The Ideal Environmental Science Curriculum: History, Rationales, Misconceptions and Standards (Part I of II)

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Introduction

April 22, 1970 will be remembered by many as the date of the first nationwide celebration of Earth Day. This event, according to Gordon (1993, p. 32) in his thoughtful appraisal of the American environmental movement, was "one of the more remarkable happenings in the history of democracy . . . 20 million people demonstrated their support [and] . . . American politics and public policy would never be the same again." From a science and science education perspective, this national opportunity to express concern for the environment was unique. Never in history had there been such an outpouring of emotion focused on the contributions of a particular scientific discipline. Only the launch of Sputnik and the aftermath of the Scopes evolution trial have impacted science teaching as dramatically as the rise in interest in environmental issues. The legacy of Earth Day was clear and immediate. Environmental science quickly found a home in both in the public consciousness and in the school science curriculum.

Now it is a rare day when the news media fail to report a story with an environmental message. From the Rio Earth summit in 1992 to the 2002 Johannesburg World Summit on Sustainable Development much attention during this past decade has focused on the environment. Science educators have the responsibility to ensure that citizens gain the intellectual tools to engage fully in the ensuing debates and decisions.

The recent renewed interest in environmental education may have had its origins in Earth Day, but the roots and founders of ecology are many; Aristotle, Buffon, Wallace, Darwin and the nameless agriculturalists worldwide who for millennia have noted and nurtured the relationships between the living and non-living worlds have helped to establish the science of ecology. It was German biologist Ernst Haeckel who is generally credited with developing the modern conception of ecological science at the end of the nineteenth century. He defined the study of the interactions of organisms with each other and with their environment (*oikos* = Greek for "household") in the following fashion:

> By ecology we mean the body of knowledge concerning the economy of nature --the investigation of the total relations of the animal both to its inorganic and to its organic environment: including above all, its friendly and inimical relations with those animals and plants with which it comes directly or indirectly into contact -- in a word, ecology is the study of all those complex interrelations referred to by Darwin as the conditions of the struggle for existence (Haeckel, 1866).

Since Haeckel, many scientists have added to our understanding of relationships between organisms and their link to the environment in which they live. We now have a much more robust appreciation for the concept of the web of life and the fabric formed between and within the biotic and abiotic realms. This scientific appreciation has even extended into philosophical thought with the proposal of the Gaia hypothesis, a conception that the Earth itself acts as if it too is a living entity.

As the modern conception of ecology was being formed in Germany the foundation for environmental education was being laid in the United States. Natural history is at the base of both the science of ecology and environmental education but the two would not come together until the latter half of the twentieth century. At the end of the 1800s, the nature study movement -- a partial proxy for present-day biology instruction -- was widely found in schools sometimes coupled with conservation education. In 1891 Wilbur S. Jackman published, *Nature Study for the Common Schools*, and through this book established the rationale for the inclusion of many ecology related concepts in the science curriculum. Groups like Harvard's Committee of Ten added to the rationale for nature study and individuals such as Cornell University's Anna Botsford Comstock and Liberty Hyde Bailey provided the instructional materials needed to support the study of nature in the schools. Comstock's book, *Handbook for Nature Study* (1939/1986) went through twenty-four editions and is still in print. Verne Rockcastle, the author of the forward to the reissue, makes the case for continued relevance both of the book and of nature study in stating that " . . . the clouds of today differ little from the clouds of yesteryear, and frost forms for the same reasons it did earlier in the century" (p. viii).

The nature study / conservation movement gradually evolved into modern environmental education as public awareness to pending environmental disaster was heightened with books such as *Silent Spring* (Carson, 1962) and *The Population Bomb* (Ehrlich, 1968). In many ways it was books such as these that provided the clarion call to action on issues ranging from the environmental dangers of ever-increasing use of the pesticide DDT and the ecological impact of unchecked human population growth. Many of the predictions made by Carson, Ehrlich and others were so frightening that they could not be ignored. The public had been awakened, informed and made to feel that only through activism could the Earth be saved. It is no coincidence that just a few years after these landmarks books were published, Earth Day was born. Just as Arbor Day, which began the century before resulted in the planting of millions of trees, Earth Day challenged a generation to do something in support and defense of the environment.

Although Earth Day no longer garners the attention it did years ago, a lasting legacy remains. It would now be unthinkable to exclude the study of ecology from the school science learning experience, but the question remains, just what should the ideal ecology curriculum contain? This paper and a related one to be published in the next issue of the American Biology Teacher will examine just that issue.

The Ideal Environmental Science Curriculum

In the past four decades ecology has found its place in the life science curriculum alongside other newer science fields such as molecular biology. However, even though the environmental science movement has more than reached its majority, little has been described about the ideal environmental science curriculum – although many clues are available to form a synthesis. Even less has been written about the nature of actual ecology instruction in U.S. schools.

The conceptual foundation guiding this review is one of curriculum orientation. Here the intended or ideal curriculum is the focus. This term defined by Cuban (1992) and others refers to the recommended content and process elements that should comprise the ideal instructional goals for a particular area of inquiry. A full taxonomy of curriculum types would include what is actually provided in class (the taught or enacted curriculum) and which is learned and remembered by those students (the received curriculum).

A number of sources of information have been amassed to help describe the ideal ecology curriculum. This paper will include a review of the rationales for the inclusion of ecology in the curriculum and will briefly summarize the history of national and international efforts to reach consensus on the goals for such instruction. The main focus of this contribution will be a synthesis of the research studies of student misconceptions of environmental topics and an analysis of the recommendations provided by scientists and the National Science Education Standards (NSES) regarding study of the environment. A subsequent paper will include suggestions for the ideal curriculum offered by one of the principal advocacy groups, the North American Environmental Education Association (NAAEE), followed by an extensive analysis of the environmental science content included in virtually all current secondary school biology textbooks. Together, these sources of information will help to define an ideal version of the ecological science content designed for a K-12 audience.

Ecology Education Rationales

The study of the interactions of organisms with each other and with their environment is worthy content for a number of reasons. From a pedagogical perceptive, ecology is easy to defend as school science content because of what it contributes to and demands from learners. Ecology education provides students the opportunity to apply and synthesize much of what they have learned throughout a typical year of biology instruction. Many of the basic biological concepts that students encounter assist them in understanding the environment; ecology is a more sophisticated, higher level and synthetic pursuit that involves almost all other domains in the life sciences. In this regard ecology is equal only to evolution as a concept that is both informed by and provides a foundation for much of the rest of biology. In the integrated domain of environmental science students acquire a richer and wider view of the life sciences and come to recognize biology as a web of interrelated and interconnected ideas

Ecology is inherently interesting because it represents the modern day successor to the popular nature study of previous generations of students. This realm of study encompasses a variety of interesting laboratory techniques, encourages students to work both in the field and with living organisms in the laboratory, permits discussion of fascinating interspecies relationships and the exploration of energy flow in nature, and provides the practical and intellectual tools so that students might effectively gauge the impact of humans on the environment and suggests solutions to problems.

It is this last dimension of environmental science that impacts students in ways that few other areas of science content can. Even the most basic study of ecology has the potential to affect students' understanding of the interaction of science and society. The larger view that study of the environment demands permits and encourages students to apply what they have learned in addressing problems, in allocating resources and in gaining a rich view of the interplay of science and society.

Goal Setting in Ecology Education: National and International Perspectives

As environmental education replaced nature study, members of the science education community realized that a formal position on the teaching of ecology should be developed. William Stapp and colleagues (1969) of the University of Michigan are credited with the first such definition. They stated that, "Environment education is aimed at producing a citizenry that is knowledgeable concerning the biophysical environment and its associated problems, aware of how to help solve these problems, and motivated to work toward their solution" (Stapp, et al 1969, 30-31).

In the years leading up to Earth Day, President Richard Nixon publicly advocated "environmental literacy" as a goal of science instruction and in October 1970 signed the Environmental Education Act. This law defined the focus of such education as " . . . the educational process dealing with man's relationship with his natural and manmade surroundings, and included the relation of population, conservation, transportation, technology, and urban and regional planning to the total human environment" (United States Public Law 91-516).

Through UNESCO, the international community found its voice with respect to environmental education during the 1972 Conference on the Environment in Stockholm and the 1975 International Environmental Workshop in Belgrade, Yugoslavia both of which featured the drafting of position papers about the teaching of ecological topics. The Yugoslavia conference (UNESCO-UNEP, 1976) resulted in the Belgrade charter titled a *Global Framework for Environmental Education* that was enhanced by those attending the Intergovernmental

Conference on Environmental Education in Tbilisi, capital of the Republic of Georgia, two years later. In part, the Tbilisi declaration stated that:

> Environmental education, properly understood, should constitute a comprehensive lifelong education, one responsive to changes in a rapidly changing world. It should prepare the individual for life through an understanding of the major problems of the contemporary world, and the provision of skills and attributes needed to play a productive role towards improving life and protecting the environment with due regard given to ethical values. (UNESCO, 1977, p. 26-7).

The Tbilisi delegates recommended a series of ten criteria to help guide the development of environmental education programs worldwide. These criteria included the ethical social, cultural and economic dimensions of environmental awareness, the roles played by different sciences in the study of the environment, and the interdependence of different nations and peoples. The Tblilisi working group further recommended that environmental education should provide necessary background knowledge while developing links between problems faced by real people and the possible solutions to those problems at the same time catering to as wide a variety of people as possible in the educational process. The Tbilisi declaration further refined the goals for environmental education by suggesting an increase in awareness and concern, advocating increased opportunities for every person to acquire knowledge, skills and commitment while creating new patterns of behavior on the part of individuals and society.

In 1980, Hungerford, Peyton and Wilke suggested a curriculum development framework based on the Tbilisi declaration. Their model contained recommended the inclusion of ecological foundations, awareness, investigative abilities and taking environmental action.

More recently, the U.S Federal government has again heightened interest in and funding for ecology instruction with the National Environmental Education Act of 1990 (United States P. L. 101-619). This law renews the role of the Federal government in environmental education and establishes an office of environmental education with the Environmental Protection Agency. The act provides funding for environmental education and training programs, establishing education grants, career fellowships and other related activities. Unlike other sciences, ecology has always had a "grassroots" consistency and advocacy component. Presently, a wide range of groups – many operating locally – help to spread the word about the importance of including an environmental component in science instruction. These groups do much of the practical work in providing ecology-specific instructional materials and workshops to educators along with the important public awareness campaigns that promote and maintain interest in the environment.

What Students Think they Know about Ecology: The Challenge of Misconceptions

Most educators accept the notion that one of the most important predictors of a student's future understanding is the level of current understanding. This constructivist view has resulted in a wide variety of research studies designed to determine what students know about aspects of nature. These views are generally called alternative or naïve conceptions if they are at odds with current scientific perspectives. Knowledge of these non-standard views of nature could be quite useful to educators who could then base instructional plans on what students already know rather than starting instruction somewhat randomly

Two sources of information regarding ecology misconceptions appear in the literature – those based on general perceptions of environmental opinions and those based on research studies of such views. In the first case, Krebs (1999) discusses a number of errant views related to ecology that he believes are widely held by members of the general public. He suggests that people generally misunderstand a number of fundamental ecology issues. First, he cites the inaccurate notion that "each plant or animal is independent and therefore has no effect on . . ." or "relationship to other organisms." (p. 220). He further states that people believe the "idea that a community (population) consists of a group of similar living things" (p. 220). The entire structure of ecology as a science negates these views. The faulty conclusion that an "imbalance of species within its local environment or community is always bad." (p. 221) and that " . . . once a biological community is destroyed by either natural disaster or mankind, it will be damaged forever" (p. 221) are also suggested by Krebs as incorrect but common views. He devotes considerable attention to what he sees as the false link between the science of ecology and the political agenda of environmentalism; many believe that they are same. In other words, Krebs is concerned that members of public base their environmental views and action on too little science and technology but consider it ecology nonetheless. For instance, he questions the current conceptions and prediction with respect to energy depletion, overpopulation, toxic substances, global warming and similar issues. If these alternative conceptions are as widespread as Krebs suggests, they should help to inform the development of an ideal environmental science curriculum

Munson (1994) has provided the most compressive syntheses of the results of actual empirical research studies of student knowledge of ecological concepts. His work and the contributions of those he cites, forms the basis of the following section accompanied by several more recent studies.

Food Chains and Webs

With respect to food chains, studies have shown that students have several fundamental misconceptions (Brumby, 1982, Griffiths and Grant, 1985, Munson, 1991). Students generally believe that food webs are more simple than they really are, that organisms higher in the food web always eat things lower in the web and that organisms at the top of food chain have the most energy and increase in number at the expense of those below (Adeniyi, 1985, Leach, et al, 1996). Hogan (2000) has added to the data with the finding that students generally fail to see the two-way or cyclic nature of energy flow. Her work supports Munson's finding that students believe that energy flows from the bottom to the top of the food pyramid. Hogan used student's knowledge of pollution as an indicator of their ability to apply what they know about food webs. She found that students did not realize that chemical pollutants are changed in form as they move through food chains. Also, students tended to overstate the importance of the initial contact with pollutants while failing to appreciate cumulative or concentration effect of pollution. Students in this study also poorly understood eutrophication as a consequence of pollution.

Marek (1986) conducted a small study (N=58) in which he discovered the unsettling fact that even after targeted ecology instruction, only one student had a sound understanding and thirty-four percent had partial understanding of the "food chain" concept. The remainder of the students either had specific misunderstanding (57%) or offered no response (7%).

Population Size and Carrying Capacity

Munson (1991) has shown that many students fail to see the link between the fluctuations in population size and related constraining and supporting environmental issues such as food supply. Instead some student believe that populations will increase indefinitely due to limitless resources (Brody and Koch, 1989) or will increase until the limits are reached at which point the population will crash and the organisms become extinct. In nature, neither view is accurate in the majority of instances.

Ecosystems and Populations

Griffiths and Grant (1985) and Munson (1991) have shown that many students fail to understand the web-like link between organisms in an ecosystem. The found that students tend to believe that certain organisms in a population are important *only* to those other organisms on which it preys for which is a food source. The concept that each organism is a thread in the fabric of an ecosystem seems missing for many students in much the same way that they lacked such understanding with respect to food chain generally.

Marek (1986) also investigated the impact of instruction on students' understanding of the concept of "ecosystem" and found that 31% of the student had some understanding, one-third had a specific misunderstanding and 36% provided no response. These results are sobering given the fact that "ecosystem" was a targeted element of instruction in their recently completed study of the environment.

Give the prominence of environmental education initiatives and the interests held by students in nature study topics, one might have expected to find a wide range of studies of students' alternative conceptions in this domain. Unfortunately, that is not case. Furthermore, the few studies of misconceptions in ecology that do exist are widely scattered in terms of their target population and include investigations of young children, preservice teachers, secondary school learners and foreign students.

Although there is an expectation that environmental misconceptions revealed in one group might be generalized across similar populations, so care must be taken in making such an assertion since the data are so sparse. Furthermore, many investigations such as the one conducted by Bordy and Koch (1989) were designed with reference to a specific environment, such as the marine ecosystem. It is not known if the findings in such cases could be extended to students' views with respect to other environments but care should be taken in reaching wide ranging conclusions until more data are available. What is clear from these studies is that even some of the foundation knowledge in ecology is not well known and, if Marek's conclusions were to hold true generally, we might be wise to question whether traditional instruction is the most effective way to change prior misconceptions.

Toward an Ideal Ecology Curriculum: The Views of Scientists and Standards

Scientists and the Ideal Ecology Curriculum

The quest for the ideal ecology curriculum continues with the views of expert scientists and educators. Cherrett (1989) surveyed members of the British Ecological Society resulting in a list of the top 20 most important concepts (Table 1). As will be noted by examining the other data sources, this list contains many of the same concepts. It should be noted that Cherrett did not have as his goal the development of a K-12 environmental science curriculum per se nor would the scientists surveyed understand the dynamic nature of the school science curriculum so it is likely that some of these concepts would not figure prominently in a final version of the ideal definition of environmental science for pre-college students.

Table 1: The 20 most important ecology concepts in rank order from a survey of members of the British Ecological Society. (Cherrett, 1989)

Rank	Concept	Rank	Concept
1	The ecosystem	11	Food webs
2	Succession	12	Ecological adaptation
3	Energy flow	13	Environmental heterogeneity
4	Conservation of resources	14	Species diversity
5	Competition	15	Density dependent regulation
6	Niche	16	Limiting factors
7	Materials cycling	17	Carrying capacity
8	The community	18	Maximum sustainable yield
9	Life-history strategies	19	Population cycles
10	Ecosystem fragility	20	Predator-prey interactions

Science Educators and the Ideal Ecology Curriculum

The well-respected National Science Education Standards (NSES) (NRC, 1996) were consulted to determine the extent of environmental science coverage. Content in the Standards is found in narrative form (rather than listed) throughout the document grouped into thematic areas within a particular science discipline keyed to grade level. As an example, one finds the theme "populations and ecosystems" for grades 5-8 within the Life

Science domain and the theme "natural resources" for grades 9-12 in the domain of Science in Personal and Social Perspectives. The NSES are not laid out as a checklist but are presented in narrative form. This made the review of the Standards both difficult and somewhat subjective. Some might lump several ecology related issues together while others would split a single paragraph from the NSES into a number of discrete content recommendations. Using a reductionistic qualitative view, forty ecology-related items in the NSES were discovered after are careful reading of the entire document. The grade level, theme and page number in the document was recorded. Next, the ecology content issues were grouped into categories similar to those used in the review of textbooks and provided in Table 2. An example from the NSES narrative is " . . . humans modify the ecosystem . . ." (p. 186) through population, pollution, etc. and "All organisms cause changes in the environment in which they live. " (NRC, 1996, p. 129).

The ecology content specified in the Standards is quite comprehensive. As can be seen in Table 2, the authors of the Standards were primarily interested in issues of population, limits on growth, and the impact of humans (and other organisms) on the environment and each other. The Standards further point out that science and technology should guide decision-making about environmental issues. This point would undoubtedly please Krebs (1999) who, as stated earlier, believes that many individuals confuse environmentalism with environmental science. Interestingly, the Standards include many ecology content issues on the "top twenty" list of the important concepts provided by environmental scientists shown in Table 1.

Second, the ecology content is spread evenly through the grade levels and, although it is primarily included as a Life Science topic, it is also featured in Earth and Space Science and in Personal and Social Perspectives. This spiral and integrated instruction approach is in evidence throughout the Standards. For instance, the notions of population ecology, food chairs, energy flow and human impact (the dominant ecology themes in the Standards) appear in all the grade levels. If this plan were followed, students would encounter these key concepts at increasingly higher levels of sophistication as they progress through school. Third, if teachers accept the recommendation of the Standards that science be taught in an inquiry fashion supported by hands-on activities, environmental science instruction could be enriched immeasurably.

Final Thoughts

At this point in the review only some of the available data sources with respect to environmental education are included but a picture of the ideal ecology curriculum is beginning to form. The next article in this series, *The Nature of the Ideal Environmental Science Curriculum: Advocates, Textbooks and Conclusions*, will provide an extensive analysis of textbooks and an examination of the recommendations from environmental advocacy groups. This pair of articles will conclude with a proposal about what K-12 learners ought to know about the important and interesting domain of science called ecology.

Table 2: Environmental Science Content in the National Science Education Standards

	Grade Level			Life Science	Earth & Space Science	Personal and Social Perspectives	NSES Page Reference(s)
	K-4	5-8	9-12				
Biotic and Abiotic Factors / Issues	✓	✓		✓			129, 140, 157-8
Food Chain Issues	✓			✓			129
Environment defined	✓					✓	140
Organisms impact the environment and each other for good and bad	✓		✓	✓		✓	129, 149,186, 198, 199
Ecosystem defined		✓		✓			157-8
Population defined		✓		✓			157-8
Overpopulation, population density and consequences	✓	✓				✓	140, 168
Population change, growth (Reasons and Types)	✓		✓			✓	140, 198
Predator, producer, consumer, etc.	✓	✓		✓			129, 157-8
Energy flow (sun)		✓	✓	✓			157-8, 186
Cycles (water, geochemical, nitrogen, etc.)		✓	✓	✓	✓		186, 160, 189
Organisms interact			✓	✓			186
Limits on growth & carrying capacity		✓	✓	✓			157-8, 186, 198
Pollution - causes, risks & consequences	✓	✓	✓	✓		✓	140, 169, 186
Resources are limited	✓					✓	140, 198
Humans impact the environment, its cycles & other species			✓			✓	168, 198
Humans use natural resources			✓			✓	198
Environmental decisions should be based on science and technology		✓	✓			✓	198, 199

References Cited

Adeniyi, E. O. (1985). Misconceptions of selected ecological concepts held by some Nigerian students. Journal of Biological Education, 19(4), 311-316.

Brody, M. J. and Koch, H. (1989). An assessment of 4th, 8th, and 11th grade students' knowledge related to marine science and natural recourse issues. The Journal of Environmental Education, 21(2), 16-26.

Brumby, M. N. (1982). Students' perceptions of the concept of life. Science Education, 66(4), 613-22.

Carson, R. (1962). Silent spring. Boston: Houghton-Mifflin.

Cherrett, J. M. (1989). Key concepts: The results of a survey of our members' opinions. In J. M. Cherrett (Ed.), Ecological concepts (pp. 1-16). Oxford: Blackwell Scientific Publications.

Comstock, A. B. (1939/1986). Handbook of nature study. Ithaca, NY: Comstock Publishing Company.

Cuban, L. (1992). Curriculum stability and change in P. W. Jackson (ed.) Handbook of Research on Curriculum. The Free Press: American Education Research Association.

Ehrlich, P. R. (1968). The Population Bomb. New York: Ballantine Books.

Gordon, J. S. (October, 1993). The American Environment. American Heritage Magazine 44(5), 31-51.

Griffiths, A. K. and Grant, B. A. C. (1985). High school students' understanding of food webs: Identification of learning hierarchy and related misconceptions. Journal of Research in Science Teaching, 22(5), 421-36.

Haeckel, E. (1866). Generelle morphologie der organismen (General morphology of organisms) Berlin: G. Reimer.

Hogan, K. (2000). Assessing students' system reasoning in ecology. Journal of Biological Education 35(1), 22-28.

Hungerford, H., Peyton, P and Wilke, R. J. (1980). Goals for curriculum development in environmental education. Journal of Environmental Education, 11(2), 42-47.

Jackman, W. S. (1891). Nature study for the common schools. New York: Henry Holt.

Krebs, R. E. (1999). Scientific development and misconceptions through the ages. Westport, CT: Greenwood Press.

Leach, J., Driver, R. Scott, P., and Wood-Robinson, C. (1996). Children's ideas about ecology 3: Ideas found in children aged 5-16 about interdependency of organisms. International Journal of Science Education, 18, 129-141.

Marek, E. A. (1986). They misunderstand, but they'll pass. The Science Teacher, 53(9), 32-35.

Munson, B. H. (1991). Relationships between an individual's conceptual ecology and the individual's conceptions of ecology. Unpublished doctoral dissertation, University of Minnesota, Minneapolis.

Munson, B. H. (1994). Ecological misconceptions. Journal of Environmental Education, 24(4), 30-34.

NRC (National Research Council) (1996). National science education standards. Washington, DC: National Academy Press.

Stapp, W. B, et al (1969). The concept of environmental education. Journal of Environmental Education, 1(1), 30-31.

UNESCO-UNEP (1976). The Belgrade Charter. Connect: UNESCO-UNEP Environmental Education Newsletter 1(1), 1-2.

UNESCO (1977, 14-26 October). Final Report -- Tbilisi. Paper presented at the Intergovernmental Conference on Environmental Education, Tbilisi, Republic of Georgia. Paris:UNESCO.

United States Public Law 91-516. The Environmental Quality Education Act. Enacted October 30, 1970.

United States Public Law 101-619. The National Environmental Education Act. Enacted November 16, 1990.