Resources for Environmental Literacy

Five Teaching Modules for Middle and High School Teachers

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Preface

The primary responsibility of teachers of science is to teach science, not to inform their students on environmental issues—and certainly not to influence the stand students may take on those issues. Fostering student understanding of the scientific view of the natural world and how science goes about its work is the first order of business in the teaching of science.

Nevertheless, experienced science teachers—backed by research on learning—know that most students do better when they see how the science they are studying helps them to understand "practical" things that matter to them. Thus, it makes sense to organize science teaching *contextually* from time to time, that is, to treat the science content from a "real-world" perspective. Many such contexts exist, including inquiry, mathematics, health, sports, technology, history, biography, art, and other cross-cutting themes, such as scale, systems, constancy and change, and models. It is the contention of this project that the environment is another such context, and a particularly important one at that.

Environmental issues and concerns provide a particularly attractive context for teaching various scientific concepts and skills. That belief is what motivated the Environmental Literacy Council (ELC) and the National Science Teachers Association (NSTA) to join forces in developing this set of science/environment modules for teachers. From an educational perspective, science learning and environmental understanding effectively complement each other in two ways:

- The environmental context can improve science learning.
- Learning science can improve the ability of students to deal with environmental issues.

Another way of putting this is that studying science in the context of the environment is doubly productive. It shows how scientific knowledge and ways of thinking, coupled with the process of making decisions about our collective interaction with nature, can illuminate each other to the advantage of both.

Development and Design of the Modules

As can be seen in the acknowledgments section of each module, these modules are the work of a large number of individuals—science teachers, curriculum specialists, scientists, environmentalists, and evaluators. At the outset of the project, an advisory committee selected possible topics to pursue and indicated the kinds of material to be included in the modules. Three-person teams—composed of a teacher, a scientist, and a curriculum expert—were then formed to prepare module drafts. Successive drafts were reviewed by other teachers and scientists, revised accordingly, and eventually tested in classrooms.

The published version of each module was produced by ELC staff under the supervision of the co-directors and the project principal investigator, approved by ELC members, and designed for printed publication by NSTA editors.

The immediate purpose of these modules is to provide middle and high school teachers of science with useful science/environment resources. Beyond that, the work was intended to develop a model for the design of contextual modules more generally. If science teachers find these particular modules to be effective in helping them to achieve their learning goals, then other groups may become interested in creating additional science/environment contextual modules and perhaps contextual modules in other appropriate domains as well. In that light, the module design that emerged has these features:

- Contextual modules are organized to serve as *professional development resources for teachers,* not primarily as student materials.
- Contextual modules do, however, contain *student activities.* These activities are presented only as examples and therefore may be modified by teachers or replaced with other activities, as appropriate. When helpful, modules may back up the student activity examples with *student materials,* such as instructions or readings, which can be copied or downloaded and distributed to students.
- A contextual module must address *specific learning goals.* This is crucial, since good instruction usually begins with a clear picture of what "take-away" learning we want students to acquire—the understandings and ways of thinking that will remain with them long after the details of instruction have been forgotten. In the science/environment context, appropriate goals have been selected from *Benchmarks for Science Literacy* (American Association for the Advancement of Science 1993) and *National Science Education Standards* (National Research Council 1996).
- A contextual module provides *background content for teachers* organized with reference to a set of *essential questions.* The intent is to provide teachers with a solid substantive base for undertaking contextual teaching. For example, responses to the essential questions in these modules are intended to foster a thoughtful way of approaching complex science-based environmental issues without leading students to particular decisions regarding the various issues.
- A contextual module provides a suggested *teaching approach.* This component includes an overview of possible student activities, suggestions regarding potential student misconceptions, commentary on assessing student learning, and some recommended resources, both in print and on the internet.

The order in which such content is presented is less important than the quality and appropriateness of the content itself. In this publication, the organization used was that which turned out to be the most effective in actual use:

- Introduction (including rationale and a list of essential questions)
- Student Learning Goals
- Background Content for Teachers
- Teaching Approach
- Activities Overview
- Misconceptions
- Assessing Student Learning
- Recommended Resources

- Student Activities
- Student Materials

Topics and Availability of the Modules

An introduction entitled "The Environmental Context," written by ELC's late Executive Director, Kathleen deBettencourt, precedes the modules. The purpose of this introduction is to provide teachers with an appropriate perspective on teaching science topics in an environmental context. The modules cover the following topics:

- *Biodiversity:* This resource for middle school life science teachers deals with differing scientific explanations of the cause of great extinctions and examines many aspects of extinctions taking place today, including the influence of humans on the rate of species extinction and the possible impact of rapid species extinction.
- *Global climate change:* This resource for middle school physical science teachers is based on the premise that understanding the nature of the Earth's energy balance and what influences that balance is necessary, though not sufficient, for making sound decisions with regard to climate change.
- *Earthquakes, volcanoes, and tsunamis:* This resource for high school Earth science teachers takes a look at earthquakes, volcanic eruptions, and tsunamis not only as hazards, but as players in the dynamic system that fashions the environment of the Earth's surface.
- *Genetically modified crops:* This resource for high school biology teachers is based on the belief that issues surrounding the genetic engineering of crops can be a powerful learning context for teaching ideas about the nature of science, genetics, and the use of technology, allowing students to connect and apply what they are learning to real-world issues that affect their lives.
- *Radioactive waste:* This resource for high school physics teachers on issues surrounding the storage and disposal of radioactive waste is based on the belief that these issues can be a powerful learning context for teaching about radioactivity, technology, risk assessment, and trade-offs.

The essay and modules are available on both the ELC website (*www.enviroliteracy.org*) and in print from NSTA (*www.nsta.org*). These modules are, however, a work in progress; they will be periodically updated to include relevant new resources as they become available. Additional modules may be developed to explore the rich array of topics related to natural resources and the environment.

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National Research Council. 1996. *National science education standards.* Washington, DC: National Academy Press.

Introduction:
The Environmental Context

The argument for teaching science in the environmental context is based on the reality of the science-environment relationship and on the potential contextual teaching has for contributing to valuable student learning. At the same time, it must be recognized that such teaching involves dealing with controversial issues. These matters are discussed briefly here as background for consideration of the five science/environment modules that follow.

The Science-Environment-Education Connection

Although we cannot predict all the challenges that the next generation will face, we can be sure that issues related to natural resources and environmental quality will be among them. As we begin the 21st century, we live in a world in which science and technology have brought enormous gains in understanding the Earth's natural systems. New tools such as computers, satellite imagery, and mass spectrometers permit us to observe, measure, and examine parts of the Earth that were previously inaccessible. Technology has also given us a better understanding of how humans have altered the Earth's systems and the risks those alterations pose to biodiversity, to human health, and to our quality of life. We now know that there are complex interactions between natural and human systems, and that human health and ecosystem integrity are intricately linked.

As the human population grows the demands on natural resources and the load on ecosystem services will increase. The challenge we face is to meet the needs of a growing population for water, land, energy, and mineral resources in ways that minimize damage to ecosystems and living things. Intelligent use of resources depends on our understanding of Earth's systems and our wise use of science and technology.

Issues related to the environment have risen to the top of the public agenda. Every day the public is called upon to evaluate evidence and assess risk: Is tuna contaminated with mercury? Do lead levels in drinking water pose health risks? Although some environmental problems, such as the loss of tropical forests, seem distant from our lives, the globalization of the economy means that consumer choices in developed countries may have an impact on the sustainability of natural resource management in developing countries far from our own. Many of the most intractable environmental challenges that confront us, such as global climate change, water quality, and loss of habitat, result from the cumulative impact of the actions of millions upon millions of individual choices and actions.

For these reasons, it is vitally important that students have an understanding of the linkages between natural systems and human activities. Most important, environmental issues provide students with an opportunity to understand how the science they learn in the classroom can help them grasp real-world concerns. Environ-

mental topics help students make connections between what they are learning in the classroom and problems that affect their lives; it also helps them make the connection from their local community to the global community.

Students may have the impression from textbooks that science is a body of facts that are difficult to understand and hard to remember. Presenting science in the context of a real problem to be solved allows students to see science as a process in which scientists make observations and collect and analyze data to try to make sense of a natural phenomenon. Environmental problems provide a story within which seemingly abstract concepts have immediate relevance; the importance of the carbon, nitrogen, and hydrological cycles in understanding global climate change is one example of fundamental science concepts that have immediate relevance to an issue of great public concern.

Environmental topics are not new to the science curriculum. The foundations of environmental literacy—of understanding the interrelationships between natural processes and human activities—are firmly rooted in the *National Science Education Standards* (National Research Council 1996), most explicitly in the standard "Science in Personal and Social Perspectives." Fundamental concepts related to the flow of energy and matter through ecosystems, weather and climate, and the biogeochemical cycles, among others, are central to many environmental concerns and can be used to illustrate the relevance of these scientific ideas. Environmental topics also provide a vehicle for students to employ important skills, including the ability to evaluate quantitative evidence, to think critically, to solve problems, and to communicate their results. Research shows that science learning is enhanced when students can demonstrate conceptual understanding by applying it to a real-world context.

Project 2061's *Science for All Americans* (American Association for the Advancement of Science 1990) clearly states the role of science literacy in preparing students to comprehend complex public issues, including those relating the environment:

> Scientific habits of mind can help people in every walk of life to deal sensibly with problems that often involve evidence, quantitative considerations, logical arguments, and uncertainty; without the ability to think critically and independently, citizens are easy prey to dogmatists, flimflam artists, and purveyors of simple solutions to complex problems. (p. xiv)

Students need to understand how scientific ideas and habits of mind help them make sense of the world. That is, in addition to being equipped with basic scientific and mathematical knowledge and the ability to gather and critically evaluate information, they must grasp how this knowledge relates to an understanding of environmental issues.

Environmental issues are useful for engaging students' interest in science. Students are clearly interested in the environment, and the importance of scientific knowledge for dealing with these issues is clear. Students' natural interest in and concern for the environment can provide a powerful motivation for students to study and learn the science that underpins the understanding of the environment and the interventions to improve it. The use of the environment to teach fundamental science concepts may interest some students in science who might otherwise not see its importance to their lives.

Teaching Environmental Issues

Environmental issues are particularly well suited for providing opportunities for students to learn

and exercise scientific habits of mind. Many issues related to the environment are controversial and are the subject of heated debates among groups representing a variety of interests. To understand these issues and the practicality of the various solutions proposed, students must evaluate evidence, critically assess arguments, and think about how scientific knowledge applies to a real-world problem.

There are challenges in teaching controversial topics of all kinds, particularly environmental topics. Students may have naïve notions about many concepts related to the environment and about the role of science in policy making. Scientific advice is most useful when attempting to identify, quantify, and understand risks to human health and ecosystem integrity. Scientific information can also help policy makers evaluate potential environmental costs and benefits of proposed actions and can provide information about probable outcomes. But although good scientific information is critical to addressing environmental issues, there are limits to scientific knowledge, particularly of complex systems, and other considerations are also important. Political, economic, social, and aesthetic factors are just some of the many considerations that affect choices about actions to take to solve environmental problems.

Students may not recognize the role of uncertainty in scientific understanding. They may tend to regard science as a fixed body of knowledge rather than an ongoing process for a systematic investigation of the natural world. Scientific ideas and theories are continually reevaluated in light of new data and observations. Sometimes improvements in instrumentation for measuring or observing can reveal new data that requires reconsideration of old theories and understanding. And there are many parts of the Earth's systems that scientists are just beginning to investigate. Only in the last few decades, for example, have scientists been able to explore the deep ocean, and they have found many surprises there. Scientists never claim to have the final answer, because new data, additional research, and new theories arise to change understanding. Science, therefore, inherently includes uncertainty.

Decisions about policies related to environmental health and quality, however, often have to be made even though the scientific understanding is not complete. Scientific knowledge can inform decision making, but scientists can rarely definitively predict what consequences will occur as the result of various actions, particularly when complex environmental systems, such as the global climate, are affected by the action.

One source of confusion is that the word *theory* has a very different meaning in common language than it does in science. As it is often used, the word implies a lack of knowledge or a guess. "It's just a theory" may be understood to mean that the science on the matter is not clear. In science, however, theories are widely accepted explanations of natural phenomena that are supported by many observations and experiments. A theory is strengthened as scientists gain additional information, but they are the explanations of which scientists are most sure. When students hear phenomena such as plate tectonics or climate change referred to as theories, they mistake the level of scientific understanding that is implied.

Even when scientific understanding of an issue is fairly well established, science alone is not sufficient. Economic considerations are almost always a critical factor in making decisions. For example, scientists can identify the sources of mercury in the environment and provide information about how it is transported and the probability of adverse effects on the ecosystems and human health at various levels of exposure. But to develop policies to reduce emissions of

mercury, such as those that come from electrical power plants, policy makers have to consider the economic effects on the community. Some actions might have devastating effects on local jobs and reduce the funding that is available for other important social needs, such as education or health care. Decisions are often complicated when there is a disagreement about whether there is a health risk to the population, particularly when the costs of mitigating the problem are high. Choices that may seem simple at first become more complex when all the factors are considered.

Policy makers have to weigh the costs of taking a particular course of action and the potential benefits to be gained against the alternatives. Although everyone agrees that air quality is an important good, people disagree about what costs they would be willing to bear. The quality of air in a community would be improved if a community agreed to restrict the use of automobiles or to raise the price of gasoline to high levels, but this would impose hardships on residents, and few areas have been willing to pursue this approach. The costs of this alternative, in the opinions of the residents, outweigh the benefits.

Some environmental interventions, though effective, are very expensive; for example, we could assure the safety of food if every meat and vegetable product was inspected before it was sold, but the cost of doing so would be prohibitive. Such a policy would take resources away from other important social needs, including other environmental programs. There is always a limited amount of resources in any community, and funding that is used to address one problem is not available for other needs.

Cost-benefit analyses, however, can be controversial. People often disagree about the value to place on various goods and benefits, and some benefits are hard to assess. In many communities there are disagreements about the value of preserving open undeveloped spaces versus the importance of providing affordable homes for the residents of the community. People disagree over the need to reduce traffic and air emissions as opposed to the convenience of having more roads for personal transportation. The aesthetic value of green spaces and the need to preserve biological diversity are important, but there are often disagreements about how to assign quantitative values to these considerations.

In addition, people disagree about the amount of the risk they are willing to assume. Every activity has some risk associated with it. Walking down the stairs can result in a fall; driving without a seat belt increases the possibility of injuries from an accident. Risk is the probability of harm resulting from an action or a set of circumstances. The degree of risk is expressed statistically; using statistical methods to calculate the probability of harm is called risk assessment.

Although almost every action involves some risks, some involve more potential danger than others. The amount of risk we are willing to assume is a subjective judgment. Skydiving, for example, is a high-risk activity that people voluntarily choose to do. Studies have shown that people are less afraid of risks from something that they have voluntarily chosen to do than they are of risks that are imposed on them. Also, people are more concerned about risks that impose great harm, even though there is a low probability that the event will occur, than they are of risks that are more probable but less dramatic. For example, surveys indicate that people rate a nuclear accident as a greater risk than x-rays, though experts rate the harm from x-rays as much higher a threat. People are also willing to accept risks if they perceive that the benefit

to be gained is worth the risk; the earthquake zones in Los Angeles and San Francisco and hurricane-prone beach towns along the coast are densely populated despite the risk because the residents believe the benefits outweigh the potential danger.

Risk assessment is an important component of environmental policy making. Scientists can provide information about the potential risk of detrimental health effects that a population may face at various levels of exposure to a pollutant. This information is expressed as a range of probabilities that harm might occur. Policy makers often have to make decisions about regulating the use of a substance that may have very beneficial uses and for which no alternatives are readily available based on this information and their assessment of whether the benefits derived from using the substance outweigh the potential risk. Weighing alternative actions can be difficult, particularly when there is a high level of uncertainty about the health risks.

Environmental decisions also involve trade-offs. Environmental systems are complex; they are composed of subsystems (atmosphere, biosphere, hydrosphere, and lithosphere) that interact in many ways that are not completely understood. A change that affects one system may affect other systems in ways that may not be known immediately or for even years or decades after the change has been made. This means that there are often unintended consequences. For example, to reduce the amount of pollution near manufacturing plants, many communities in the United States began to require that manufacturers build smokestacks to vent the emissions high into the air, where the winds would carry it away. The emissions of particles containing sulfur dioxide, however, are carried into atmosphere, where they react with water particles in clouds to form acid rain; winds in the atmosphere carry the acidic particles long distances in the air before they fall as rain, affecting water quality in lakes far from where the pollutants are produced. The solution to a local air quality problem therefore became a regional water quality issue.

More recently, communities in the Washington, DC, area found that there were high levels of lead in their drinking water; concentrations in some areas and schools were above the level considered safe (see *www.epa.gov/dclead*). Researchers investigating the problem found that the increase in lead in the water was the result of the city's decision to switch from using chlorine to using chloramines to disinfect the water; the chloramines reacted with the lead in the pipes, releasing particles into the water. The city had switched to chloramines because the U.S. Environmental Protection Agency tightened standards on using chlorine owing to concerns that chlorine by-products might be carcinogenic. Thus, the response to one potential health risk led to the exposure of a significant number of the population to another serious health problem.

There are consequences—both intended and unintended—for every action taken or not taken. Trade-offs are inevitable in environmental decision making. Every choice involves a decision not to choose the alternative policy. There are costs and benefits associated with each alternative that have to be weighed in the decision. For example, as discussed in the module on radioactive waste, the decision to transport and store nuclear waste at Yucca Mountain is a controversial one. Those who oppose the policy have pointed out the risks and costs of shipping wastes across the country; on the other hand, if the waste is not transported, it will continue to be stored in cooling ponds on the sites of nuclear reactors, many of which are near large urban populations.

Teaching Controversial Issues

Many environmental issues are controversial, and students, parents, and community members may have strong opinions about them. People may agree on the long-term goal of protecting environmental quality and human health but vigorously disagree about the best means of achieving that goal. Controversial issues can be excellent teaching tools because they engage student interest and can be used for spirited debates, and there are a number of resources that provide guidance on teaching controversial issues. Some advice that teachers have found helpful is to remember that the educator sets the tone and the ground rules for the debate. Teachers should make sure that all sides are presented and that students provide evidence to substantiate their arguments.

Environmental issues tend to be complex. Often simple solutions may be offered that appear compelling but do not take into account the legitimate interests of various groups or the trade-offs that are inherent in any choice. Once students begin to analyze the effect of any decision on the parties involved, they may begin to see the issues differently. On the other hand, students may find it discomfiting that there is not one "right" answer and that the needs and concerns of the various parties must be weighed and addressed.

Students should be cautioned to examine quantitative evidence offered in defense of an argument for or against a specific approach. It may be useful to examine common fallacies in logical reasoning to accustom students to recognize these errors as they research an issue. One of the most common errors is to confuse cause and correlation. Often data are presented that imply a relationship between two phenomena; however, it is important for students to learn how to evaluate the data to see whether there is sufficient information to indicate a relationship. Two phenomena may be positively correlated, which means a change in one is associated with a change in the other. Yet even a strong correlation does not necessarily mean that one is a cause of the other. Either one could cause the other, or they could both be related by chance. For example, there might be a correlation between ice cream sales and shark attacks. One could say that eating ice cream makes a person more susceptible to being attacked by a shark; another explanation is that more ice cream is eaten in the summer and more people in the water increases the likelihood of shark attacks. It is possible to find all kinds of statistical associations, but it is necessary to do further research to determine if the phenomena are in fact associated.

Students should become accustomed to analyzing the quality and validity of arguments. Advocates on all sides of an environmental issue may make self-interested claims. This does not mean that the claims are not valid, or that the factual evidence offered in support is not accurate, but the argument may leave out the equally valid arguments of other parties involved in the debate. It may be a useful exercise to have students investigate the arguments made by various parties and to identify and assess the evidence offered by each. Students should be encouraged to look for equally valid evidence or arguments that may be made and to think about what other information one would want to know to make a decision. Students can learn to recognize weak arguments and to critically evaluate quantitative claims.

Debates and research projects also provide opportunities for students to communicate, both orally and with graphics, their understanding of an issue. Working with teams or individually, students have to marshal their evidence, organize it, and communicate it clearly. The point

of teaching in ways that involve controversial issues is not to lead students to some supposed "right answer" but rather to give them experience in assembling arguments that take scientific knowledge and ways of thinking into account.

—Kathleen B. deBettencourt (1953-2004),
Founding Executive Director of the Environmental Literacy Council

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About the Authors

The **Environmental Literacy Council** is a nonprofit organization dedicated to improving the knowledge base of K–12 teachers in environment-related sciences. Its membership—drawn from the life, physical, Earth, mathematical, and social sciences of prestigious institutions—reflects the cross-disciplinary nature of environmental concerns.

The **National Science Teachers Association** is the oldest national association of science educators in America and the largest organization in the world committed to promoting excellence and innovation in science teaching and learning for all.

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Dedication

This publication is dedicated to the memory of **Kathleen B. deBettencourt**. She was known for her dedication to the preservation of our environment through a better understanding of science, for being extraordinarily informed on the connections between science and responsible environmental stewardship, and as a leader in environmental education with a keen ability to collaborate effectively with others. As the founding executive director of the Environmental Literacy Council, Kathleen was innovative and tireless in advancing the Council's goals. To those of us fortunate to have worked with her, she was both an admired colleague and dear friend.

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