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A framework for integrating ecological literacy, civics literacy, and environmental citizenship in environmental education

INTRODUCTION

Environmental education practitioners span all of the natural and social sciences in terms of their training and passion. Practitioners have a range of science backgrounds, from very little science background to science degrees and some view science as a root cause of environmental problems. The matter is made more complicated by the fact that environmental education does not have a professional training dimension in the same way that physics or sociology do. Although such training gives disciplines focus and rigor, some say this leads to a rigidity that environmental education does not require. Thus, there is a diversity of perspectives on the role the science of ecology should play in environmental education.

There are two concerns about ecology in environmental education. First, the ecology can reflect outdated ecological science and epistemology. Second, at times, too much or too little attention is given to ecology, or there may be an overly rigid, linear, and hierarchical view of environmental education building on science (ecology) "facts" toward "environmentally responsible behaviors." There are several reasons why these problems arise and persist. Educators who emphasize "Environmental Literacy," or "Citizenship" as the primary mission of environmental education, especially those advocating the development of "pro-environment values," or "environmentally responsible behavior," can at times ignore, misinterpret, or take a strong oppositional stance towards the science component of environmental education. This problem is exacerbated by the marginalized

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nature of environmental education within formal education, the persistent challenges of scientific literacy, and the urgency of current environmental issues. This puts enormous pressure on educators to squeeze everything into environmental education, or to leave whole parts out. The lack of a socially sanctioned scope and sequence for environmental education makes educators wary that its goals can actually be accomplished.

This chapter will provide a perspective on the essential part that the science of ecology plays in environmental education. The first section will provide an overview of possible definitions, and relationships between *ecological literacy*, *civics literacy,* and *environmental citizenship*. The second section will provide a new framework for *ecological literacy* that can help guide future environmental education theory, research, and practice. The final section will identify possible pathways and challenges to integrating contemporary ecological science and the proposed ecological literacy framework in environmental education.

ECOLOGICAL LITERACY, CIVICS LITERACY, AND ENVIRONMENTAL CITIZENSHIP

Definitions and relationships

Environmental education involves two types of literacy – *ecological literacy* and *civics literacy*. *Ecological literacy* can be defined as the ability to use ecological understanding, thinking and habits of mind for living in, enjoying, and /or studying the environment, while *civics literacy* can be defined as the ability to use an understanding of social (political, economic, etc.) systems, skills and habits of mind for participating in and/or studying society. Being literate does not necessarily mean that one will act literate. The literate person may not read, the "financially literate" person may not balance his/her checkbook, and the ecologically literate person may not live more lightly on the earth. For this we need another term, *environmental citizenship* as the overall goal of environmental education. Thus, *environmental citizenship* can be defined as having the motivation, self-confidence, and awareness of one's values, and the practical wisdom and ability to put one's civics and ecological literacy into action. Environmental citizenship involves empowering people to have the knowledge, skills, and attitudes needed to identify their values and goals with respect to the environment and to act accordingly, based on the best knowledge of choices and consequences.

Explicit in our view of environmental citizenship are values, but we do not specify *what* these should be. We see it as inevitable that learners are exposed to values in all educational activities. The questions about values then become: (1) What and who determines which values students get exposed to – those of the teacher, the producer of the education material they're using, or socially agreed-upon values? (2) How will this exposure be carried out and placed in the fuller learning experience? (3) Will the values be made clear and explicit, and are the learners given the freedom, guidance, and opportunity to integrate the values(or not) into their own value system?

Perhaps the biggest challenge educators face is to move environmental education and its goal of environmental citizenship from a marginal to a more central position within education, social discourse, and public conscience. One manifestation of the marginality of environmental education is the propensity to include every facet of environmental education, no matter how limited the time. For example, a nature center running a single two-hour program might try to address all the dimensions of environmental education, thinking that this might be the only exposure to nature in a student's entire schooling. This puts tremendous pressure and constraints on our ability to elaborate a broad, comprehensive, and robust definition of the goals of environmental education. Another manifestation of the marginal position of environmental education is its focus on "problems." That is, much of what we dream of for humanity is not just the solution of problems, but also the generation of positive action and endeavors addressing human and non-human needs, values, and wants. Environmental citizenship should reflect this dream.

One of the most troubling consequences of environmental education's marginal position is that it fosters divisiveness and competition within the field. If we have only two hours for environmental education, what can we leave out? Is it the values piece, the science piece, or the action piece?' In explicit opposition to this tendency, we argue for an integrated environmental education whose goal is environmental citizenship.

An integrated framework for environmental citizenship

In order to address the central question of this chapter – what and how should ecology be taught within environmental education – we first must elaborate more completely a framework for *environmental*

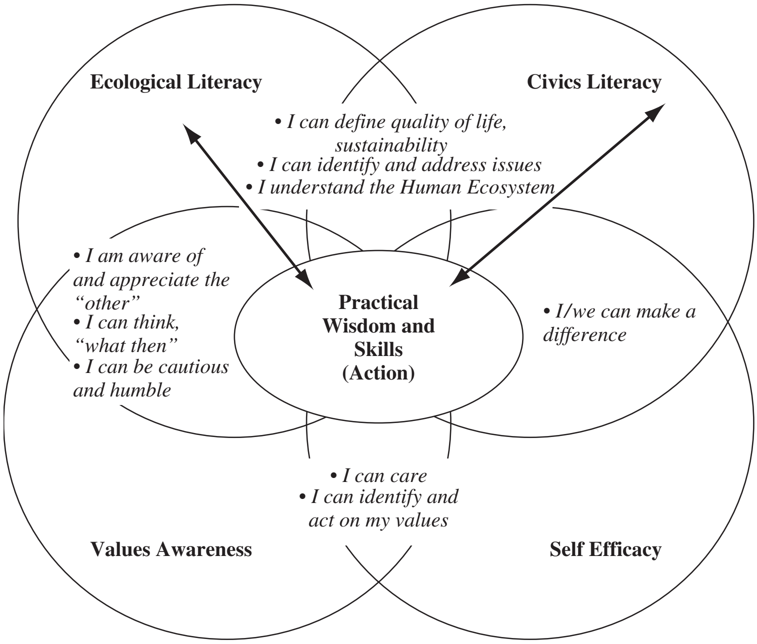

Figure 11.1. The five overlapping components of environmental citizenship. For each area of two-way overlap, illustrative statements of an environmental citizen are included. The prominent arrows emphasize the dynamic pathways by which literacy, awareness, and self-efficacy contribute to *and also benefit from* acquisition of practical wisdom and skills through action.

citizenship as a primary goal of environmental education. Figure 11.1 shows five overlapping components required for the development of environmental citizenship:

- *Ecological Literacy*: understanding the key ecological systems using sound ecological thinking, while also understanding the nature of ecological science and its interface with society.
- *Civics Literacy*: understanding the key social, economic, cultural, and political systems using the requisite critical thinking skills.
- *Values Awareness*: awareness of personal values with respect to the environment, and ability to connect these values with knowledge and practical wisdom in order to make decisions and act.
- *Self-efficacy*: having the capacity to learn and act with respect to personal values and interests in the environment.
- *Practical Wisdom*: possessing practical wisdom and skills for decision-making and acting with respect to the environment.

These components of environmental citizenship do *not* comprise a simple sequence, or hierarchy of steps, but are interrelated and highly overlapping. This framework makes explicit the idea that there are multiple "entry points" to teaching environmental citizenship. The arrows in Figure 11.1 emphasize the dynamic and two-way nature of interactions between action and the other components. This is in contrast to a more linear view of action as simply the culmination of knowledge and affective outcomes. The overlap zones between ecological literacy and each of the other components of environmental citizenship are rich areas for further development, now underexplored by environmental education. These overlap zones are personalized with statements of what environmental citizens might say in reflecting on their capabilities in each area.

While the bottom two components of the framework, Values Awareness and Self-efficacy, have a clear affective emphasis, there is a significant affective dimension to each of the other two components within this framework. For example, the disposition for self-reflection or metacognition and the ability to keep an open mind are essential parts of ecological and civics literacy. Also, cognitive skills identified in the North American Association for Environmental Education's (1999) definition of environmental literacy are subsumed within the two literacy components of this framework. The skills range from the ability to learn from experience and action, to thinking through one's feelings and values, to developing one's self-confidence to act and make a difference. Environmental literacy, as defined by NAAEE, might be viewed as the amalgam of the ecological and civics literacy components of this environmental citizenship framework.

Ecological literacy

A framework for this component will be described in detail in the next section.

Civics literacy

Civics literacy is the ability to understand social systems and to use this understanding to participate in society responsibly. While beyond the scope of this chapter to explore in much detail, we would like to raise the following questions about civics literacy. Are we being comprehensive enough in teaching civics literacy as defined above? Does environmental education address the importance of applying a whole-systems analysis to society?

The overlap between ecological literacy and civics literacy is a new dimension worthy of considerable attention and development. Perhaps this overlap zone replaces the third "knowledge" dimension in the NAAEE *Guidelines for Excellence* definition of environmental education, i.e., "Knowledge of Environmental Issues" (NAAEE 1999). Environmental issues and problems should be seen as essential topics for civics *and* ecological literacy, rather than as a separate dimension of environmental citizenship.

Values awareness

In order to foster environmental citizenship, people need the opportunity to develop and be aware of their own values having to do with other people and other organisms next door, up and down wind, up and down hill, up and down stream, and in the present and in the future. Environmental citizenship should build on the socially accepted value that the environment is a crucial consideration when making decisions and acting, rather than trying to agree on specific ways of valuing the environment or resolving the trade-offs individuals and societies face between competing values of the environment. This consideration is based on a recognition that humanity's health and happiness is inextricably linked, albeit in complex, contradictory, and confusing ways, to the status of the living and physical world around us. Environmental citizenship is the propensity to develop our values in this regard and act on them as we choose. It is also a process that evolves as our relationship with and understanding of the environment evolve, as our abilities as individuals and societies evolve, and as the world around us changes.

Self-efficacy

The development of understanding and skills, exploring and developing one's values, applying these to action, and using lessons from one's actions to further develop understanding and values, all require self-confidence. The connection between self-efficacy and the other components of environmental citizenship is a very intriguing and fruitful area of future research. How does ecological and civics literacy contribute to developing a sense of self-confidence in understanding the environment, and how does confidence, in turn, influence one's ability to learn and to make choices in the environment? How does self-efficacy grow from taking action and building practical wisdom and insight, and in what ways do low levels of self-efficacy or disempowerment limit action? Interestingly, these questions reemphasize the two-way interactions among components of the environmental citizenship framework.

Practical wisdom and skills

Environmental citizenship requires that one possess practical wisdom and skills for using knowledge, self-awareness, and self-confidence for action. It is through the application of practical wisdom and skills to real circumstances that people sharpen their understanding, develop self-efficacy, identify and clarify values, and reap the rewards and frustrations of citizenship. Taking action, and other expression of environmentally responsible behavior, are listed as goals in many visions of environmental literacy. Our framework for environmental citizenship differs from these positions in two ways. First, the ability to take action is placed at the center of an interactive and iterative process among the components of environmental citizenship framework, rather than as an endpoint. This approach is similar to Shulman's (2002) taxonomy of learning, wherein action is considered "the pivot point, one might argue, around which most of education revolves." Second, we intentionally omit a values statement about the kinds of action environmental citizenship enables (e.g., "responsible, environment-friendly, sustainable"), to highlight our conviction that educational efforts to foster citizenship should be open-ended with respect to the specific values that are fostered.

The skills and practical wisdom needed to be an effective environmental citizen should build on knowledge from the ecological and civics literacy components. Practical skills are well described in existing standards (e.g., NAAEE 1999) and include skills such as problem-solving, issues clarification, communication, and persuasion. However, the specific arenas in which people choose to act, through community organizations, the political process, the legal system, policy and management, or individual behavior, leave open a broad range of practical skills needed, with each individual choosing his/her own path in this regard.

A NEW FRAMEWORK FOR ECOLOGICAL LITERACY

As part of this vision for environmental citizenship there is a need to develop a new conceptual framework for ecological literacy that will

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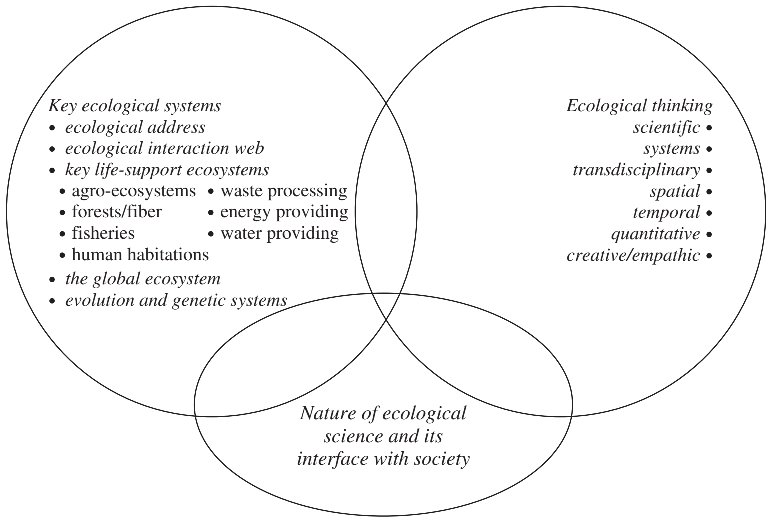

Figure 11.2. The three dimensions of ecological literacy.

provide clear guidance for environmental education theory, research, and practice. In our effort to craft a pedagogy-guiding view of ecological literacy, we struggled with the same challenges that previous efforts faced: balancing brevity versus comprehensiveness; assuring practicality while still trying to be provocative and inspirational; being synthetic and novel while sufficiently reflecting current vernacular. We are proposing a framework that we hope is novel and intriguing enough that it will spur debate, discussion, and reformulation.

In this effort we were significantly inspired by Paul Risser (1986), who, in his Past President's Address at the Annual Meeting of the Ecological Society of America, presented a definition of ecological literacy that took seriously the challenge of brevity. Risser's definition included just four things that everyone should understand: (1) multimedia transport of materials; (2) clarifying the "everything is connected to everything" concept; (3) ecology–culture interactions; and (4) familiar ecological field observations based on a specific, local "spot." We join Risser in accepting that we cannot teach everyone the whole discipline of ecology and the other environmental sciences, and ask, again, what is the shorter list of key things people should know and be able to do? The new framework we propose (Figure 11.2) has three components:

Constructing an understanding of five key ecological systems.
Building the disposition, skills, and capacity for ecological thinking.
Developing an understanding of the nature of ecological science and its interface with society.

Five key ecological systems

What are the essential things people need to understand about ecological systems in order to be ecologically literate; i.e., what are the key ecological systems which merit understanding? This is where our thinking departs most significantly from the current frameworks used for ecology (summarized in Pickett *et al.* 1994). Rather than structuring our framework for ecological literacy on the traditional sub-field structure of the discipline of ecology – autecology, populations, communities, ecosystems – we are proposing that for the general learner, as opposed to the future ecologist or environmental scientist, there is a need for something different. Specifically, there is a need to understand, using the tools of *ecological thinking* (defined in the next section), the following five key ecological systems:

- One's ecological neighborhood or ecological address – one's home community and ecosystem.
- The ecological basis of human existence – the ecological connections that sustain and are impacted by us.
- The ecology of the systems that sustain us – e.g., the food-, fiber-, and other ecosystem service-providing systems we depend upon.
- The globe as an ecosystem and our impacts on it.
- Genetic/evolutionary systems.

There is significant and important overlap among all of these systems, reflecting the interrelated nature of the science of ecology. Another feature of the systems is the pervasive place of people, in contrast with many traditional views of ecology that exclude humans or treat them as external influences on the systems of interest. The science of ecology is expanding its scope of legitimate inquiry to include humans as parts of ecological systems, including managed systems, settlements, and engineered systems. Ecology is starting to define and understand new ideas, such as ecosystem services, and links with the social sciences and

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humanities. As such, environmental education also needs to address these five key systems more directly, critically, and thoroughly.

Ecological neighborhood or ecological address

What are the physical, biological, and social systems right in one's immediate environment, and how do they interact with and affect us? Ecological neighborhood includes developing a sense of place, an understanding of how one is connected to the local environment, and how it affects and is affected by the people living there. It requires familiarity with some of the more common and unique organisms, biological communities, soils, landforms, climate, human institutions, and cultures near one's home. A multidimensional community perspective of one's home is the ultimate goal here, with a basic appreciation of the interplay between environmental conditions and organisms and how this interplay helps explain the distribution, abundance, and diversity of organisms in the immediate environment.

The ecological basis of human existence

What are the essential movements of matter and energy that sustain humans and connect us with both local *and* distant ecosystems? In a sense, this is similar to one of Risser's (1986) components of ecological literacy – understanding multimedia transport – but with the specific application to people's central role in gathering and dispersing materials both near and far. This means being able to answer: Where do my food, water, energy, and oxygen come from, and where do my wastes go? While many of the answers to these questions are part of understanding one's ecological address, many of our resources and connections are quite distant both in space and in time, requiring a much more distributed understanding that complements an appreciation of our local ecology. It also means being able to answer: Why are there the numbers of people in my home, region, country, or the world, and what are the consequences of these numbers on the flow of energy and matter at each scale?

The ecology of the systems that sustain us

While the previous component emphasizes the ability to understand the flows of material and energy from and to people, this component focuses on understanding the ecosystems that sustain human existence. Specifically, people should understand the following systems: (1) agro-ecosystems; (2) fiber-producing ecosystems (e.g., forests); (3) fish-producing ecosystems; (4) waste-assimilating ecosystems (septic systems, sewage treatment/aquatic ecosystems, landfills); (5) clean water-providing systems (groundwater, surface water, etc.); (6) energy-yielding systems (e.g., biomass production systems, wind farms, hydro-electric plants, tidal flow harnessing); and (7) human settlements (cities, suburbs, etc.) (Berkowitz *et al.* 2003). The specific systems one needs to know about will vary from place to place; people should understand *at least* the systems that they, personally, rely on. The term ecosystem services, receiving increasing attention within science and education recently, provides another shorthand for this idea. In this framework, we emphasize the need to understand the source areas of these services *as ecosystems*, rather than focusing on the services themselves. For example, rather than simply appreciating the value that near-shore ecosystems provide to people through their use as fish farms, we suggest people need to understand these fish farms as ecosystems. This means applying spatial and temporal systems thinking (as defined in the next section on ecological thinking) to understand the key components of these farms and the important connections that these enterprises have with the systems that contain and are adjacent to them. This is one of the prominent places where this framework for ecological literacy connects directly to education for sustainability.

The globe as an ecosystem

People need also to understand the globe as an ecosystem, appreciating the ways that the laws of conservation of mass and energy function at the global scale and the implications for life on earth. Interestingly, an understanding of the globe's atmosphere and the fundamental roles of plants, heterotrophs, and people in shaping it, is a special case of a "key system that sustains us" as described in the preceding paragraph. Since humans are impacting the entire globe through atmospheric alteration, land surface conversion, long-distance movement of species, etc., people need to know the basic flows and their consequences. An appreciation of the magnitude of our impacts and the time lags involved in current and projected changes is essential.

Genetic/evolutionary systems

How do genes operate in ecological systems, how and why does the genetic make-up of populations change over time through evolution, and what is the significance of evolutionary processes in helping us understand the other facets of ecological systems identified in this framework? This part of ecological literacy lies at the interface between the theory of evolution and our understanding of the environment. People need to know what the basic sources of heritable variation in populations are and how natural selection works on this variation. They also need to understand the tension between the persistence of traits and what can be either the slow or rapid change of traits through time. Finally, they need to understand how humans, intentionally and inadvertently, use selection to affect both the generation of variation and the selection of traits (e.g., by introducing novel chemicals into the environment, moving species and genes around the globe, etc.). An understanding of processes such as disease resistance to antibiotics, pest resistance to chemicals, and human genetic responses to environmental changes must be included in the development of an ecologically literate citizen.

Disposition, skills, and capacity for ecological thinking

How should people think about ecological systems? We propose to answer this question by identifying and describing an "ecological thinking toolkit" comprising seven essential components:

scientific or evidence-based thinking
systems thinking
trans-disciplinary thinking
spatial thinking
temporal thinking
quantitative thinking (emphasis on probabilities and uncertainties)
creative and empathic thinking

These components are related to the "scientific ways of knowing," thinking skills, critical thinking, and cross-cutting skills identified in the US National Science Education Standards (National Research Council 1996), the AAAS Project 2061 Benchmarks (American Association for the Advancement of Science 1993) and the questioning and investigation skills in the NAAEE *Guidelines for Learning* (NAAEE 1999). These ways of thinking also build on and are complementary to other frameworks used to describe scientific ways of knowing, e.g., the different reasoning modes of Hogan and Weathers (2003); important criteria for understanding defined by Mintzes *et al.* (2001); and different types of causality elaborated by Grotzer and Perkins (2000). However, there are three key reasons for identifying ways of knowing or thinking that are *specific to ecology*. First, we assert that thinking skills or ways of knowing are best learned within a specific domain and their application to a domain is best accomplished by teaching them within that domain. Developing domain-specific knowledge and more generalized thinking skills are linked (Schauble 1996; Mintzes *et al.* 1998). Second, we think that ecological thinking can be defined in a more clear and specific way than if left as more generic or across the sciences ways of thinking. Finally, we think that the implications for pedagogy and environmental education practice are more apparent and less subject to misinterpretation.

While beyond the scope of this chapter, it would be interesting to consider what kinds of advances in defining environmental education might come from developing a similar list of critical thinking components for civics literacy. If *understanding* of social systems was the goal, rather than simply enabling individual and collective behavior, then the list of thinking skills might be broader and more comprehensive than what is found in current frameworks.

Scientific or evidence-based thinking

Scientific thinking might most simply be considered evidence-based thinking. The ecologically literate person:

- understands the different types of evidence needed to answer ecological questions;
- understands and evaluates the different sources of evidence addressing ecological questions;
- can think through, investigate, and participate in the collection and application of evidence to address questions they have about the environment.

Note that the pedagogy implicit in this component requires learning by doing. However, we suggest engaging students in doing research *not* so that they will become lifelong researchers, but so that they will become better scientific thinkers (i.e., more adept at grappling with evidence in all of their dealings). Students should learn how to evaluate different kinds of experimental evidence by conducting their own ecological experiments and by reflecting on the utility and limitations of the results, in order to apply this form of evidence-based thinking in other aspects of their daily lives (Finn *et al.* 2002).

Table 11.1 lists some of the important types of evidence in ecology and their various sources that people should know about. We should also provide guidelines for integrating and evaluating scientific thinking and types of evidence in ecology. For example, stronger scientific arguments often involve the use of more than one type of evidence, such as combining experimental with comparative evidence or modeling with careful quantitative description. Indeed, it might be true that the strongest arguments integrate all four types of evidence. While current trends may place a premium on experimental over other forms of evidence in science in general, it is important to help people understand the limitations of this approach and other forms of evidence, specifically in ecology. Thus, the ecologically literate person knows the basic strengths and limitations of the different types of evidence, as well as the pros and cons of the different sources of evidence they might use or see used in public discourse.

Systems thinking

Systems thinking is a "contextual module" of thinking skills, knowledge, dispositions, and habits of mind (Bereiter 1990; Hogan and Weathers 2003) central to ecological thinking. Through systems thinking an ecologically literate person can:

define an object of study in the environment as a system with all the key components and their connections specified and bounded in time and space;
identify the two main types of (often overlapping) systems in ecology, those involving individuals, populations, genes, and evolution and those involving groups of species, communities, and ecosystems in functional ecological time;
place whole systems into their hierarchical context, using reductionism to look at mechanisms, comparisons across space and time at the same level to look at structure/function relationships, and holism to understand the role of the system in the systems that contain them;
understand the nature of causal factors, constraints, and feedbacks in ecological systems.

There is considerable interest in the teaching of systems thinking in ecology (Keiny *et al.* 2003; Smith 2003). Systems thinking provides a

Table 11.1. *Dimensions of scientific thinking in ecology: types and sources of evidence the ecologically literate person should be familiar with and adept at using.*

Types of evidence			
Descriptive	**Comparative**	**Experimental**	**Modeling**
		• microcosms and mesocosms	
• monitoring • natural history observations • preliminary data • long-term studies	• space-for-time substitution • gradients, real or conceptual • patches	• controlled studies • semi-controlled • time-for-space substitution • social action and management as experiments	• mathematical/ deterministic • simulation/ stochastic • physical models
	• natural experiments		
Sources of evidence			
• direct investigation, data collection			
• primary literature, direct communication with research scientists, use of available data			
• secondary literature, intermediaries, hearsay			

framework for people to cope with the diverse scales and types of ecological systems and a vehicle for integrating understandings from the diverse disciplines that apply to the environment (e.g., physiology, chemistry, physics). Together with quantitative-probabilistic and trans-disciplinary thinking, systems thinking helps integrate internal and external contingent factors, since ecological systems have multiple causality and complexity. Rigorous systems thinking provides a productive alternative to being too holistic or too reductionist, forcing us to be comprehensive in our understanding. For example, the recent emphasis within the field of ecology on including humans, conceptually, as part of ecosystems (e.g., McDonnell and Pickett 1993), is an example of using a rigorous specification of the earth's systems by recognizing that there is no place on earth free of human influence. In applying systems thinking in ecology, we must be careful not to romanticize systems or to misapply notions of self-assembly or self-regulation where there is no evidence for these features. Hogan and Weathers (2003) elaborated a more thorough treatment of systems thinking as a goal for ecology education.

Trans-disciplinary thinking

A scientific understanding of the environment requires facility in linking perspectives from disparate disciplines. Thus, the ecologically literate person:

- is able to apply understandings of the environment from the other natural sciences (physics, chemistry, geology, hydrology, meteorology, mathematics, and the social sciences) to ecological phenomena;
- possesses a working framework for how to use the disciplines that surround and interlink with ecology for understanding;
- has the dispositions and personal traits needed to reach out and to collaborate with people in other disciplines.

The ability to apply other disciplines to environmental questions requires a number of skills and attributes. There is, unfortunately, no substitute for understanding the specific ways of thinking from these other disciplines that are most essential for ecology. For example, from physics – the ecologically literate person must be comfortable with the basic laws of thermodynamics and states of matter; or from chemistry – some basic acid/base and Redox chemistry or the unique features of water and a few other key substances. As in ecological literacy, literacy in these other areas must hinge on a few key ideas and ways of thinking, and these contribute to trans-disciplinary thinking in ecology. Here is an obvious place where these more discipline-specific frameworks dovetail with the broader scientific ways of knowing frameworks that provide people with a knowledge structure for synthesis and integration (e.g., Grotzer and Bell Basca 2003). Finally, in order to have the confidence and motivation to think across disciplines, one needs a flexible mind, self-confidence, enthusiasm for going beyond one's own expertise or the topic at hand, and the inclination and ability to learn from and get along with others.

Temporal thinking

Ecological phenomena are on the one hand quite often immediate, with recent conditions often dominating the current state of a system. On the other hand, we know that longer-term legacies and lags can be significant. Thus, the ecologically literate person must be able to:

- think about the two principal time scales at work in ecology, historical/ecological time (years to millennia) and evolutionary time (centuries to eons), taking a long and very long view of the past and into the future;
- expect lags and legacies from the past and anticipate their effects on current systems and future trajectories;
- engage in "selection thinking" (Orians 2000; Freeman and Herron 2004) in order to understand how organisms change through time via natural selection;
- think about both "time's arrow" and "time's cycle" (Gould 1987), understanding the basic patterns of change, constancy, repetition, and unique events.

To be an adept temporal thinker takes imagination, especially when it comes to an appreciation of the role of disturbance in ecological time or natural selection in evolutionary time. Such understanding is made more challenging by the fact that neither set of processes are easily visualized in class or semester time (Grotzer and Bell Basca 2003; Dodick and Orion 2003). Temporal thinking as part of ecological literacy requires a basic familiarity with the time scales of ecological, geological, and evolutionary processes, and a sense of when ecological and evolutionary time scales and processes overlap. For example, when do organisms evolve significantly in ecological time, such that evolution is a current concern (e.g., diseases, weeds, etc.)? By understanding the nature of evolutionary legacies, or the "ghosts of selection past," and what determines how long-lived ghosts are, people can understand key ideas relating to trade-offs and constraints.

Spatial thinking

The ecologically literate person:

- understands how location in space determines the quality of any place;
- is accustomed to applying the notion that most ecological interactions are most intense among adjacent entities at many scales, and also knows when this may not be true;
- is adept at seeing how the environment changes over space, for example as gradients or patches, and the ecological causes and consequences of these patterns;
- knows that the surrounding environment or neighborhood can override internal processes in shaping ecological systems;
- understands his/her role as an observer on a particular scale and can think beyond this scale to smaller and larger scales.

Ecological systems are, for the most part, physically or geographically bounded. Whether we are talking about an individual organism, a community, an ecosystem, or landscape, all exist in an explicit area in space. Thus, ecological literacy requires being able to understand how things operate in space – identifying boundaries, patterns, causes, and consequences of change, and how the location of any given spot on the globe affects what happens there. To complement the overall generalization that interactions and effects are location- and scale-dependent, ecological literacy demands that one also understands that not *all* interactions follow simple spatial rules. For example, some nearby players are more tightly linked than others, and some important connections span large and hard-to-predict distances. The habits of mind involved in thinking about space include a spatial imagination and the ability to apply basic principles from physiology and the physical sciences to ecological entities. It also involves having the disposition to look beyond obvious patterns for less obvious causes and consequences. Spatial thinking overlaps with most of the other forms of ecological thinking – systems thinking, temporal thinking, scientific thinking – and also with the systems of interest component, most obviously, as an essential tool for understanding our own ecological neighborhood and the ecosystems that sustain us. Exciting tools and approaches are available for teaching spatial thinking (e.g., Gauvain 1993; Gould 1994) and its application to landscapes (Gergel and Turner 2002).

Quantitative thinking about probabilities and uncertainty

Ecological phenomena are, for the most part, stochastic or probabilistic. Thus, the ecologically literate person:

appreciates the nature and basic sources of variability in ecological processes and controlling factors;
understands how to use the basic ideas of probability in coping with the stochastic and highly variable nature of ecological systems;
can think and act "with uncertainty in mind."

Basic quantitative skills are essential for all forms of scientific literacy and perhaps even more so for ecology in light of the complex and variable nature of the systems and processes of interest. The key is to give people useful tools for coping with this complexity, including models (Grosslight *et al.* 1991; Ewing *et al.* 2003), the tools they need to relate models to the real world (Hilborn and Mangel 1997; Best 2001), and basic skills in statistics and probabilities (Cothron *et al.* 1989; Maret and Zemba 1997; Gross 2000; Kugler *et al.* 2003). At the same time,we need to build people's appreciation for the limitations of different kinds of statistical arguments. Finally, people need to develop the dispositions and habits of mind that will allow them to make the best judgments they can, even in the face of uncertainty, balanced by the requisite humility and open-mindedness needed to learn from experiments and mistakes.

Creative and empathic thinking

The ecologically literate person:

- thinks creatively about environmental questions;
- uses their empathy with other organisms and their human insights about systems that are on the same scale as human experience to better understand the environment;
- knows how to guard against the pitfalls of subjectivity and teleology in scientific thinking, even while using creative and empathic thinking;

- enjoys the fundamentally generative, creative process of building meaning and understanding (i.e., sees knowledge building as a satisfying and creative act).

Science involves a particular form of creativity on the part of its practitioners, one that benefits from the individual's use of metaphor, analogy, intuition, and insight, but where the products of these creative acts are regulated through other forms of critical thought and social construction. There are several obvious sources of creative thought in ecology that are worthy goals for ecology instruction (Fisher 1997). One involves a type of transdisciplinary thought, where conceptual viewpoints and perspectives from other disciplines are tried out in ecology. The idea of "ecosystem engineers" (Jones *et al.* 1997) is an example of borrowing the engineering concept as a creative leap in thinking about organisms' roles as habitat modifiers in shaping ecosystems.

Empathy, spatial thinking, and temporal thinking all comprise what we might call one's "ecological imagination," and the ecologically literate person needs a well-developed imagination. The empathy we feel for other organisms is a key source of creative insight that can contribute to our ability to understand them. For many, this motivates us to understand ecological systems and the organisms they contain, building on our sense of concern and compassion for "the other." Of course, there are enormous pitfalls in the anthropomorphism involved in this sort of creative thought. However, rather than squelch the underlying empathy, we suggest that it is essential to recognize it and nurture it in the context of critical thought and safeguards of objectivity (Zohar and Ginossar 1998; Tamir and Zohar 2004). Indeed, forcing oneself to have empathy with organisms that are not familiar, or that do not elicit emotional empathetic feelings (i.e., imagining the environment through the "eyes" of others) can be a powerful form of inquiry; for example, taking the ant's or the microbe's view of the environment. By making empathy an explicit target for instruction, we are more likely to develop it appropriately as a tool with clear safeguards, since people will think and feel based on empathy whether we want them to or not (Kellert and Wilson 1993).

Integrating the seven components of ecological thinking

The different modes of thinking proposed here are the thinking skills and approaches needed to go beyond the basic conceptualization of ecological thinking that "everything is connected," as posed by Muir (1911) and Orr (1993). Systems and hierarchy thinking, quantitative and probability thinking, spatial, temporal, and trans-disciplinary thinking all come to bear on this issue, helping us figure out just which things are connected in important ways. Ecological thinking, as a whole, builds on the notions that people's actions shape ecosystems, both because we are components within most ecosystems and because we are important agents of their negative as well as their positive changes (Keiny 2002). It recognizes that people's values shape their interactions with the world, in terms of our mental conceptualizations of reality as well as our physical actions. It addresses our dual roles in ecosystems building on the assertions that reality is human perception, that knowledge is what the scientific community has accepted as the best interpretation of the world at any given moment, and that interactions played out in a social context lead us to have mutual respect for the "other" and to recognize their right to be different. In conclusion, we must strive to develop ecological thinking as an entire set of tools that individuals use when confronted with an environmental question or a need for an ecological perspective.

The nature of ecological science and its place in society

The third component of ecological literacy places environmental science into its social context. The ecologically literate person:

- understands how ecological knowledge is constructed in society, how values can influence this process and how to safeguard against bias; this requires knowledge of the dynamic, social, open and conditional nature of ecological science (Pickett *et al.* 1994; Del Solar and Marone 2001);
- understands how society, politics, and economics can influence the theories and practice of environmental science;
- is able to apply or support the application of ecological understanding to social needs and problems;
- has an ethical stance concerning responsibility to use their ecological literacy.

This component of ecological literacy provides a clear connection to the other parts of environmental citizenship: civics literacy, values awareness and self-efficacy. We suggest that ecologists and ecology educators would be well served to embrace this as *part* of their mandate so that they can take the lead in defining, shaping, and teaching ecology and its interface with society. Otherwise, defining this crucial interface and directing practice to foster understanding of ecology and its role might fall to those who have a less nuanced view of science and its interface with society. By helping people understand the nature and limitations of scientific explanations, our definition of ecological literacy contrasts with others that portray science as a source of static and immutable building blocks for environmentally responsible or sustainable behavior. Ecological understanding should not be construed as a product, nor should ecological science be represented as static and external to the learner, but rather as being dynamic and within the continued grasp of the learner.

A much more insidious problem that is involved here is the naïve notion that many have about the nature of science and ecology. These notions include the ideas that every question has opposing answers with scientists behind them, that science is completely subjective (e.g., radical relativism (Tauber 2001)), or that science and its intellectual tools are part of the problem we all face with the environment and therefore cannot be part of the solution. It is incumbent upon environmental educators to repudiate these naïve notions and replace them, as much as possible, with more sophisticated and productive views of science. Therefore, a working definition of ecological literacy must address this topic directly.

CHALLENGES AND PATHWAYS TO INTEGRATING ECOLOGICAL LITERACY AND ENVIRONMENTAL EDUCATION

By what pathways does ecological literacy, however we might define it, get into environmental education? By understanding the basic pathways, we hope to gain insight into why the gaps we have noted exist and what we might do about them. Three important pathways, or sets of flows, are involved: (1) people; (2) ideas; and (3) power and influence among the key components of the environmental science/education knowledge "system." How can we integrate this new framework of ecological literacy with environmental education by working through these pathways?

We hypothesize a number of reasons why the ecology in environmental education practice might not reflect the version of ecological literacy described above:

- ecological literacy requires hard-to-develop thinking skills and understandings, made more difficult by the marginal place that environmental education plays in education systems;

- people who know ecology are not teaching it and those who are teaching environmental education did not learn modern ecology or do not have ready access to it; this is exacerbated in systems where people teach outside their specialty (by choice or edict);
- the ecology in texts, curriculum materials, and frameworks is almost necessarily outdated, especially texts at the secondary school level (i.e., texts based on texts);
- the environmental education knowledge system, like many human systems, is inherently conservative and resistant to change;
- some practitioners in environmental education see ecology as providing building blocks for specific environmental actions, and thus are less interested in a dynamic view of ecology emphasizing thinking skills and scientific process.

Despite these challenges, there has been great progress in the evolution of environmental education and the integration of ecological science into its practice. Likewise, there are exciting and pressing needs for the future. This section will describe seven possible pathways to integrating ecological literacy and environmental education:

education research
Pedagogy
instructional materials and curriculum scope and sequence
K-12 teachers' and environmental educators' training and support
schools and other institutions
standards and assessment
academics' roles in integrating ecological literacy

Education research

We need new scholarship in education research. How do students and the general public learn ecology? How do people learn to think ecologically? What are the cognitive processes at work for the individual and how do social and other contexts shape learning in the diverse situations in which learning takes place? Research on learning, necessarily set in the context of innovative programs and curricula, will do much to advance the integration of ecological literacy into formal and non-formal education. A similar research agenda faces non-formal and media-based efforts aimed at general public education. These, however, might face the added challenge of the blurred distinction between education and influence, or even the wholesale abandonment of education completely by certain outreach campaigns. However, we think great progress could be made by coming to understand how members of the general public, or targeted groups (e.g., neighborhood leaders, environmental activists, etc.), learn to think ecologically and how they come to understand the key ecological systems they are in. (National Environmental Education and Training Foundation 2001; Murphy 2002) in that it must be informed by and should likewise inform theory about cognitive and epistemological development. Consistent with our interactive and dynamic view of the environmental education knowledge system, we do not expect or suggest that education and cognitive research will serve as a simple "first step" in a linear chain of ecological literacy integration, but rather will interact with the other parts of the system to inform, inspire, and learn from practice.

Another key question we need to understand concerns what students or the general public already know about the key ecological systems we've identified as essential components of "Ecological Literacy." This is necessary to guide a constructivist approach to teaching and the development of age-appropriate instructional materials. However, it poses an interesting challenge that will come up again when we consider assessment and standardized testing – how do we measure understanding of very local and individualized things such as one's ecological address or the interaction web one is embedded in? While it might be helpful to know whether people can tell where most of the energy used in their country comes from, we argue that for the purpose of guiding the teaching of ecological literacy, it would be more useful to know whether a learner knows where their regional energy comes from. The obvious but hard-to-implement solution is to build partnerships between education researchers and ecologists who, in fact, know the local and particular, in order to craft education research projects that gauge genuine understanding of real places.

Pedagogy

What kinds of teaching strategies, or pedagogy, do we think will be needed to foster ecological literacy within environmental education? Any pedagogy aimed at fostering ways of thinking clearly must engage students in thinking. One of the important advantages of the ecological literacy framework we propose is that it makes explicit pedagogy of thinking and reflection (Feinsinger *et al.* 1997). Inquiry-based teaching must be augmented with other forms of active engagement in thinking – systems, spatial, temporal, and quantitative. Teaching scientific thinking must also include working with the many different sorts of data and evidence described in Table 11.1. Since students should be aware of the major goals of their learning and the ways these are to be developed and assessed, they should be aware of and regulate their own thinking (i.e., engage in metacognitive discourse). The adept ecological thinker must know when to engage specific tools or sets of tools. One of the consequences of this pedagogical stance is a variation on the theme of "less is more," wherein students will consider fewer concepts but be engaged in deeper thought about what they are learning.

Teaching for ecological literacy must have a strong constructivist base, making the need to know what students already know imperative (Novak and Gowin 1984; American Association for the Advancement of Science 1993; Mintzes *et al.* 1998; Novak 1998). From research on learning and cognition in ecology that identifies basic patterns of student thinking, and from embedded assessments during instruction that reveal specific mental constructs and conceptions held by students, teachers can devise strategies to help learners develop more robust and accurate understandings.

One of the major goals of instruction for ecological literacy is to apply the scientific thinking part of people's ecological thinking toolkit (Figure 11.2) to fostering their understanding of the five key ecological systems. Students should also learn how to collect, use, evaluate, and synthesize different kinds of evidence (Table 11.1). in order to understand their ecological address, the systems they depend upon, evolution, and genetic systems, etc. This should be done with data they collect themselves, with raw datasets from others, and through various types of synthesized evidence presented in the primary and soft literature. We are further intrigued by the idea of linking direct inquiry via data one collects oneself with comparative and long-term study, for example, comparing one's ecological home using climate data collected locally with that from schools in other biomes. The availability of data on the Internet, and electronic communication to exchange queries and findings makes this possible in new and exciting ways.

Teachers and instructional materials also should "model" or actively demonstrate ecological literacy. For students to learn how to think ecologically, they need to interact with scientists and educators who give life to the skills, dispositions, and understandings they are striving to attain. Thus, teachers must be ecological thinkers and understand the key ecological systems that comprise ecological literacy. Curricula should include a focus on local ecosystems, on real connections between learners and the environment, and on the actual service-providing ecosystems learners are linked to. For example, a school's resource use (water, energy, materials, air), its environmental footprint, and its structure's or landscape's derivation from the environment near and far should be made plain and accessible to students and their teachers.

We need to make the invisible visible and tangible for students if they are going to develop strong ecological thinking skills and come to understand the critical ecosystems they are part of. Fortunately, we know a lot about some of the major stumbling blocks (e.g., microbes, chemistry, slow or long-time processes, large-scale systems, and distant influences) in this regard and how they manifest and influence learning, and the effective means of addressing them. The availability of new tools provides optimism in this regard, e.g., inexpensive microscopes and those that can be used in museums and other settings, time lapse technology, computerized animations, GIS, air photo and satellite imagery for large-scale visualization of spatial patterns.

Finally, pedagogy must engage learners in *doing* ecology. Clearly, learners should have multiple opportunities to do ecological inquiry, producing and applying evidence of the types shown in Table 11.1 in their own investigations, while relating these to results from the scientific community at large. This must include repeated, in-depth and progressive exploration of the real organisms and environments in their immediate neighborhoods, along with comparisons across regions and worldwide where appropriate. But the action component of our pedagogy must go beyond scientific inquiry and include opportunities for people to engage in participatory and community-based approaches to research and learning about the environment. Such action is not just a critical source of ecological knowledge, but also plays crucial roles as a motivator for engagement and as a tool for assessment. A suite of challenges faces this form of pedagogy, such as maximizing ownership and commitment on the part of the learners while keeping the activity manageable by the educator and brokering individual versus group interests, especially when the group is diverse and might include students, teachers, community members, and scientists.

Instructional materials and curriculum scope and sequence

What kinds of materials, curricula, and scope and sequence do we need for ecological literacy? Clearly, teachers and other educators need curricula and support resources that focus on local ecosystems, on the actual connections that exist between learners and the environment, and on actual service-providing ecosystems that people are linked to. This calls for new kinds of education material and support resources, either replacing or complementing standardized textbooks and national curricula with localized materials, or localized versions of materials where possible. The pioneering work of Feinsinger and colleagues (Feinsinger and Minno 1995) in developing materials for northern Florida inspired a whole generation of new efforts to provide resources for teachers about the ecology and natural history of local and readily accessible organisms (e.g., Anon. 1993; Brewer 2002a, 2002b). New field guides are available (Stevenson *et al.* 2003), and new educational tools for helping people understand their own ecology are under development (e.g., Ecological Footprint, Wackernagle and Rees 1996). There has been a tremendous expansion of spatially referenced and accessed data about environmental conditions (e.g., Environmental Protection Agency 2004).

The five key ecological systems identified earlier in this chapter should provide students with very concrete and directly relevant topics of investigation and experiential learning. Sequences should start with local key service-providing ecosystems. The school, neighborhood, watershed, and region should, to a large extent, *be* the curriculum. Human habitations, be they cities, villages, or even individual homes, are one of the key ecosystems all students must learn about, and therefore the home-schoolyard-city ecosystem must be not just the setting but the subject of study.

We need guidance from education research about what would be a reasonable scope and sequence in order for students to develop a progression of concrete to abstract understandings of real ecosystems (neighborhood, life support, ecosystem service-providing, etc.) and ecological thinking skills. For example, the sequence could start with the ecological address and even with a focal organism, population, or community within the nearby ecosystem for learners to study. At first there might be less emphasis on distant parts of the environment or phenomena that cannot be observed directly. However, revealing critical but invisible agents and processes (microbes, chemical and physical transformations) should not be left too late in the scope and sequence. Indeed, we hypothesize that many of the most significant misconceptions and conceptual difficulties high school and college students (Green 1997; White 2000), and adults have in ecology (e.g., biotic nature of decomposition and nutrient cycling, accurate understanding of photosynthesis, primary production, and matter transformations) stem from a lack of attention to fundamental ecological processes early in education.

The Atlas developed by the American Association for the Advancement of Science (AAAS 2001) and the work of Barker and Slingsby (1998) are good examples of progress in this regard. The challenge is to develop learning sequences that flow from simple to more complicated without sowing the seeds for misconceptions. None of the dimensions of ecological thinking are completely beyond even the youngest learner; to the contrary, young people grapple with evidence, systems, space, and time throughout their lives. What we need to decide is when to make the details of thinking explicit to students, what kinds of tasks to engage them in, and what kinds of benchmarks to use to gage their progress. We might, for instance, start with a single form of ecological thinking (e.g., spatial thinking) and apply it to simple systems and then build more sophisticated thinking skills and start to link these with the other forms of thinking. Again, the AAAS Atlas presents one example of this kind of developmental thinking applied to the idea of systems.

It is essential that we make the desired sequence of thinking skills *explicit* to learners and their parents, to teachers and administrators, and to political leaders who shape education policy. However, developing a scope and sequence for ecological literacy is particularly challenging since we have argued earlier in this chapter against a hierarchal and linear sequence. Thus, we should identify an appropriate number of "cycles" over the K-12 formal education through which environmental education can develop ecological literacy. The resultant scope and sequence for each component of ecological literacy might build on Schulman's (2002) taxonomy of learning: engagement and motivation, knowledge and understanding, performance and action, reflection and critique, judgment and design, and commitment and identity.

Ecological literacy education must also be integrated with other disciplines. For instance, students need to know certain things from basic biology, physics, and chemistry before they can apply these ideas to ecological systems. AAAS's Atlas project makes significant progress in this regard, including strand maps linking several sets of ecological ideas to those in other disciplines.

Teaching for environmental citizenship (Figure 11.1) requires a diversity of instructional models, with multiple entry points into a highly interactive process. Thus, ecology will not always come first, or in a set position within a rigid sequence. The goal is to achieve a robust, and diverse environmental education program at the school, school system, or state level, such that individual components or facets of environmental citizenship – such as a focus on ecological literacy, civics literacy, or values clarification – can be pursued in depth.

K-12 teachers' and environmental educators' training

The nature and quality of direct instruction of students and the general public by educators depends on: (1) Who is recruited into and retained in the education profession, and what training and knowledge do they receive before they start teaching? (2) How do substantive, epistemological, and pedagogical ideas flow to educators as they teach or communicate? (3) How do input and feedback from students, before, during, and after instruction, influence teaching? and (4) How do external factors and contexts influence educators' practice? Rigorous answers to these questions with respect to environmental education practice are beyond the scope of this chapter, but some issues can be identified to guide future research and practice.

The first important issue is the ability of educators to be strong ecological thinkers. However, are we training educators in this way in the K-12 system, or in colleges and universities? Even more vexing, are we recruiting people who are good ecological thinkers into the teaching professions or recruiting individuals who are less capable in this regard? For example, are K-5 teachers or environmental educators at nature centers stronger in civics and the affective domain of environmental citizenship and less strong scientific thinkers? If so, what are the implications in terms of their ability to teach ecological thinking by example?

The second important issue for teachers is the in-service training and support they receive. Where do teachers get their new ideas about the environment and about how to teach ecology? Some knowledge flows among teachers and from academic scientists and educators, while other sources include print and electronic resources that teachers acquire on their own. How can these pathways better support the integration of ecological thinking and literacy into environmental education teaching?

Third, the teaching practice is influenced by real or perceived input from the learners themselves. Teachers will benefit from the

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results of cognitive research about learners, especially if the information is made relevant and accessible. Teachers also need authentic assessment tools they can use to find out what their students know and what they learn about the new topics, along with the thinking skills we've identified as crucial for ecological literacy. The current movement towards developing instructional designs that embed authentic assessments strategically throughout the program will help and is especially challenging, but no less important, for the many environmental education programs that are short in duration (Moorcroft *et al.* 2000). Another key part revolves around teachers' ownership of and commitment to the goals of their instruction and to serving the full diversity of students they work with. Our vision of ecological literacy must evolve in at least two essential places in this regard. (1) There is a need for an overarching framework for environmental education, requiring collective construction and consensus so that there is some level of mutual agreement that what we're shooting for is both worthwhile and attainable. And (2) There is a need for a working definition of ecological literacy that individual teachers feel is relevant, important, and within their grasp and that of their students.

Finally, a complex diversity of other external factors influence teachers – the social dynamics of the school, the physical and community setting, school system, professional unions and associations, available instructional materials and resources, standards and the results of a full suite of assessments ranging from their own to high stakes standardized tests.

Many of the teacher-oriented strategies that are needed to integrate ecological literacy into environmental education are not unique to ecology or to environmental education. The strategies include: creating a culture of ongoing professional development; establishing communities of inquiry and education that include teachers, scientists, educators, and community members (Brewer 2002b); providing peer and scientist support; providing resources and the opportunity to use them; working to increase the number of teachers actually teaching in their field; and developing standards for formal or informal educator proficiency and training (e.g., National Research Council 1996; NAAEE 1999).

Schools and other institutions

Teaching for ecological literacy is shaped by the institutional context within which teaching and learning take place. For schools, nature centers, museums, and other non-school educational settings, this includes: the social and professional community of the institution and the systems it is contained within (e.g., school district, state, and national agencies; or regional systems of nature centers, or institutional context of museums or field stations, etc.); political and public power and control; and resources such as instructional resources, human resources in the surrounding community, and the bio-physical resources of the institution and its surroundings.

What can institutions do to foster ecological literacy with these factors in mind? Education institutions such as schools, school systems, and non-formal centers should embrace environmental citizenship as an overarching goal for education, on a par with other forms of citizenship. They should also define for themselves the components of environmental citizenship, including the critical literacies they seek to foster and an overall strategy for attaining it and assessing their success. As part of this commitment, institutions should create a professional culture that supports the kinds of teaching, professional development, and community engagement necessary to foster ecological literacy, civics literacy, and environmental citizenship. Since much of what students should learn about is the local environment, this will require building close connections with important actors in the local environmental scene, such as government agencies, non-governmental agencies, neighborhood groups, and academic scientists. School–community partnership initiatives are outstanding examples of creating a positive context for fostering ecological literacy, with service learning and other connections between knowledge and action being prominent examples having wide application in recent years.

As suggested in the pedagogy section above, educational institutions should develop ecological literacy by providing students, teachers, and others with access to information about how the institutions themselves function as ecological systems. Ideally, they would also serve as laboratories for students and teachers to experiment with applying their knowledge to making changes and then learning from these manipulations (Kobet 2003). Imagine a school or nature center that routinely measured its energy and water use, wastewater discharge, rain- and snow-water fluxes, or one that kept careful records of its landscaping activities, mowing and clipping removal, fertilizer inputs, or exotic plant introductions. These data could be made available to the community and embedded directly into the curriculum to help students understand the real systems of which they are part. Schoolyards, neighborhoods, and other local environmental resources should be utilized to their fullest extent, because this is the learner's ecological address and contains the nearby parts of the ecological interaction web of all learners.

Institutions play a vital role in providing access for teachers and students to the wealth of resources available through libraries, on the Internet, and in their greater community. Scientists at government agencies, colleges, and universities, and non-governmental organizations all have invaluable expertise and perspectives to contribute. It is at the level of the school or the school system that we really can achieve the kind of diversity of professionals and resources that is needed to carry out the diversity of teaching approaches needed to foster environmental citizenship. Thus, ecologically literate teachers can focus on their specialty, collaborating with and complementing work by others proficient in civics literacy, values clarification, building self-confidence or crafting educational and rewarding action projects. This is not to say that each specialist operates in isolation or without some comfort and facility in the full suite of environmental teaching approaches, but specialization should occur without others feeling their specialty is left out if the institution as a whole has an effective and diverse community of professionals.

Standards and accountability

Standards lie at the interface between education research, institutions, curriculum, instruction, and assessment. Ideally, standards should reflect the most current vision for what students should know and be able to do as informed by the interaction of these components. Standards should be useful for instruction, grounded in education theory and research, and linked to productive assessment tools for educators. Finally, standards are molded and prioritized by education institutions with important inputs from the public and political leaders. Input by professional associations of scientists often does not take place in a concerted fashion. The NAAEE however did seek input from professional science associations and has developed a very progressive set of standards for environmental education (NAAEE 1999) that are quite consistent with our vision for ecological literacy. However, what impact and role such non-mandatory national standards can and will play remains to be seen.

The next step in implementing our vision of ecological literacy will be to identify standards for participants in formal and non-formal education programs. This includes the challenge to develop assessments for gauging ecological literacy. Many of the intended learning outcomes are novel and complex, and others hinge around local and

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individual-based understandings that are difficult to look at through standardized tests. Likewise, it is difficult to assess the development and ability to use thinking skills, especially in the context of standardized tests (Blank and Brewer 2003), placing our framework for ecological literacy at or beyond the cutting edge of the assessment field. Many national and state standards include an emphasis on thinking skills, general or crosscutting dispositions or habits of mind (e.g., AAAS 1993; NRC 1996), and this framework can inform integration and synthesis of these skills. However, the success of translating these parts of the standards into state and local mandates, and into practice, with reliable assessment to back them up, has been much more challenging than the adoption of the more straightforward content and inquiry standards. However, it appears that the field of education is well aware of this challenge (Bybee 2003), and our framework for ecological literacy can be part of the cutting edge work in the future. The environmental education field needs to tackle this challenge head-on, developing ecological literacy metrics, and working to have them used by teachers, schools, and systems to provide feedback on how the framework helps guide practice.

There are pros and cons in the struggle to infuse ecological literacy more thoroughly and explicitly in national and state standards. While being omitted helps to perpetuate the marginal position of environmental education in the curriculum, being included opens it to be misconstrued and constrained. Standards that embody pedagogy, like our own definition of "Ecological Literacy," could be progressive if adopted. The AAAS 2061, NRC National Science Education Standards, and NAAEE *Guidelines for learning* documents all emphasize a much broader range of standards than simply focusing on learning and learners. Those interested in fostering ecological literacy would be well advised to learn from the successes and the limitations of these efforts.

Another dimension of the standards and accountability issue revolves around equity. As long as environmental education and ecological literacy are *not* hard-wired into agreed-upon standards and programs, there will be inequalities in the delivery of environmental education programs and an asymmetry in the distribution of environmental citizenship among our population (Bryant and Callewaert 2003; Shu 2003). There is clear evidence that this is the case, with urban, poor, and minority populations often, though not always, evincing lower levels of environmental knowledge or awareness (Lee and Luykx 2003). This might be the most important reason to wage the battle for inclusion in high stakes standards and tests, linking to current efforts to avoid leaving any children behind. If parts of our populace continue to receive less instruction in ecological thinking, there will be dire consequences to society as a whole. Thus, resources and support for environmental education by institutions is a key dimension of environmental equity.

Academics' roles in integrating ecological literacy and environmental education

Academic scientists and educators, or, more specifically, ecologists and other natural and social scientists who study the environment, and education researchers who study teaching and learning, have multiple roles to play in integrating a modern version of ecological literacy into environmental education theory, research, and practice (Brewer 2001). These roles emerge for them as individuals, groups within their academic institutions, and in their disciplinary associations. The goals of their involvement should be to assure that environmental education has the tools it needs in terms of instructional materials, models, and other resources; is up to date and responsive to changes in scientific understanding of the environment and of how people learn; is responsive to societal changes; is balanced in terms of its emphasis, as a whole, on each critical facet of environmental citizenship; provides feedback and input into environmental research, decision-making, and management; and is given adequate attention and resources by society at large.

Who has power and influence to shape the way ecology and ecological literacy are integrated into environmental education? As a diffuse field, without an established place in either the overall curriculum or a unified professional identity, this is not easy to answer for environmental education. We suggest that ecologists and other academics must play a central role in this regard. Here, then, is a set of recommended actions for ecological scientists (again, broadly construed to include all natural and social scientists working in the environmental arena), including professional associations, to help address the need for a new framework of environmental literacy in environmental education. Ecologists and other environmental scientists are the best ones both to advocate for ecology in environmental education and to provide the frameworks and approaches needed to do so.

They can do this in many ways: through local and regional associations, by collaborating on projects to develop education standards, assessment, curricula, and training; and through their professional societies. Ecologists need to work with academic educators to shape the vision of ecological literacy in a pragmatic way and to define and advance a research agenda. As active educators in their own right (with undergraduate and graduate students, and in their work with teachers, students, managers, policy-makers, and the general public), environmental scientists can bring insights into developing innovative pedagogy, especially in light of the essential links between the key ideas in the field, ways of thinking, pedagogical content knowledge, and teaching. Thus, the content and pedagogy built into our working framework of ecological literacy and corresponding standards and assessments must be informed by scholarly natural science and cognition.

Ecologists and other scientists need to provide strong, positive models of excellent education practice to the fullest extent that they can. Many of the recommendations made in this chapter can easily be implemented in undergraduate teaching, where professors can focus on developing ecological literacy, addressing frameworks that emphasize key understanding and thinking skills, and using innovative and effective techniques that suit the full range of learners. A good number of their students will go on to be educators, and their future practice is shaped by the way they learn. Intensive research experience and internship programs provide, among other things, an opportunity for students and mentors to "think together." To the extent that academics can live and breathe ecological thinking, making their ways of looking at the world plain to their students and collaborators, they can help support others in developing these same understandings, knowledge, skills, and dispositions. This same notion of "modeling" ecological thinking should extend to the way that scientists structure the resources they produce for education, i.e., the texts (McComas 2003), websites, and curriculum supplements produced for formal and nonformal education use.

Ecologists are also in the best position to provide the kinds of local natural history and ecology knowledge needed to address ecological literacy as we envision it. The long legacy of nature study started over 100 years ago builds on a vital role for naturalists in the education process, and our modern vision of ecology education does not transcend the need for location-specific knowledge.

Finally, academics can provide a model for approaching ecological literacy through their very institutions. Our departments need to embrace trans-disciplinary thought and training, must support collaboration, and must honor a diversity of pathways to scholarly contribution if we are to have the kinds of programs in research and education

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that ecological literacy and environmental citizenship demand. Likewise, our professional associations need to transcend traditional boundaries and monolithic definitions of excellence to celebrate contributions from educators, social scientists, policy-makers, and researchers. Indeed, many of the professional associations, both research-oriented ones like the Ecological Society of America and educational ones like the National Science Teachers Association, are moving in this direction, giving us much optimism for the decade to come.

CONCLUSION

As humans' capacity to alter the environment reaches unprecedented levels, the urgency of fostering environmental citizenship in all people has never been greater and, perhaps, more difficult. Through specialization and urbanization, people find themselves further from the sources of their resources and less connected to the biological and non-human physical world. Though simple solutions might exist for some of the challenges we face, making simplistic behavior-oriented campaigns an option in these cases, for the most part the challenges are complex and difficult. Indeed, their resolution requires engagement and consideration by the full diversity of people involved, making environmental citizenship essential. In this chapter we have argued for a vision of environmental citizenship that is dynamic, involving an unfolding interplay between thinking, feeling, and acting through the course of one's life. Knowledge and understanding both feed and spring from one's actions. Values and a sense of self-efficacy contribute to and grow out of learning and doing. Perhaps most importantly, by making environmental citizenship an explicit and recognized goal of education, we raise each person's awareness of what it means to be a good environmental citizen. They, too, can then participate in the ongoing process of "inventing" the goals and vision of the environmental education enterprise.

One of the key components of environmental citizenship is ecological literacy. We have presented a framework for ecological literacy that is open and inclusive, and that involves the overlap and interaction between subjects of study (five key ecological systems) and ways of knowing (seven dimensions of ecological thinking), linked by innumerable areas of overlap, and by the additional emphasis on understanding how ecological science and society interact. Embodied in this view is a clear set of implications for practice: the need to make thinking skills and practical understandings of real ecological systems explicit to learners, teachers, and education systems; the need to engage teachers and learners in ecological thinking that builds their capacity and confidence over time; the need to provide local resources to support the teaching and assessment of learning about specific, local ecosystems and organisms; the need to carry out research in how people develop ecological thinking skills; the opportunity to capitalize on service learning, participatory research, and other action-oriented teaching approaches as sources of ecological understanding; and the challenge for ecologists to take an active role in assuring that their science is being taught – enough and well – in environmental education.

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