THE GAIAN GENERATION: A NEW APPROACH TO ENVIRONMENTAL LEARNING

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How would schooling change if it were completely overhauled so as to educate students to observe, assess, and interpret environmental change? What if our most prominent educators and scientists developed an approach to K-16 schooling in which an understanding of the biosphere—a Gaian approach—became the foundation of an entire curriculum? How might we train a "Gaian Generation" of environmental learners? This essay is a speculative attempt to answer that question. We are on the verge of a new twenty-first century environmental science, and we urgently need cohorts of learners who can apply this science to the daunting task of planetary well-being.

Our challenge is compounded by the prevailing absence of natural history knowledge and awareness. Fewer children spend time outdoors.[i] Fewer children can identity the local flora and fauna of their neighborhoods and communities. And yet, with just basic computer skills, they have access to a global network of environmental information and tools. How do we revitalize an interest in the natural world, supplement it with the vast information repository that's available, and educate a new generation of environmental learners?

"Pattern-based" environmental learning must become the conceptual foundation of an integrated environmental change science curriculum. This can be accomplished, in part, by linking a hands-on, empirically oriented, observational approach to natural history (visceral learning), with a broader conceptual, computer-enhanced, pattern-based approach to environmental science (virtual learning). Make no mistake. Gaian learning starts with intimate awareness of local natural history. Direct observation of the natural world is the curricular substrate for understanding the biosphere. But such learning also requires an awareness of spatial and temporal variation. With the power of laptop computers, interactive databases, and the scaling tools that both facilities enhance, a pattern-based approach to environmental learning is at our fingertips.

I am urging a reformulation of K-16 science, an approach that is substantively informed by but also linked to new conceptual frameworks. What are the developmental structures, the cognitive orientations, and the perceptual foundations that form the basis of this reformulation? This essay proposes exactly such a reformulation, informed by state-of-the-art global change science, culminating with concrete suggestions for educational institutions.

THE MANDATE (THE IGBP CHALLENGE)

The International Geosphere-Biosphere Programme (IGBP) is an interdisciplinary consortium of research scientists who are primarily concerned with the earth system challenges posed by global environmental change. Its research agenda "comprises a suite of research projects focused on the major Earth System components (land, ocean, and atmosphere), the interfaces between them (land-ocean, land-atmosphere and ocean-atmosphere) and system-wide integration (Earth System modeling and paleo-environmental studies)."[ii]

They publish a series of comprehensive environmental change science anthologies (The IGBP Series) representing the epitome of peer-reviewed, international, interdisciplinary, innovative, approaches to a holistic, biospheric assessment of the earth system.[iii] Anyone interested in developing a deep understanding of the complexities of environmental change science should be familiar with these volumes. The seminal work, Global Change and the Earth System, provides both a comprehensive assessment of the various stresses and pressures on the earth system and a compelling epistemological approach for researching, interpreting, and communicating concepts of environmental change. The final chapter, "Towards Earth System Science and Global Sustainability," offers an "earth system science toolkit."

The guiding premise of the IGBP approach is that an "integrative Earth System science is beginning to unfold" as "Observations of Earth from the surface and from space are yielding new insights almost daily." They suggest a conceptual reorientation is necessary and the "biggest challenge" facing the scientific and educational communities "is to develop a substantive science of integration."[iv]

The IGBP Mandate trumpets a challenge to reorient environmental science education to provide students with the conceptual tools for interpreting, assessing, and comprehending global environmental change.

I will describe this challenge in some detail as it offers an authoritative, compelling, and ultimately urgent case for such a reorientation. The IGBP Mandate provides a biospheric perspective on environmental change science, with an emphasis on both the analytical and cognitive orientations that such a science demands. Its additional emphasis on sustainable solutions links theory and practice—there is a tangible reality to environmental change. Human life, ecosystem integrity, and planetary health will be profoundly impacted by earth system changes. Hence urgency, if not a moral imperative, is the foundation for this mandate.

In 2001, the Global Analysis, Integration and Modeling Task Force (GAIM), a subcommittee within the IGBP, "developed a set of over-arching questions as a challenge to the scientific community concerned with global change." These questions were organized into four categories: analytical, operational, normative, and strategic. The analytical questions are of particular interest for environmental science education.

1. What are the vital organs of the ecosphere in view of operation and evolution?
2. What are the major dynamical patterns. teleconnections, and feedback loops in the planetary machinery?
3. What are the critical elements (thresholds, bottlenecks, switches) in the Earth System?
4. What are the characteristic regimes and time-scales of natural planetary variability?
5. What are the anthropogenic disturbance regimes and teleperturbations that matter at the Earth System level?
6. Which are the vital ecosphere organs and critical planetary elements that can actually be transformed by human action?
7. Which are the most vulnerable regions under global change?
8. How are abrupt and extreme events processed through nature-society interactions?[v]

Further, the IGBP Mandate poses a series of conceptual challenges, dictated by the characteristics of a complex, multi-layered template of interconnected biospheric systems. For example, a student of environmental change science must be able to cope with complexity and irregularity. "Most environmental systems are characterized by a multitude of non-linear internal interactions and external forcings."[vi] How do you learn to interpret non-linear Earth System behaviors? How do you recognize thresholds and irreversible changes? How you do accommodate for indeterminacy or intrinsic uncertainty? How do you recognize the characteristics of emergent properties and complex systems? Finally, and at the core of the tool-kit, is an understanding of scaling effects, recognizing the interactions and distinctions between local, intermediate and global spatial scales, as well as interpreting vastly different temporal relationships. The IGBP Mandate describes these as the "visionary tools" that are a prerequisite for global change research.

THE EARTH SYSTEM SCIENCE TOOL KIT

These conceptual challenges are the cognitive foundation for an "Earth System Science Toolkit….an interlinked suite of probes and processors that sense and interpret Earth System behavior in a holistic way."[vii] This suite includes paleo-science, contemporary observation and monitoring, earth system experimentation, global networks, and the simulation of earth system dynamics.

Although rapid environmental change presents complicated "no-analogue states," that is, the "Earth System has recently moved well outside the range of the natural variability exhibited over the last half million years," the use of "multi-proxy" approaches remains crucial. Paleao-science emphasizes the recovery of "key archives of past change."[viii] Those archives include mountain glaciers, coral reefs, tree ring records, biological species assemblages in lakes, boreal peat lands coastal environments, coastal tropical wetlands, or any ecosystem in rapid transition, where data gathering from the more recent past provides an historical context for assessing rapid environmental change. The collection, interpretation, and assessment of this data must become a foundation for environmental science teaching.

In the last few decades we've seen a proliferation of earth system data, enabled by extraordinary advances in computer technology, observation of the Earth from space, and sophisticated monitoring techniques. Through global computer networking and the relative accessibility of the Internet, much of this data is publicly available and accessible. This global change information base should be effectively organized so that educators can use it as the basis for teaching environmental science.

Rapid environmental change results in dramatic earth system experimentation—altered biogeochemistry of the oceans, the introduction of alien species, the removal of endemic species—these processes reflect a contemporary, ubiquitous, perceptual challenge. Any student of environmental science can observe simulations of future environmental conditions on Earth by studying "the structure and functioning of ecosystems under new combinations of atmosphere and climate."[ix]

The depth, richness, and complexity of this data requires a global network of thousands of trained, dedicated observers, who use similar protocols, and who have access to this shared data. "Planetary patterns emerge more clearly when small-scale or site-specific measurements and process studies are carried out in a consistent and comparative way across the globe."[x] Emerging global computer networks facilitate the exchange and accessibility of this data. Such a global initiative should be linked to a similarly comprehensive network of schools and other educational institutions.

The portability and power of computer technology also supports increasingly instructive and dynamic "virtual" simulations, scenarios, and experiments. Although highly technical knowledge is required, for example, to "simulate mathematically the physical dynamics of the atmosphere and the oceans and their coupling,"[xi] or to incorporate the dynamics of major biogeochemical cycles, more simplified versions of these models serve to enhance a student's understanding of earth system processes. Why not provide school systems, teachers, and students, with the software and training to explore such simulations in environmental science classrooms?

For the purposes of this essay, I will present hands-on, educational approaches that integrate the IGBP Mandate as the basis for environmental science education. To create a resilient, comprehensive, and deep understanding of biospheric processes, environmental science must emphasize the interpretive dimensions of the eight analytical questions as suggested by the GAIM task force. What are the conceptual, developmental, and perceptual challenges intrinsic to their investigation? This is the educational essence of the IGBP Mandate. What particular challenges do they create for environmental learning?

PATTERN-BASED ENVIRONMENTAL LEARNING

How can we train an entire generation of students and teachers to reorient their approach to learning so as to enhance their understanding of biospheric processes? This is both a perceptual and substantive challenge. Learning about biospheric processes requires a perceptual reorientation, an educational approach that stresses pattern-based learning. The task for the science educator is to develop a conceptual curricular sequence that helps students perceive, recognize, classify, detect, and interpret biospheric patterns. At the core of this approach is an emphasis on scale, an understanding of how to interpret spatial and temporal variability, linked to the dynamics of biospheric processes and local ecological observations.

Consider some of the dynamic biospheric processes that are crucial to understanding global environmental change: biogeochemical cycles, watersheds and fluvial geomorphology, biogeographical change (including, species migrations, radiations, and convergences), plate tectonics, evolutionary ecology, and climate change. What if these concepts became the basis of science teaching as soon as a child starts school? You can teach a first grader to follow the hydrological cycle, to observe the flow of water in a river, to observe phenological changes, to understand animal and plant migration. You can teach an elementary school child about plate tectonics, climate change, seed dispersal and pollination, or atmospheric and oceanic circulations.

I believe that the source of this learning is a pattern-based orientation. Once you understand the basic earth/land/water movements of a biogeochemical cycle and the various teleconnections between these mediums, you have perceptual awareness of a fundamental biospheric process. Depending on the grade level and learning sequence of the curriculum, the substantive depth of the investigation may be enhanced. Each year, K-16, a student can study the carbon cycle, with additional layers of complexity as the necessary mathematics, modeling, or mechanics is enhanced. The curricular substrate is the ability to interpret the patterns that are intrinsic to biogeochemical cycles as linked to a growing understanding of scale and connectivity.

Variable scalar hierarchy is an important conceptual tool for biospheric perception. The observer learns that causation depends on context. Depending on the scale of your observation, you learn to link different phenomena, and you understand the dynamic changes inherent in any landscape are a function of spatial and temporal boundaries. There is a pattern language that transcends scale. The emerging science of landscape ecology, for example, works with a taxonomic lexicon that implies such a structured pattern language: corridors, gaps, mosaics, borders, and boundaries. Observing such structures through tangible, hands-on, research projects provides students and teachers with the opportunity to explore these patterns.

A deeper exploration of biospheric patterns and processes (as in the case of landscape ecology) yields mathematical and linguistic learning opportunities that further deepen the curricular sequence. Should this change how we teach math and language? Would math instruction be more meaningful if it was coordinated with the observation of biospheric patterns? Can such coordination be linked to the earliest years of schooling?

Pattern-based environmental learning is the conceptual foundation for a biospheric curriculum. This approach is necessarily visceral and virtual. It must proceed, on the one hand, with hands-on, outdoors-based, field observations, taking advantage of the perceptual gifts of the five senses. There is no better educational approach for biospheric learning, than intimate, empirical observations of field natural history. However, pattern-based learning also requires the ability to explore and practice the manipulation of data by experimenting with scale. Through the use of computers and other forms of instrumentation this manipulation can occur through magnification and miniaturization. Science teaching has some remarkable perceptual tools that are now widely available. How might they further enhance biospheric perception? First, let us look at the visceral approach and why intimate awareness of local natural history is a prerequisite for pattern-based environmental learning.

THE VISCERAL APPROACH: BIOSPHERIC NATURAL HISTORY

Richard Louv's 2006 book Last Child in the Woods: Saving Our Children From Nature-Deficit Disorder, suggested that an entire generation of North American youth no longer play outside. This became a rallying cry for dozens of environmental organizations, culminating in the sponsorship of federal legislation entitled the No Child Left Inside Act of 2007, an effort to restore and revitalize environmental education funding for American public schools. The explicit assumption of such legislation is that less time outdoors results in declining awareness of and interest in ecological issues and knowledge. Implicitly, it assumes that the dominance of computers, television, video games, and other electronic entertainment, leads to inactivity, a decline in physical fitness, and less curiosity and interest in the natural world.

I'm not sure there is enough evidence to warrant a clinical psychological term such as "nature-deficit disorder" but Louv's basic point is well taken. One can presume a declining awareness of natural history, and such a decline can only be reversed with a dedicated effort on the part of schools, communities, and families to promote outdoor learning. Louv suggests that outdoor play is crucial to the healthy psychological development of children. Environmental educators insist that outdoor play is a prerequisite to promoting an ecological understanding of the natural world.

What's the relationship between outdoor play and biospheric natural history?
Intimate awareness of local natural history is the educational foundation for interpreting biospheric patterns.[xii] There are "exemplary biospheric naturalists," scientists whose lifework is to study the ecological, evolutionary, and geological dimensions of earth system science, and whose insights are grounded with their natural history skills. Lynn Margulis and Tyler Volk (see their work elsewhere in this volume), derive their Gaia-based interpretations from a combination of lab-based studies (using sophisticated instrumentation), and avid field observations. Margulis, a remarkable science educator, as well as a great theorist, has written a series of outstanding "five

kingdom" field guides which stress how immersion in field-based observations yields rich insights into environmental evolution. Volk's work emphasizes field-based observations of biogeochemical cycles, linked to observing the interfaces between oceanic, atmospheric, and terrestrial milieus.

Charles Darwin, surely an exemplary biospheric naturalist, is a particularly interesting educational case study. How do Darwin's impeccable field observations, detailed analytical investigations, and insatiable curiosity lead to his expansive theoretical view? The Voyage of the Beagle is the ultimate biospheric field trip, a circumnavigational data-collecting journey, which enabled Darwin to juxtapose data from different habitats, link ornithological and geological observations, and speculate on both spatial and temporal variation. Yet, some of the most compelling reading in Voyage of the Beagle is Darwin's Galapagos material, specifically, his comprehensive experimental observations of the Amblyrhynchus, a "remarkable genus of lizards."[xiii] Here Darwin demonstrates his extraordinary capacity for asking profound ecological questions. His deeply interpretive, sharply analytical questioning process throughout "The Voyage" depicts an attention to detail, ultimately linked to broader patterns. _ The source of Darwin's inspiration and perceptual awareness originates in his outdoor, field-based investigations, the basis for his investigative protocol.

The integration of hands-on field exploration with global travel is the milieu of nineteenth century natural history, and serves as the origins of evolution, ecology, geology, and ultimately earth system science.

Visceral approaches to natural history provide an intimate awareness of species and habitats. The outdoor experience provides a dynamic learning milieu and an inspirational and motivational context. There is sufficient narrative evidence to suggest that outdoor, immersive, field-based studies are crucial to developing the observational capacity that leads to biospheric awareness. Only extraordinary individuals have the motivation and perseverance to pursue such learning on their own. Like all forms of learning, this approach requires supervision, structure, mentoring, and a learning community of like-minded collaborators. What are the implications for environmental learning in schools? How is this approach incorporated into a unified environmental change science curriculum?

Consider the curricular potential of phenology (the scientific study of periodic biological phenomena, such as flowering, breeding, and migration, in relation to climatic conditions). Phenology is essentially the study of the changing of the seasons. People interested in phenology might study plant budding and floral blooms, spring and fall migration of birds or butterflies, and the appearance of insects. Of particular interest, phenological observations can be tracked locally, compared to other data on an annual basis, and then compared between places. You can study changing climatic circumstances, the life cycles of specific plants and animals, and other indicators of biological and climatic change.

In a 2001 article in Science, Josep Penuelas and Iolanda Filella report that although phenological changes differ from species to species, there are geographically diverse, substantial climate-warming induced changes in a variety of habitats. The report cites several dozen studies in peer-reviewed scientific publications indicating short-term phenological change is a global phenomenon, linked to climate warming.

They conclude “as in many areas of environmental science, the key requirement is long-term data sets.”

“Today, thousands of people—professionals and volunteers—record phenological changes all over the world, as do international and national phenological monitoring networks such as Global Learning to Benefit the Environment (GLOBE) or the European Phenology Network. Together with remote sensing, atmospheric, and ecological studies, these data will help to answer the many questions raised by the recently reported climate effects on phenology: What are the limits of the lengthening of the plant growth season and the consequent greening of our planet? Will the (less seasonal) tropical ecosystems be less affected than boreal, temperate and Mediterranean ecosystems? How will different aquatic ecosystems respond? How will responses to temperature and other drivers of global change interact to affect phenology and the distribution of organisms? How will changes in synchronization between species affect population dynamics both in terrestrial and aquatic communities? Will appropriate phenological cues evolve at different trophic levels?"[xiv]

Answers to these questions all require field-based observations, locally gathered data sets, and scores of professional and volunteer observers. What an ideal learning opportunity for science classrooms. Students and teachers can track the weather, keeping daily logs of moisture, sunshine, cloud patterns, and the accompanying landscape changes. These on the ground observations can be linked to satellite photos and other global climate patterns. Gardening serves as a fine introduction to both local natural history and global climate patterns, or as an introduction to plant domestication, evolutionary ecology, and coevolution. Watershed studies teach the movement of water in a landscape, hydrological cycles, and basic geomorphology.

What's crucial is that the outdoor field experience serves as the foundation for pattern-based environmental learning. The visceral, hands-on experience— integrating sensory observations with empirical data collecting—provides an enduring, whole body/mind perceptual approach to learning about the biosphere. It serves as the template for more abstract learning, and deeper explorations of the scaling phenomena that is fundamental to understanding biospheric patterns.

THE VIRTUAL APPROACH: EXPLORING A BIOSPHERIC PATTERN LANGUAGE

As much as environmental educators rue the great numbers of children left inside, there is another side to the increasingly screen-filled hours of childhood. Video games, internet-based communications, cell phones, digital photography, and digital recording programs, have profound conceptual impact on their users. I take a McLuhanesque view—the use of these technologies promotes specific, pattern-based conceptual practice. Concepts of connectivity (networking), scaling (magnification, miniaturization), and complex systems (emergent properties, non-linearity), are all intrinsic to the use of computers and the Internet.

A basic word processing program teaches its users how to instantaneously change the size of text, rearrange text on a page, organize notes and information, create layers of text within text, and how to share text with other users. Any basic digital photography program provides its users with remarkable scaling tools—changing the size and detail of pictures, rearranging them, linking them to music, turning them into slide shows. A power point presentation (when skillfully arranged) can be a magnificent exercise in juxtaposing scale.

Consider a highly popular computer game like The Sims. In this simulation you observe and manipulate a community of individuals who interact differently depending on how you program them. Their social interactions are a lesson in emergent properties. Entirely unanticipated situations can occur. Based on the variables that contribute to this emerging sociology, you can change the social settings and characters accordingly. The Sims is a “simplified simulation” of complex systems.

Any computer user can freely download Google Earth, which gives you the ability to instantaneously find your neighborhood, zoom out to a spinning globe, and then come back again. This is an extraordinary, hands-on experiment in scaling, a global atlas of unprecedented conceptual power.

We have raised an entire generation of computer-oriented, screen-based learners who already have many of the conceptual skills (scaling and networking) that are a prerequisite for biospheric perception. Indeed, in ways that we cannot even imagine, perhaps we are on the verge of a true Gaian generation of educational opportunity. What if you take all the conceptual skills that are so easily learned with the use of computers and the Internet and apply them to pattern-based environmental learning? Exploring the spatial and temporal dimensions of biospheric processes requires scaling and connectivity tools. These are at the fingertips of anyone who has access to the Internet and a computer.

I am suggesting that the scaling, networking, and complex systems skills that are intrinsic to the IGBP Mandate are already being taught by virtue of computer technology and the Internet. Our challenge is to apply those skills with environmental change science in mind. This can only be done through organized curricular approaches, integrated in formal and non-formal educational settings. Imagine if the power of Google Earth became the foundation for a K-16 environmental change science curriculum. Surely elementary school children raised on computers and video games would be comfortable with Google Earth software, as they already have the conceptual ability to intuitively navigate the software with minimal supervision. But what exactly do we ask them to do with Google Earth?

At this moment I am looking out the window of my small cottage in rural, central Maine, watching a dynamic shower pass through the landscape. It's mid-September and the wetland maples have already turned to shades of red and orange. The strong winds accompanying the shower are sending the first wave of brown leaves to the ground. I fully expect a wave of migrating warblers to arrive on tomorrow's northwest wind. My gaze shifts from the window to the laptop. I visit an appropriate website so I can trace the storm on a weather map. I notice the heavy showers from this morning over downeast Maine. I see that the current shower is part of a thin band of rain, and that the heaviest rain has passed. I zoom out on the map and notice there is one more band of showers in New Hampshire, still a few more in New York State, and dry air will soon follow.

But I am not satisfied. I wish that from this same Internet mapping location I could view a wide-ranging series of maps to challenge my ecological curiosity. I would like to view a biogeographical portrait of the changing leaf patterns, or a map of bird, insect, and bat migrations. I imagine collecting daily ecological or meteorological data and inputting them on these maps. I would like to know about other folks who have similar interests and communicate directly with them about what they're seeing.

All of these requests are feasible. They are technologically available, inexpensively provided, easy to use, and absolutely pertinent to the ecological portrait of the planet. How can the use of the Internet and computers and all of the conceptual skills they embody be integrated with hands-on field observations? And how might this integration serve as the basis for a comprehensive environmental change science curriculum?

THE COGNITIVE PERCEPTUAL CHALLENGE: AN INTEGRATED FRAMEWORK FOR TEACHING ENVIRONMENTAL CHANGE

How exciting it would be to organize a conference for an internationally statured group of cognitive theorists, anthropologists, educational researchers, environmental change scientists, classroom teachers, and experts in traditional ecological knowledge who would be convened to organize a k-16 environmental change science curriculum that is developmentally appropriate. Is there an exemplary sequence of instruction and an effective layering of teaching methodologies that coordinates multiple intelligences, childhood and adolescent development, and cognitive development so as to optimize learning about environmental change?

Pending the research agenda necessitated by such a charge, I offer some tentative suggestions, influenced by reading dozens of autobiographical and biographical accounts of "exemplary biospheric naturalists," as well as observing dozens more undergraduate and graduate environmental studies students. These suggestions are merely an example of paths that may facilitate pattern-based environmental learning, based on relative “success stories,” that is individuals, who have always been attracted to studying ecological and biospheric phenomena. My assumption is that the single greatest conceptual challenge in perceiving environmental change is the difficulty in interpreting spatial and temporal relationships. The challenge then is how to develop the ability to observe what is close at hand (intimate awareness of local natural history) and link those observations to biospheric phenomena. How do educators sequence such learning?

Exemplary biospheric naturalists understand how to juxtapose scale, see multiple spatial and temporal dimensions in a landscape, and move conceptually through ecological space and geological time. I suggest there are three interconnected learning approaches that form the basis of this awareness— field-based natural history, interpretive questioning, and an ability to observe patterns at different scalar levels. These are coordinated dimensions of learning, appropriate at all age levels, but with increasing degrees of sophistication. With greater depth of knowledge, more refined perceptual awareness, and greater sophistication of expression, the learner is increasingly capable of discovering and understanding the patterns of environmental change.

For a child or adolescent, field-based natural history often is organized around a natural history collection of some kind, often informed by either a standard (keys and taxonomies) or an improvisational classification scheme.[xv] The child typically plays with this collection, using it as the basis for understanding order and structure. Young naturalists gather these collections by immersing themselves in whatever local habitats are available, often experiencing sensory exploration of the outdoors. These collections are further enhanced with note-taking, visual illustration, or other forms of coding and explanation.

I suggest that natural history collections should be a priority for an integrated environmental change learning sequence. Such collections can take the form of photographs, note taking, mapping, other forms of visual illustration, as well as a "leave no trace" approach to handling natural artifacts. However, what's most important is how these collections become the basis for interpretive classification schemes. It's not enough to collect things and sort them. The purpose of the collection is to heighten your observational awareness—to know what's common and what's rare, to know what can be found here and what can be found there, to observe associations, characteristics, and correspondences.

By an interpretive classification scheme, I refer to a method for asking and answering questions about environmental change. Why do so many birds migrate from the North to South and back again? Why have invasive species become so dominant in this landscape? Why are there more (or less) Monarch butterflies in the garden this year? How much carbon is there in this forest? How much carbon is there in the atmosphere? When is there too much carbon in the atmosphere?

You can't ask questions such as these unless you first know what you are looking at. Collection, identification, and classification are meaningless without interpretation, causation and sequence. Taken together, collection and interpretation lead to observations of scale. The essence of good interpretive questions is the juxtaposition of time and space. How did events over there influence what is happening here? How did events from the past set up the circumstances of the present?

PATTERN-BASED ENVIRONMENTAL LEARNING

Ultimately, to satisfy the learning requirements of the IGBP Mandate, an educational curriculum should aspire to cultivate "pattern-based environmental learning." There are patterns that transcend scale, that emerge in a variety of landscapes and milieus, that link atmospheric, oceanic, terrestrial, and organismic phenomena, and that show the relationship between spatial and temporal variation. The purpose of environmental change science is to detect, interpret, and assess these patterns, and use them as a basis for public policy.

This is the essence of the cognitive perceptual challenge: how to derive a curriculum and a teaching methodology that allows the observer to detect such patterns. My educational hypothesis is that such pattern-recognition is the conceptual foundation for understanding how to cope with complexity and irregularity—the core of the Earth System Science Toolkit as proposed by the IGBP. Understanding non-linearity, thresholds, irreversible changes, indeterminacy, complexity, emergent properties, and scaling effects, requires an environmental change pattern language.

Landscape ecology provides an approach that illustrates concepts of ecological spatial variation (mosaics, gaps, boundaries, corridors, patches, edges, fragments, etc.). How might we elaborate such a pattern language as a template for teaching environmental change science? What are the patterns of connectivity (networks, nodes, and link)? What are the patterns of oceanic and atmospheric circulations (wave, rhythm, flow, fluidity, and fluctuation)? Is there a language to discern various rates of change? What is the relationship between a trend and a discontinuity?

In teaching how to observe environmental change, concepts such as waves, thresholds, and cycles are crucial, and with supervised curricular attention, can be taught throughout the K-16 learning sequence. Waves appear ubiquitously as visual and acoustic representations of rates of change. They reflect frequency, longevity, and periodicity. They can be evaluated mathematically as ratios and rates. A wave is a tangible manifestation of environmental change, observed both virtually and viscerally.

Waves can be used to teach about thresholds. A threshold describes a point, level, sequence, event or flow that causes a dramatic shift in condition. When is a threshold reached? How do you know? At what point does it cause an irreversible condition? Can thresholds be predicted? Is a threshold a discontinuity in a cycle?

A cycle is a continuous and predictable series of relationships within a system, in which the flow and exchange of materials, ideas, or events, move according to repeatable, yet variable patterns. Of particular interest is the relationship between cycles, which may form another system of cycles, or have non-linear emergent properties. School children can observe cycles, and yet it is the depth and complexity of cycles that is so crucial to understanding environmental change.

An integrated cognitive framework for teaching environmental change is an epistemological challenge. It requires a reconsideration of how science is taught, how it's linked to mathematics, language, and the arts, and how it serves to empower students to assess and propose solutions for problems of planetary significance. It starts with emphasizing how important it is to promote ecological awareness and observe natural history. It is deepened and enriched with the use of computers and the Internet and the implicit scaling conceptualizations embedded in their use. It is coordinated with substantive curriculum about the earth system. It is applied by changing the meaning and purpose of schooling.

SCHOOLS TO TEACH ENVIRONMENTAL CHANGE: A "GAIAN GENERATION"

I propose developing an international network of high schools organized around teaching to the IGBP Mandate, designed to train a new "Gaian" generation of environmental change science researchers. Let's design these schools as educational laboratories for teaching environmental change science. Let's organize them so that the schools become nodes in a research network, each becoming a center for long-term environmental change research, with teachers supervising students through community-based projects, linked to partner schools in an international network.

These schools will share both their teaching approaches and results, while compiling databases of biospheric observation. Let's organize art and music instruction, literature and philosophy, social studies and psychology, around environmental change.

As a starting point, consider a field-based approach (linking the visceral and virtual), as informed by the IGBP "earth system science tool kit." For example, using *paleo-science* as the foundation for hands-on field natural history, provide students with the interpretive skills to reconstruct past environments at a variety of spatial and temporal scales and at different organismal levels. Every habitat has a uniquely interesting history. Teach students to reconstruct a habitat using a sequence of time scales, starting with the immediate past to a historical time frame, to a Pleistocene approach and then finally a geological time scale. What creatures walked this place ten million years ago? Were there mountains here or was this place covered with ocean? And then have the students envision what the place will look like in the future (ten years, one hundred years, one thousand years).

The IGBP Mandate stresses *contemporary observation and monitoring*. Teach the students how to understand, develop, and assess indicators of ecosystem health, and to apply those indicators to human well-being. Let the school become the center for assessing ecosystem health. Equip the school with laboratory capabilities to become a regional monitoring center for ecosystem health. Publish those observations on a school website, in local newspapers, as public demonstrations of the vitality and usefulness of such learning.

Emphasize ecological monitoring of the school itself. How much energy does it use? Where does its food come from? How much carbon does the school emit? To what extent is the school a living laboratory for sustainability initiatives? How are those initiatives linked to a broader conception of global environmental change?

Let this monitoring become the basis for integrated regional studies. What environmental issues does your community face? How can the school collect data to better inform public decisions about those issues? What role can the students and their teachers play in informing the public about local environmental issues? How might these regional studies involve local politicians and businesses? Let's elevate our high schools by making them centers for community deliberations about urgent environmental issues.

These regional studies can be the basis of international partnerships and learning affiliations. The IGBP Mandate recommends *global networks* for sharing research data. Schools can have both "sister" schools in diverse regions and affiliations with relevant NGO's, especially those that themselves are nodes in long-term environmental change networks. Students can spend a year at their partner schools. They can be sponsored by science education facilities (museums of natural history) or service organizations (Rotary International). They learn to see their work as international in scope and importance.

Finally, the IGBP Mandate recommends *earth system experimentation and simulating earth system dynamics*. Depending on the scale, one can design "what if" scenario-based curriculum. What will happen to a given place given several different climate change scenarios? How will the habitat change if a particular invasive species travels here? How are these local changes linked to more complex, biome-scale variables?

This is an excellent milieu for using innovative computer software. Some years ago, Electronic Arts released two outstanding computer games, Sim Earth and Sim Life, modeled after their commercially successful Sim City, and then followed by the remarkably successful The Sims. Unfortunately, Sim Earth and Sim Life lacked that same commercial success. However, they were remarkable simulations about earth system experimentation. Sim Earth, designed with Gaian principles in mind, allowed the user to explore a range of atmospheric, oceanic, and biological variables. Sim Life allowed you to tinker with ecosystems at the community and genetic level. What if Electronic Arts and other computer game designers were commissioned by the National Science Foundation to develop a new generation of these simulations, linked to an international network of environmental change pedagogy? Might the NSF partner with the IGBP in developing such software for use in schools, in combination with a comprehensive approach to pattern-based environmental learning?

These suggestions, by way of example, are merely a few of the possibilities that are within the reach of imaginative educators and scientists. They can be applied in diverse educational environments, anywhere on the K-16 learning spectrum, modified accordingly. None of them are beyond the educational capacities or the international learning infrastructure of twenty-first century schools, colleges, and universities. But they do require a mobilization of resources in service of environmental learning. And they require an urgency of purpose, a common awareness that the future of the planet is at stake.

We live at a time when extraordinary learning resources are available for schools everywhere. We are on the threshold of a deeper planetary awareness, an emerging understanding of biospheric dynamics, a comprehensive "science of integration." But none of this will occur without challenging the status quo of science education. We should be planning schools so as to train a "Gaian" generation of learners, students who see the biosphere in every habitat and organism, who are equipped to interpret environmental change, who are keen to observe the natural world, and who know that their very survival may depend on it.

[i] See Richard Louv, *Last Child in the Woods: Saving Our Children From Nature Deficit Disorder*. 2006. Chapel Hill: Algonquin Books. Louv's book triggered a national movement in environmental education, culminating with proposed national No Child Left Inside legislation. See the following website for more information (http://www.naaee.org/ee-advocacy).

[ii] See Page 3 of the IGBP Brochure (http://www.igbp.kva.se/page.php?pid=363)

[iii] The book series is described here: (http://www.igbp.kva.se/page.php?pid=230)

[iv] Steffen, W., Sanderson, A., Jager, J., Tyson, P.D., Moore III, B., Matson, P.A., Richardson, K., Oldfield, F., Schellnhuber, H.J., Turner II, B.L., Wasson, R.J., Global Change and the Earth System. Berlin: Springer-Verlag, 2004, p. 264.

[v] Ibid., p. 265

[vi] Ibid.
[vii] Ibid., p. 267.

[viii] Ibid., p. 269.

[ix] Ibid., p. 274.

[x] Ibid., p. 277.

[xi] Ibid., p. 279.

[xii] Mitchell Thomashow, *Bringing the Biosphere Home: Learning to Perceive Global Environmental Change*. Cambridge: The MIT Press, 2002.

[xiii] Charles Darwin, *The Voyage of the Beagle*. New York: Penguin, 1989, p. 282-285.

[xiv] Josep Penuelas and Iolanda Filella, Responses to a Warming World. Science, Volume 294, October 26, 2001, p. 795.

[xv] For an interesting anthropological approach to collections, natural history, and the organization of ecological knowledge, see Scott Atran, *The Cognitive Foundations of Natural History: Towards an Anthropology of Science*. New York: Cambridge University Press, 1993.