Ecological Systems Thinking☆

David W Orr, Oberlin College, Oberlin, OH, United States
Valentina Niccolucci and Simone Bastianoni, University of Siena, Siena, Italy

Introduction

The greatest discovery of the past century had nothing to do with nuclear physics, or computer science, or genetic engineering. Rather it was the discovery of the essential connectedness of life and environment. The primary discipline of interrelatedness is ecology beginning with the work of Ernst Haeckel in the nineteenth century. The discovery of evolution extended the awareness of our connections to life in time and more extensively to the story of life on Earth. Fields such as ecology, general systems theory, systems dynamics, operations research, and chaos theory added details and theoretical depth, but with each advance in the precision and extent of knowledge the larger story remained the same. Living systems are linked in food webs and ecological processes into larger systems whether called the noosphere, biosphere, ecosphere, or Gaia. The boundaries between life forms and between what we take to be living and nonliving things shift and sometimes morph into other forms and processes. In Earth systems, small changes can have large effects somewhere else and at some later time. Natural systems and the world made by humans are intertwined in more ways than we can possibly imagine. The result is less like a machine than it is like a web stretching across all life forms and back through time. The effects of human actions millennia ago still ripple forward, intersect with other changes sometimes amplifying, sometimes diminishing in intensity. Some human-wrought changes, such as deforestation and saline soils throughout much of the Middle East, are permanent as we measure time.

Nothing in the preceding paragraph is particularly new or controversial. But the idea of interrelatedness has yet to take hold of us in a deep way. We still live in thrall to a world created by Descartes, Bacon, Galileo, and their heirs who taught us to dissect, divide, parse, and analyze by reduction but not how to put things back together or see the world as systems and patterns. The results were intellectual power without perspective so that, in time, overspecialization became a kind of a cultural disease. There are many reasons why things do not change long after their deficiencies are apparent: the inertia of habit, economic inconvenience, the preservation of reputation, and intellectual laziness. But the most important barrier to change remains simply that science and the technology it spawned works and is a powerful presence in our daily lives. Automobiles, airplanes, the cornucopia evident in every supermarket, miracle cures, and the wonders of computers and communications are a constant reminder of the powers of a particular kind of science and a promise of things to come. That much of our technology also “bites back” and incurs costs that we do not see is mostly lost on us. Many live in what has been called a “consensus trance,” believing that things will go well for us, which is to say that progress will continue indefinitely. Beneath such ideas is the faith that nature does not “set traps for unwary species,” as biologist Robert Sinsheimer once put it or that progress itself is not a self-made trap.

There have always been skeptics, however. Toward the end of his life, H. G. Wells could see no grounds for hope. More recently, Joseph Tainter, Martin Rees, and Jared Diamond have expressed doubts about our longevity based in no small part on their views of scientific progress. Rees, for example, believes that our odds of making it to the year 2100 are no better than fifty-fifty. Diamond has cataloged the reasons why past societies have collapsed and they bear more than a passing resemblance to our present behavior. James Lovelock, coauthor of the Gaia hypothesis, believes that we are approaching a climate-tipping point somewhere between 400 and 500 ppm CO_2 in the atmosphere after which “nothing the nations of the world do will alter the outcome and the Earth will more irreversibly to a new hot state.” In various ways, each of these attributes our vulnerability to the failure to see systems, patterns, and to exercise foresight. As a result, we stumble toward a time of severe climate destabilization, biotic impoverishment, and ecological surprises.

The failure of ecological knowledge to penetrate very deeply into the larger society and its decision-making systems ought to be a matter of grave concern. The early work of ecologists Howard and Eugene Odum on the productivity of salt marshes, for example, may have slowed but certainly did not stop the juggernaut of development that has severely damaged coastal ecosystems virtually everywhere. Similarly, we know a great deal about the services of natural systems and the impossibility of duplicating these by human means. Yet the drawdown of natural capital and the destruction of ecosystems are still trumped by narrow short-term concerns of profit and economic expansion. Sometimes the costs of ecological folly become starkly apparent as they did following hurricane Katrina in the fall of 2005 in which the damage done by a class III hurricane (at landfall) was amplified by the removal of mangroves and coastal forests that would otherwise have absorbed much of its energy and dampened the destructive

☆*Change History*: March 2018. S Bastianoni, editor in chief of this section of the Encyclopedia of Ecology, has updated the “Ecological Systems Thinking” chapter with the coauthor V. Niccolucci. Section “Applied System Thinking” has been integrate to better emphasize the importance of Systems thinking within sustainability science and the methods or indicators used to appraise it. Section “Environmental Education” has been updated with a paragraph dedicated to the central role played by Education within the SDGs framework proposed by UN in 2015. Edited entries were also added in Further Reading.

This is an update of D.W. Orr, Ecological Systems Thinking, In Encyclopedia of Ecology, edited by Sven Erik Jørgensen and Brian D. Fath, Academic Press, Oxford, 2008, pp. 1117–1121.

 doi:10.1016/B978-0-12-409548-9.11135-2

effects. That, too, was known in many circles but did not have much effect on the policies that prevailed along the Gulf Coast, where oil extraction, commerce, and gambling ruled the day.

Public attitudes toward science are often undermined by poor education, inadequate public funding, and, sometimes, religious dogma. In the United States, evolution, once thought to be an established part of science, is hotly contested as just another "theory" by advocates of "intelligent design." The scientific evidence about human-driven climate change is indisputable, but ignored or underestimated even when alternatives are economically advantageous. The results are evident in the considerable data describing ecological deterioration virtually everywhere and the failure to seize better alternatives as well. Law based on ecological knowledge and the hope that we might calibrate our public business with the way the world works as a physical system is under constant assault. Evidence about the health and ecological effects of toxins is downplayed. Public access to information about the release of toxics is restricted. The result is a significant gap between what is known about how the world works as a physical system and the public policy in every country. The cumulative result is that we are much more vulnerable to ecological ruin and extreme events than we might otherwise be.

What can be done with ecological knowledge? One answer is that ecology as a science ought to do what it has been doing, which is to say document the deterioration of ecosystems in ever finer detail. Ecology, the argument goes, is a science and its practitioners ought to maintain their credibility as scientists and not assume the role of advocates and risk losing their credibility even when they recognize folly disguised as public policy. If that is the future of the discipline it will, I think, flourish for a time while the human prospect withers.

There is, however, another perspective on the uses of ecology. Paul Sears in 1964 and later Paul Shepard and Daniel McKinley in 1969 once called the discipline "the subversive science." They proposed ecology as an integrative discipline, "a kind of vision across boundaries" and a "resistance movement"—an alternative to being "man fanatic." Ecology in their view "offers an essential factor … to all our engineering and social planning." In their perspective, the world needs to know what ecologists know and needs to take that knowledge seriously enough to transform the ways by which we provision ourselves with food, energy, materials, shelter, and livelihood. Ecology as a subversive science would be integrated with building, industry, agriculture, landscape management, economics, and governance. In short, the idea of interrelatedness would move from the pages of obscure scientific journals out to the main street, and into board rooms, editorial offices, courtrooms, legislatures, and classrooms. It would progress from being just one more interesting but obsolete idea to become the design principles for a better world—the default setting for everyday behavior.

Applied Systems Thinking

In this regard, the news is guardedly optimistic. The art and science of high-performance building is growing. The result is a new generation of buildings that require a fraction of the energy of conventional buildings, use materials screened for environmental effects, minimize water consumption, and are landscaped to promote biological diversity, moderate microclimates, and grow foods. The best of these are highly efficient, powered substantially by sunlight and feature daylight, water recycling, and interior green spaces. They are a finer calibration between our five senses and the built environment and tend to promote higher user satisfaction and productivity. The costs of building green, as it turns out, are not necessarily higher than conventional buildings while having lower operating costs. The goal is to design buildings as whole systems, not as disjointed components. The green building movement is now a worldwide movement and is transforming the practice of architecture, landscape architecture, and engineering. It could, in time, transform the design of communities and cities as well.

Business, too, is beginning to go green. The best example of a well-run environmentally sensitive business is that of Interface, Inc., a global manufacturer of carpet tiles and raised flooring. In the mid-1990s, company founder and CEO, Ray Anderson, decided to transform the company to eliminate waste and carbon emissions. Interface launched a pioneering effort to develop carpet products that were returned to the company as a "product of service" not otherwise discarded in a landfill. Interface now leases carpet to its customers and takes it back to be remade into new products, thereby eliminating much of the petrochemical sources at one end and waste at the other. In the past decade, the company has eliminated 56% of its carbon emissions and is on track to becoming carbon neutral. The model for the company is consciously that of ecology all the way down to carpet products that mimic a forest floor. Interface is not alone. Other companies like Wal-Mart and DuPont are beginning to transform themselves as well. Some day, perhaps, all business will be powered by sunlight with materials cycles that mimic the circular flow of nutrients in ecosystems.

In agriculture, Wes Jackson, cofounder of the Land Institute, is pioneering the development of natural systems agriculture. The goal is to model agriculture on ecological systems such as forests and prairies. If successful, the end product will be agricultural polycultures of high yield perennials, long thought to be a biological impossibility. The early results, however, have confirmed Jackson's hypothesis that the two can be stitched together, thereby eliminating a great deal of fossil energy and soil erosion.

Materials science is a fourth area in which ecology is being taken seriously. Nature, as chemist Terry Collins has noted, uses only a relatively few ingredients while industrial chemistry uses virtually the entire periodic table, creating ecological havoc. The field of biomimicry has grown in response by studying how nature works in fine detail. Natural systems are a carnival of color, for instance, but nature does not use paints. To answer such questions, Janine Benyus, author of *Biomimicry*, is developing a database of the ways nature works to filter, reduce, recycle, color, purify, form, and join—all done without the use of toxics and fossil fuels and all of it biodegradable. The result could be a transformation of materials and industry that dramatically reduce pollution and energy use.

Systems thinking is also fundamental to provide useful support in addressing the complex challenges that sustainability science needs to solve. With the introduction of this concept, many interesting holistic methods or indicators have been proposed to appraise the human dependence from Nature and its resources, and to support policy making decisions. Among others, there are some methods that are widely used for the simplicity and the immediacy of their message, that is, ecological footprint accounting, emergy evaluation, material flow accounting, and (partially) life cycle assessment (LCA), to make some examples.

All these methods have different perspectives, rationales, pro and cons, but a common *modus operandi*, that is, all inputs needed for the functioning of the analyzed system are converted into a common unit. The unit is the element of diversity among the methods: it is expressed in term of solar emergy joules needed, directly and indirectly, to produce and input or product (in emergy evaluation), of biologically productive land needed to make available life supporting resources or to absorb wastes (ecological footprint), etc. In this way, flows of different kinds can be accounted for, at the same time, in order to make a picture of the system according to systems thinking.

In these examples and elsewhere, the science of applied ecology has begun to seriously influence decisions and behavior and the evolution of architecture, engineering, materials science, agronomy, urban planning, and economics. The driving force is partly economic (to reduce the costs of unnecessary energy, materials and water use) and partly a matter of conviction (that it is wrong to leave a legacy of ruin behind us). While promising, such measures are necessary but insufficient. Ecological thinking, in one way or another, must become a more central part of global society and this is the task of education.

Environmental Education

The idea of specifically environmental education entered the public discourse in the late 1960s. Among the recommendations of the Stockholm Conference in 1972 was to "establish an international program in environmental education." UNESCO and UNEP subsequently undertook to prepare curricular materials, establish priorities, develop pilot projects, and organize meetings. The result was a UN-sponsored Conference at Tbilisi, Georgia, in 1978 that produced a consensus statement including the words:

Environmental education … should constitute a comprehensive lifelong education … it should prepare the individual for life through an understanding of the major problems of the contemporary world, and the provision of skills and attributes needed to play a productive role toward improving life and protecting the environment with due regard given to ethical values. By adopting a holistic approach, rooted in a broad interdisciplinary base, it recreates an overall perspective which acknowledges the fact that natural environment and manmade environment are profoundly interdependent….

The Tbilisi Conference produced 41 recommendations spanning the needs for environmental education between developed and less-developed countries. In the subsequent decades, initiatives, including those spawned by Agenda 21 **(see article 36)** and discussions about the Earth Charter, have advanced the discussion of environmental education into a major part of the dialog about the role of education relative to the human prospect. There is no serious discussion about the transition to sustainability launched by the Brundtland Report in 1987 that does not include changing the goals and methods of education. From Tbilisi (US Department of Health, Education, and Welfare, 1978) and Talloires (UNESCO, 1977), and subsequent international gatherings, a strong consensus about the importance of environment in higher education is clearly apparent.

Despite considerable progress, both conceptually and practically, there are serious differences about the goals and methods of environmental education that reflect and, in some ways, amplify larger disagreements about education. At the lowest level, there is a general consensus that the young ought to know something about how nature works as a physical system—the rudiments of biology and planetary science. There is considerably less agreement about how this should be incorporated into the standard curriculum or at what level. Most elementary schools include curricular components such as "project learning tree" or "Wet and Wild" that introduce children to what was once called natural history along with some field experience and practical outdoor skills. But the later inclusion of values or discussion about the causes of environmental ills has often been controversial, especially when it has led to questions about conventional economic or political wisdom.

In important respects, all education is environmental education, that is, by what is included or excluded students are taught that they are part of or apart from ecological systems. The standard, discipline-centric curriculum may have contributed to a mindset that helped to create environmental problems by separating subjects into boxes and conceptually by separating people from nature. As a result, graduates are often ignorant of ecological relationships or why they are worthy of consideration. Not surprisingly, the first response to proposals for environmental education attempted to accommodate environmental issues and ecology into formal education as a kind of add-on. More radical critics proposed that formal education ought to be reformed along ecological lines, raising another and no less contentious issues. From either perspective, environmental mismanagement and the larger discussion of sustainability raise questions about the meaning of human mastery over nature, or more accurately as C. S. Lewis once put it: what does it mean for some men to control other men through the mastery of some parts of nature? What is the core knowledge of the environment that ought to be standard in an educational curriculum? At the heart of such questions are important differences about what it means to be human, what part of that definition ought to remain inviolable, and about the manipulation of natural systems through technological means such as genetic engineering. Is the problem, in other words, one in education or one of education?

What can be said with certainty is that public schooling and higher education have been underachievers in the task of inculcating essential knowledge about the environment. Public opinion surveys show high levels of support for environmental quality but little ecological knowledge. In the words of one typical survey, people have acquired a "substantial familiarity with environmental issues, but [have] a long way to go in developing a working environmental/energy knowledge." Much of what people know about the environment is derived from television in bits and pieces and not through direct experience with nature or through cultural transmission.

One particularly encouraging aspect is the development of environmental education in institutions of higher education. Stemming from innovations in the 1980s, a vibrant campus ecology movement has emerged in Europe, Australasia, and the United States, along with a wide discussion of sustainability of educational institutions. Beginning with the studies of college food, energy use, and pollution, the movement has grown in subsequent decades to a worldwide scale. Hundreds of colleges and universities globally have organized efforts to systematically reduce energy use, water consumption, and material flows. Campus sustainability and climate stability have come to the center of institutional planning, purchasing, and construction. Beginning in the late 1990s with the advent of means to promote and measure environmental performance of buildings, the construction of academic facilities is undergoing a rapid revolution. Green or high-performance building standards are increasingly regarded as necessary to reduce energy and maintenance costs as well as laboratories for research and education. Many of the problems of sustainability—ecological design, applications of solar energy, water purification, food production, ecological restoration, and landscape management—can be studied in buildings and adjacent landscapes at a scale that is both significant yet manageable. Given recent developments on many campuses, it is not inconceivable that educational institutions at all levels will one day become models of ecological design mirroring the larger solutions necessary to the transition to sustainability.

A decisive step forward in the awareness of the importance of education in sustainability has been done in 2015, when the state members of the United Nation approved the so-called sustainable development goals (SDGs), a set of 17 goals and 169 target, to support the country transition toward sustainable development, by 2030. The SDGs framework recognize a central relevance to Education and include it in most of the 17 SDGs. In particular, the SDG4 is specifically aimed to "Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all" and the target 4.7 entitled "Education for sustainable development and global citizenship" is dedicated to a sustainable and equitable education "*by 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and non -violence, global citizenship and appreciation of cultural diversity and of culture's contribution to sustainable development*."

Education is specifically mentioned also in other targets: target 12.8 (*by 2030, ensure that people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature*) and target 13.3 (*Improve education, awareness —raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning*) are the most relevant among the others.

Summary

In the decades since the Stockholm Conference in 1972, environmental education has emerged as a significant component of education virtually everywhere in the world. It has, for the most part, flourished at all levels of education. There are magazines and journals such as *Sustainability in Higher Education*, professional associations, and regular conferences. It is not difficult to imagine all of this as the start of something like an ecological enlightenment emerging in the decades or centuries ahead. But no such thing is certain. If education is to be midwife to a deeper, broader, and sustainable transformation, it will have to surmount serious challenges.

See also: Human Ecology and Sustainability: System Sustainability; Ecosystem Services Evaluation

References

UNESCO (1977) *Intergovernmental Conferenceon Environmental Education, Tbilisi (USSR) 74–26 October 1977*. Final Report.
US Department of Health, Education, and Welfare Toward an Action Plan, Education, and Welfare, 1978. A Report on the Tbilisi Conference on Environmental Education. Washington, DC: US Government Printing Office.

Further Reading

Barlett, P., Chase, G., 2004. Sustainability on campus. Cambridge, MA: MIT Press.
Benyus, J., 1998. Biomimicry. New York: William Morrow.
Bowers, C., 1993. Education, Cultural Myths, and the Ecological Crisis. Albany, NY: SUNY Press.
Bowers, C., 1995. Educating for an ecologically sustainable culture. Albany, NY: SUNY Press.
Corcoran, P., Wals, A., 2004. Higher education and the challenge of sustainability. Dordrecht, The Netherlands: Kluwer Academic.
Coyle, K., 2005. Environmental Literacy in America. Washington, DC: The National Environmental Education & Training Foundation.
Creighton, S., 1998. Greening the ivory tower. Cambridge, MA: MIT Press.
de Chardin, T., 1965. The phenomenon of man. Harper Torchbooks: New York.
Fischetti, M., 2001. Drowning New Orleans Scientific American. In: 76–85 (October).
Kuhn, T., 1963. The structure of scientific revolutions. Chicago: University of Chicago Press.

Lovelock, J., 2006. The revenge of Gaia. London: Penguin Books.
Lovelock, J., 1979. Gaia: A new look at life on Earth. New York: Oxford University Press.
Lovins, A., 2005. Winning the oil endgame. Snowmass, CO: Rocky Mountain Institute.
Meadows, D., 2008. Thinking in systems—A primer. UK: Earthscan.
Oakeshott, M., 1989. The voice of liberal learning. New Haven, CT: Yale University Press.
Orr, D., 1992. Ecological Literacy. Albany, NY: Suny Press.
Orr, D., 1994. Earth in Mind. Washington, DC: Island Press.
Orr, D., 2006. Design on the edge. Cambridge, MA: MIT Press.
O'Sullivan, E., 2005. Millennium Ecosystem Assessment Report vols. 1–5. Washington, DC: Island Press.
Rees, M., 2003. Our final hour. New York: Basic Books.
Sears, P., 1964. Ecology—A subversive subject. Bioscience 14 (7), 11–13.
Shepard, P., McKinley, D., 1969. The subversive science. Houghton Mifflin: Boston.
Sinsheimer, R., 1978. The presumptions of science. Daedalus 107, 23–36.
Sobel, D., 1996. Beyond Ecophobia. Great Barrington, MA: The Orion Society.
Steffen, W., Sanderson, A., Jäger, J., *et al*., 2004. Global change and the earth system. Berlin: Springer.
Tenner, E., 1996. Why things bite back: Technology and the revenge of unintended consequences. Knopf: New York.
Union of Concerned Scientists World Scientists, 1992. Warning to Humankind. Boston: Union of Concerned Scientists.
United Nation (UN), 2015. Transforming our world: The 2030 agenda for sustainable development. General assembly. Seventieth session, A/RES/70/1.
Vernadsky, V., 1998. The biosphere. New York: Springer.
Washburn, J., 2005. University INC: The corporate corruption of higher education. Basic Books: New York.
Wright, R., 2005. A short history of progress. New York: Carroll & Graf.
Wright, T., 2004. Evolution of sustainability declarations in higher education. In: Corcoran, P.B., Wals, A.E.J. (Eds.), Higher education and the challenge of sustainability. Dordrecht, The Netherlands: Kluwer Academic, pp. 7–19.