can live for weeks without food however they can only live a few days without water. The dependence of people on water is apparent at many levels, from humidity to keep our lungs moist so that we can breathe to providing energy for industry.

If education is to move into an integrated and holistic mode, we must seek out clear examples of concepts which can be used to bridge the so-called traditional disciplines such as biology, chemistry, social studies, mathematics and art. Water provides such an example.

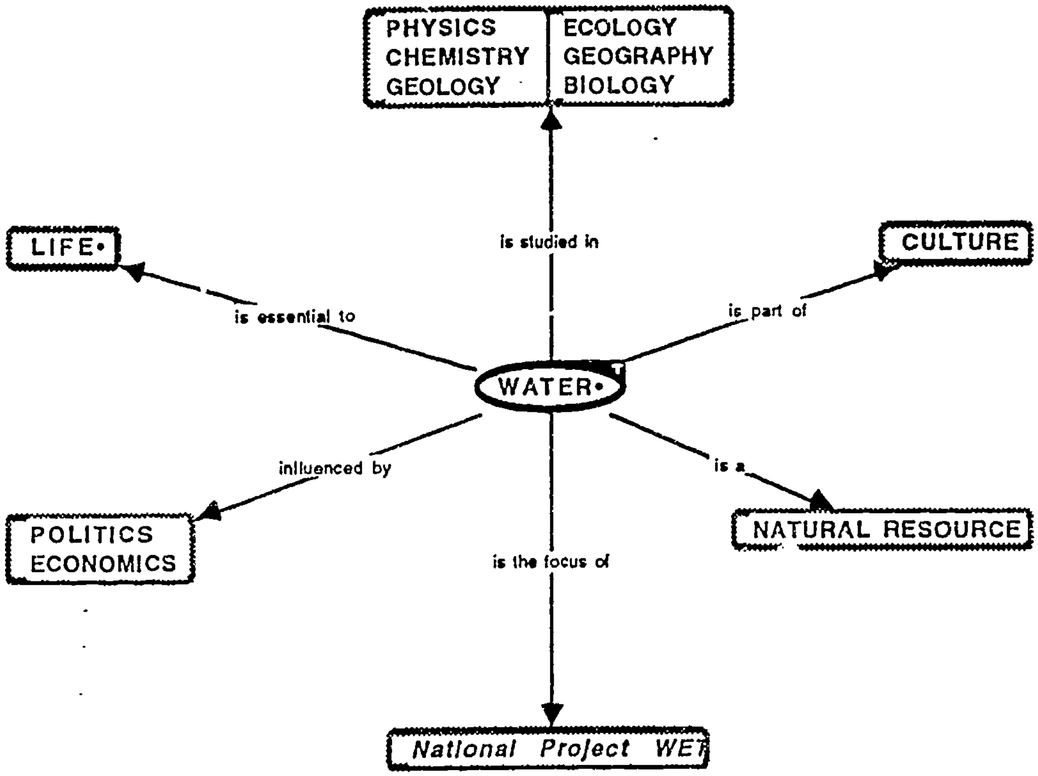

Figure 1. Opening frame of semantic network focusing on water showing interdisciplinary nature of concept (Brody in print).

Although water is obviously integral to all life processes and thus central to the study of biology, it is powerful in its ability to relate all disciplines in interesting ways. In the natural sciences physics explains the structure of water, its electromagnetic configuration and molecular bonding which leads to its unique properties. Chemistry helps us understand the role of water in all life processes. Waters distribution and movement is a major component of geological sciences. Biology and the study of life is based on an understanding of water and all ecological processes are water related. The role of water in politics may not be more clear than disputes over water rights. World economics is dependent on water for the production of food and products as well as transportation of goods around the globe. Finally our worlds cultures, from desert to rainforest, are shaped by people's relationship to water and water resources. Even the spirits, to which some people attribute great power and religious connection, are associated with the water. Take for example the water of baptism in Catholicism, the river spirits of native North Americans, the thunder of the Roman and Greek Gods and finally the ocean god Neptune.

The social sciences are inextricably linked with our understanding of water. Ancient and modern civilizations grow and collapse based on availability of water for their people. Economics is based on access to water. Manufacturing and agriculture are water dependent and politics is often used to legislate water resource availability and quality. Natural resource management strategies for water, such as dams, have a significant influence on energy, transportation, recreation and commercial interests. Water can be considered a continuous web which unites the entire earth and thus an understanding of its role can lead to new meaning of interrelationships on earth.

Student Understanding of Water Related to Physics and Chemistry

Several studies have been done on the nature of children's learning related to states of matter, in particular in relation to water, based on heat and temperature (Osborne & Cosgrove 1983, Straus 1987 & Rafel 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 explain bubbles as containing air and subsequently that in evaporation water vapor becomes air. These results are very similar to those reported by Driver (1985).

Giesse (1987) reports in a study of thirteen eighth graders, that although most students understand that pressure increases as depth increase in water, they do not know that pressure is equal in all directions at any depth. These results are similar to those of Clough and Driver (1985). These studies have all led to claims about children's understanding of particles, atoms, molecules and their interactions (Schollum 1982; Osborne, Cosgrove & Schollum 1982; Osborne & Cosgrove 1983; Osborne & Schollum 1983).

From these studies it is clear that, student explanations related to the physical and chemical characteristics and properties of water are based in part on their conceptions of atoms, molecules and their interactions. This is clear in the case of the concept of dissolving of substances in water. Evaluation of this concept has involved student explanations of what happens when a solid substance is put into a beaker of water. Students exhibit little understanding of how substances dissolve, no less how particles are formed, how they disperse or which substances form ions.

A related study of student conceptions of the second law of thermodynamics is included here because the researchers attributed little understanding and misconceptions to the particle model in the explanation of thermal processes (Kesidou & Reinders 1993).

According to Osborne and Freyberg (1999) children's problems in understanding and explaining physical and chemical phenomena related to water and states of matter appear to be associated with often unobservable events such as ionization. Other explanations of these problems include: children's sensory data leads to naive conclusions like things disappear or go away when water evaporates into "air", school instruction does not influence student understanding and classroom instruction influences student understanding in unanticipated ways (see Figure 2 below).

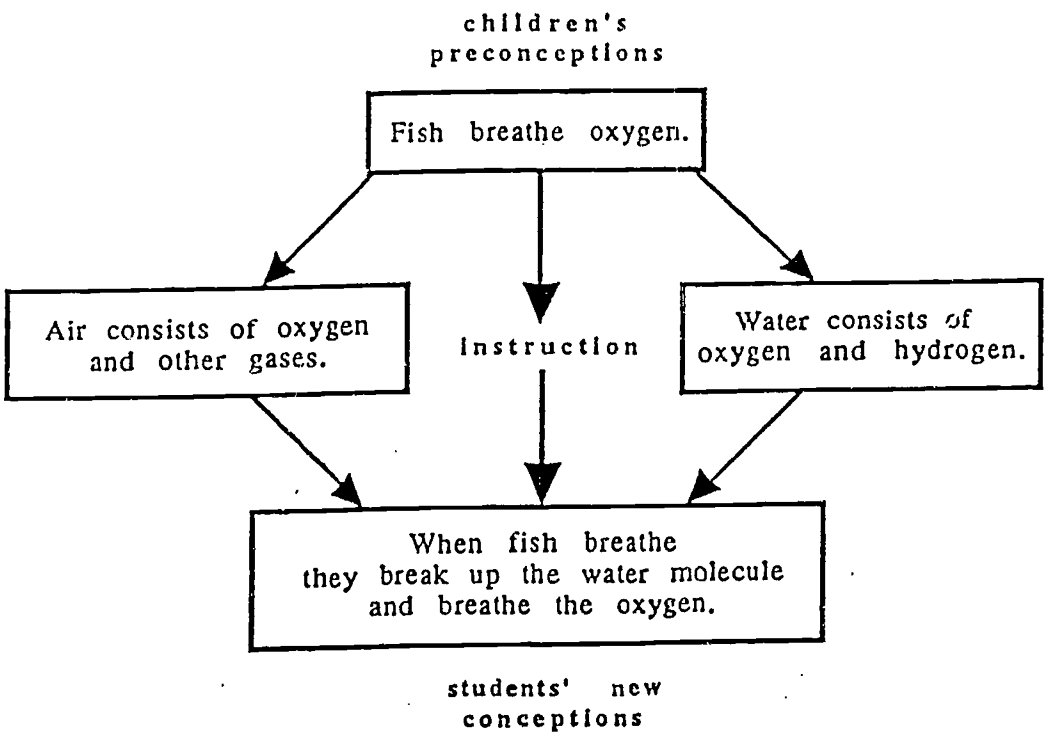

Figure 2. A possible explanation how a child's conception of fish respiration is influenced by classroom instruction.

Student Understanding of Water Related to Biology

All physiological events occur in solution with water as the major solvent. These events range from cellular processes to digestion to communication between nerve cells. Therefore, knowledge of water, its properties, behavior and function are essential to biological knowledge. Studies in biology education have not necessarily focused on the role of water as such but several studies have reported children's understanding of biological phenomena in which water is a major factor.

In a cross age study of student understanding of the concept of diffusion, Westbrook and Marek (1991) report that misconceptions are prevalent in students from 7th grade through college. They found no obvious increase in the level of understanding of diffusion as well. They felt this was traceable to student understanding of phenomena at the molecular level and related misunderstandings concerning dissolving, density and the cell. The results of an earlier similar study by Marek (1986) with tenth graders also identified a high number of specific misunderstandings related to diffusion. Typical misunderstandings as exemplified by student comments are:

> "The molecules in the water accept the blue dye so then as the molecules in the water move so does the dye."
>
> "The blue dye spread through the water because water is semipermeable therefore the dye could spread through it."
>
> "The blue dye is heavier than the water so it spreads throughout the water making a chemical change occur!"
>
> "Water is the universal solvent and is in more mass than the dye so from gravity and movement the dye would slowly make the water turn blue."
>
> "The cells of the water and the cells of the dye are moving through the water and passing through each other." (Marek, 1986, p. 39)

Arnaudin (1983) reported on the acquisition of concepts and alternative interpretations about the human circulatory system. In this study of students in grades 4, 5, 8, and 13, the researcher found that alternative conceptions of students in the elementary grades persist in the higher grades levels. Murray (1983) studied students' misconceptions related to osmosis. Those reported in this study relate to the concepts of concentration, semipermeability and pressure. Of course, in this case, water is the only substance which is free to move across a membrane and is directly related to the concepts listed. Murray indicates that conceptions of concentration and dilution may be acquired by children through direct experience and believes these existing conceptions can be used to provide a foundation for the scientific conceptions needed to understand the role of concentration in osmotic events. In terms of semipermeability of membranes, most students in this study believed there was either no movement of materials or the solute moved across the membrane. Only a small percentage of students had any understanding that pressure was related to water movement and osmosis.

Water and related concepts are at the root of understanding biology. Among those topics that have been studied, osmosis and circulation, there are a number of identified areas that students need help in understanding.

Student Understanding of Water Related to Earth Systems

An emerging movement in science education is the concept of Earth Systems education (Fortner 1992). This approach is based on the fact that all living and non-living things are connected and children need to understand these interconnections. Water provides an excellent focus for this approach since it is the basis of life and connects all earth systems. At the center of this approach is the water cycle and there is common agreement among scientists and educators that the water cycle is critical to understanding how the earth works (Brody 1993).

Several studies by Mills and his colleagues (1983, 1991 & 1992) take a broader conception of water than those studies previously described and begin to describe how elementary through college age students understand water and how it relates to earth systems. In the first study Mills (1983) describes the development of the Water Resource Knowledge Assessment (WRKA). In addition to the methodological results several areas of content related to water were assessed for recent high school graduates who were going on to college. On the WRKA instrument students scored percent correct on items assessing knowledge of relationship of water to living things (38.4%), life processes (39.6%), water sources and distribution (43.4%), influence on physical world (45.2%), chemical and physical properties (52.3%) and the hydrologic cycle (80.9%). The sample is biased towards college bound students and in addition the number of items for each category was small ranging from 2-9. These results do not reflect general student population knowledge of water or water resources.

A set of papers prefaced by Mills (1991) describes several studies of elementary, secondary and pre-service student knowledge of the water cycle as well as an evaluation of textbooks. In the first study, McJunkin (1991) interviewed 25 kindergarten, 29 second grade, 22 fourth grade, 23 sixth grade and 12 eighth grade students about the water cycle. Results indicate that all student describe the water cycle in physical terms such as melting and freezing. Students were unable to explain evaporation or condensation and few had an abstract, conceptual understanding of the water cycle. McJunkin comments that," older children seemed to be concerned with trying to fit scientific terms into their explanations that they lost sight of the phenomena at hand." He also indicates that fourth graders had the highest level of understanding of the water cycle and that although verbal ability increased with age, conceptual understanding did not.

In the pre-service study conducted by Van Thiel (1991) one hundred and fifty students were given the WRKA and fifty were clinically interviewed. Interestingly it was found that the score on the WRKA was not correlated to the amount of science classes the students had taken. The interviews indicated prevalent alternative conceptions related to evaporation, condensation, kinetic molecular theory and water pollution.

In a study at Ben-Gurion University of the Negev, Bear Sheva, Isreal conducted by Hoz et al (1987) students exhibited a number of earth science misconceptions related to fluviatile and karst ground water environments. Among the related concepts in this study are: lateral erosion, river terraces, flood plain, fluvial systems, solutions, caverns, seepage, intake area, equilibrium, coastal zone and glacial landscape. Numerous misconception were identified using student generated concept maps. Most misconceptions were environment related (coastal zone & glacial landscape) or related to the system approach (equilibrium & maturity).

Two studies focused on ecological effects related to the water cycle, namely acid rain. They both assessed student understanding of this environmental problem related to water and water resources. 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. It appears that lack of understanding of water in these instances may lead to student misconceptions.

In the second study by Brody et al (1988-89) 4th, 8th and 11th grade students in the state of Maine, USA were interviewed on a number of concepts related to acid rain. Among those related to water which were determined to be missing from most student understanding were: soil produced from, and sedimentary rocks act as buffers against the effects of acidic precipitation, acidic waters leach essential plant nutrients from the soil and liberate metals and toxins, and chemical pollutants and water combine in the atmosphere as a result of reaction triggered by the sun. Evidently from the results of these two studies of student knowledge related to acid rain, an understanding of water and the water cycle are critical to our understanding of the problem.

Student Understanding Related to Water Resources

A number of studies related to water resources have been completed. One of the major characteristics of this work is that the researchers used an interdisciplinary approach integrating both natural and social sciences. In this section the focus is on the social concepts in relation to the natural resource.

Mills (1983), as reported earlier in this paper, developed the WRKA which included a number of social science concepts related to water resources. The results indicated that student knowledge was lowest for social concepts as compared to natural science topics. Percent correct responses for selected topics were; contemporary issues 25.7%, water resource management 28.4%, and historical influences 36.4%.

A study by Fortner and Mayer (1983) of fifth and ninth grade students in Ohio assessed student knowledge and attitudes about the oceans and Great Lakes. They found that student exhibited low levels of knowledge of marine and aquatic topics with the poorest performance in these topics related to the humanities. In this study ninth graders did score significantly higher on the test than fifth graders.

Several studies by Brody and his colleagues (1987, 1987-88, 1988-89, 1992, 1993 in press) focus on student understanding of concepts related to water and water resources particularly in regards to Atlantic and Pacific coastal areas. In the first study based on modified clinical interviews with 4th, 8th and 11th grade students, several general conclusions concerning student knowledge of marine ecosystem, in particular the Gulf of Maine, emerged: (1) students learned a few basic marine science and resource concepts in the elementary grades, relevant to current marine natural resource issues, (2) there was relatively little further assimilation of new concepts or differentiation of existing concepts as students progressed through the grades and (3) overall, the level of understanding of basic concepts and principles related to marine ecosystem dynamics, resource utilization, management and decision-making processes was low. It seems that many Maine students do not understand or appreciate the significant role of the marine environment in their state's socio-economic past, present and future. The Maine sample was later compared to similar student interviews in the Canadian Atlantic Maritime and there were striking similarities in most areas. However, it was clear in the cross cultural analysis that Canadian students did have a much greater knowledge and appreciation for their marine resources than USA students (Stilwell & Brody 1987). A number of misconceptions were identified in these studies, among them; the oceans are a limitless resource and there are no political boundaries in the oceans. A third study using similar methodology but conducted in the Pacific Northwest region of the USA, namely the state of Oregon, indicated similar results. However, several differences between the Maine and Oregon studnets appear to be associated with geo-cultural differences between the samples (Brody 1992).

Conclusions

Based on this review of research related to children's understanding of water, it is apparent that the sources of information are found in wide variety of areas ranging from physical to biological to ecological to social science education. This proves to make it difficult to review research of children's knowledge of water, a naturally interdisciplinary subject. There are a number of areas where research of this type has been done. Among them are: physical and chemical characteristics of water, biology, earth science, ecology and natural resources.

In terms of the physical and chemical properties of water, a number of research studies have been completed which address water related concepts. The results of these studies lead to several generalizations. Of note are the fact that children are typically unable to explain water related processes such as evaporation or condensation. In the course of interviews it was found that students possess prevalent alternative conceptions related to evaporation, condensation, atomic and kinetic molecular theory.

In regards to more ecological concepts, particularly the all important concept of the water cycle, students describe water properties and the water cycle in physical terms such as melting and freezing. Few children had an abstract, conceptual understanding of the water cycle. A number of biological concepts are unclear in children's knowledge and many of these can be traced to inadequate understanding of water and its importance in life processes. A number of studies have led to claims about children's understanding of particles, atoms, molecules and their interactions. These certainly influence children's understanding of water.

Children's understanding of water resources is a function of both natural and social science concepts and thus possess a significant challenge to researchers interested in interdisciplinary knowledge. Of those studies in this area, several have reached similar independent conclusions. Of these the general conclusion is that students' level of understanding of basic concepts and principles related to marine or aquatic ecosystem dynamics, resource utilization, management and decision-making processes is low. In addition there exist prevalent alternative conceptions related to water pollution.

An interesting question in this area is how does knowledge about water and water resources change as student progress through school? Our understanding of student understanding between grades is not extensive although a few studies have addressed this issue. It appears from the results of these studies that students learn a few basic natural and social science and resource concepts in the elementary grades, relevant to current water resource issues and there was relatively little further assimilation of new concepts or differentiation of existing concepts as students progressed through the grades. It has been found by several independent researchers, that in the course of answering clinical interview questions about water and water resources, older children appear concerned with trying to fit scientific terms into their explanations and subsequently lose sight of the phenomena at hand.

This research area can be summarized in several principles. It appears student understanding of science terms related to water and water resources is superficial, there are no sound underpinnings of relevant concepts and students attempt to fit terminology into answer questions about water related phenomena. Students hold onto their views of common phenomena that they have acquired through personal experience even after instruction. Students gain misunderstandings as they progress through school and scientific models of water related phenomena are abstract and do not relate to the everyday experience of children.

Discussion

Natural resource education, and water resource education in particular, provide an interesting alternative agenda for teachers and curriculum specialists throughout the world. It is widely recognized that we need to educate children in ways that allow them to deal meaningfully with the world around them. It is clear that water and its management regarding both issues of quality and quantity will be an top agenda item for the earth's citizens.

However the challenges are great. The interdisciplinary nature of water management in both natural and social science terms is a challenge for teacher understanding. In-service and pre-service work to help teachers understand and appreciate these concepts is critical. Researchers, both educational and scientific, who adopt this perspective will be challenged to represent this knowledge base in understandable forms, as well as communicate its complexity to others. The identification of key concepts and their relationship is imperative.

Some areas such as physics, chemistry and biology, ecology and natural resources have made some attempt to address these issues. However, individual work is often unconnected to other important disciplines. As ecological sciences shift to more interdisciplinary research efforts, so also should educators.

Finally, there are areas of children's understanding concerning water and water resource education which are unrecognized. Among them are the historical and cultural contexts of water. Although there is some evidence that indicate student knowledge in the areas of history, management and contemporary issues is very low more comprehensive work must be done. Again educators and curriculum developers are challenged to identify relevant materials, analyze natural and social science content and prepare lessons and activities which will help children understand some of the critical relationships between,water and civilization.

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