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Integrative environmental research and education

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Das Forschungszentrum Nachhaltigkeit (artec) – Kurzportrait

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- **Was kann erkannt und getan werden, um die Verletzlichkeit sozialer und natürlicher Systeme zu reduzieren?**
- **Was ist nötig, um deren „Abwehrkräfte“ zu steigern?**

Die Hauptkompetenzen liegen in den Bereichen: Arbeitswissenschaft, Technikfolgenabschätzung und Technikbewertung, Managementlehre, Umweltsoziologie und Umweltpolitik.

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2. Nachhaltigkeitsmanagement und Unternehmensentwicklung

Effizienz und Nachhaltigkeit; Probleme der strategischen Planung nachhaltiger Unternehmensentwicklung und Kooperationsperspektiven.
(Georg Müller-Christ, Brigitte Nagler)

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(Hellmuth Lange, Ines Weller)

Integrative Environmental Research and Education

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Abstract

This paper is based on the premise that without integration of knowledge across disciplines, without integration of research with education, and without dialogue between science and stakeholders, opportunities to bound the complexity of environmental processes will be missed. Without adequate integration, solutions to environmental challenges will be partial at best, and new problems and unintended impacts will likely arise that prevent natural resource, economic and social systems from flourishing. On that premise, the paper explores what specifically needs to be integrated, and why, how that integration may occur, and what emotive, social and institutional conditions need to be achieved that may foster integration.

Key Words

Environmental science, integration, environmental education, complexity

Biography

Matthias Ruth holds the Roy F. Weston Chair of Natural Economics at the University of Maryland, USA, where he also directs the Center for Integrative Environmental Research and co-directs the Engineering and Public Policy program. He is a visiting professor at artec, Institute for Sustainability, University of Bremen, Germany. His research focuses on dynamic modeling of natural resource use, industrial and infrastructure systems analysis, and environmental economics and policy. His theoretical work heavily draws on concepts from engineering, economics and ecology, while his applied research utilizes methods of non-linear dynamic modeling as well as adaptive and anticipatory management.

1. Introduction

The history of environmental research and education is long and varied. Great strides being made through both single-disciplinary and interdisciplinary efforts in the natural, engineering and social sciences. As the complexity of environmental systems becomes apparent through these efforts, the research endeavor and education plans have recently been re-thought, and in some cases re-designed, to do justice to that complexity. At the same time, as the ramifications of human actions for environmental quality are better understood, environmental research and education have often taken on an advocacy role, cautioning of impending, long-term consequences of investment and policy choices, and working closely with stakeholders from the public, private and nonprofit sectors to better understand and guide the decisions of households, firms and government agencies.

Yet, despite decades of efforts by government agencies, funders and researchers to promote interdisciplinarity and dialog with stakeholders, significant room for improvement persists. In a US National Science Foundation report on environmental research (NSF, 2005), for example, Sandy Andelman, then Deputy Director of the National Center for Environmental Analysis and Synthesis, is quoted to have said:

"There is not a strong culture of multi-investigator, integrated planning of research… Ecology, and other related disciplines have amassed vast stores of relevant information, but because this information is in so many different forms and formats, and many different places, it is not accessible or useful."

Andelman focuses on linking disparate and diffuse information in ecology and related disciplines more systematically – one important pre-requisite for effective multi-investigator, interdisciplinary research. However, for environmental research to adequately deal with the complexities it addresses, it needs more than just better information sharing. What is required for the researchers and educators to be effective are common goals, substantive dialog, adequate funding, and other institutional infrastructures. With it may come an integration of diverse pieces of knowledge in order to better bound the complexity of environmental processes and influence them through adequate investment and policy decisions.

This paper concentrates on the opportunities for, and obstacles to, integrative environmental research and education, which in many ways are part and parcel of society's quest for sustainable solutions for resource valorization and regeneration. The following two sections of this paper address, respectively, the questions of "Integration of what?" and "Integration for what?". These sections are followed by reflections on the purposes of integration and suggestions for how integration may be promoted. The paper closes with a brief summary and conclusions.

2. Objects of Integration

2.1 Research

My arguments for integrative environmental research and education start with the premise that without integration and dialogue, knowledge will be incomplete, solutions to environmental challenges will be partial at best, and new problems and unintended impacts will likely arise that prevent natural resource, economic and social systems from flourishing. Based on the object and purpose of study, different disciplinary building blocks may be integrated to provide a more in-depth and/or a better systems representation of the issues at hand.

Frequently suggested candidates for bases of integration are thermodynamics, ecology and economics. Each of them are briefly discussed here individually and in their relation. More extensive elaborations can be found elsewhere (Daly and Umaña, 1981; Proops, 1985; Mirowski, 1989; Ruth, 1993). Other candidates as bases for integration include cognitive neuroscience, molecular genetics, evolutionary biology (especially sociobiology) and human ecology, which, some content, will together provide fundamental, new insights into linkages between genetic evolution and cultural evolution (see, e.g. Wilson, 1998 a, b), and thus into the human-environment relation.

Thermodynamics, ecology and economics address, inter alia, material and energetic, life system, and human decision aspects of any environmental process (Ruth, 1993). Thermodynamics deals with material and energy flows, and with the changes in the quality of those flows as natural processes occur. Its basic laws govern all processes on earth. The First Law of Thermodynamics states that matter and energy can neither be created nor destroyed. This law identifies therefore the overall material and energetic budgets for any process. The Second Law, or Entropy Law, states that any natural process is always accompanied by a decline in the quality of energy, i.e. an increase in entropy. This law establishes unidirectionality and irreversibility of energy flows from high to low quality. It describes the limits for change at all levels of system organization, from a cell or machine to an entire ecosystem, industry or economy.

Ecology has, to some extent, built on insights from thermodynamics to better understand how materials cycle in ecosystems and how energy flows through ecosystems. It has also provided insights into the requisite linkages among material cycles, energy flows and ecosystem structure, function, and change (Odum, 1971; Ulanowicz, 1972, 1986; Kay, 1984; Ulanowicz and Hannon, 1987).

Economics deals with the optimal use of scarce resources to meet the needs of humans. In many ways that means that economists study how goods and services are produced and allocated, and what institutions (markets, regulation, etc.) may need to be put in place to achieve optimality. The key concepts in economics are the concepts of opportunity costs, substitution and time preference (Ruth, 1993). Opportunity costs are the costs associated with foregone actions. Minimizing those costs provides the guide for rational decision making. The concept of substitution permeates both the analysis of household and firm behavior, suggesting that typically more than one set of goods and services or more than one set of inputs into the production process can be used to achieve desired results. While limits on substitution bound the realm of human action, opportunity costs help choose within that realm. Since decisions typically have ramifications over time, benefits and costs that accrue in the future may need to be valued, and alternatives be ranked, from today’s perspective. The concept of time preference establishes how future benefits and costs translate into such current values. A commonly chosen means for that translation is a discount rate (Lind et al., 1982).

Biology and ecology have not only borrowed extensively from thermodynamics but also introduced a wide range of concepts and tools from economics, for example for the development of optimal foraging theories (Pyke, 1984), input-output analysis to describe food webs (Hannon, 1991), optimal control theory to model energy allocation by plants (Hannon and Ruth, 1997), cost-benefit optimization and discounting (Carpenter et al., 1999), and more. Likewise, economics has borrowed from biology and ecology – not only where it came to better describe the dynamics of reproducible natural resources such as fish populations or forests (Fisher 1981). Especially those parts of ecology that were influenced by nonequilibrium thermodynamics, such as applications of chaos and complexity theory, have made it into strands of modern economics (Leydesdorff et al., 1994; Bak, 1996). Most frequently, though, the "borrowing of concepts" was in the form of analogies (Ruth, 1996; Mulder and van den Bergh, 2001) instead of empirical applications.

Building on the conceptual relationships among thermodynamics, ecology and economics (Figure 1), a new "environmental economics" has emerged that sees the economy as an integral part of the ecosystem, explores the mutual constraints that changes in ecosystems and the economy impose on each other, and draws conclusions for optimal allocation of scarce resources not just with respect to the economy but with respect to the larger system within which the economy is embedded (Boulding, 1966; Georgescu-Roegen, 1971; Daly, 1977). This new economics, which goes under the rubric of "ecological economics", has considerably contributed to the debate about sustainable resource use (Costanza et al., 1997).

Another new field of research that has been emerging in the last decade is industrial ecology (for an extensive overview see, e.g., Ayres and Ayres, 2002). Similar to ecological economics, the roots of industrial ecology lie in thermodynamics, ecology and economics (Figure 1). However, industrial ecology draws more heavily on engineering than economics, and historically has focused more on industrial processes than, e.g. on consumption. Recent developments in industrial ecology, though, have broadened the approaches and methods to embrace a broader systems view (Jelinski et al., 1992). As a result, the boundaries between the two new fields of ecological economics and industrial ecology have somewhat become blurred.

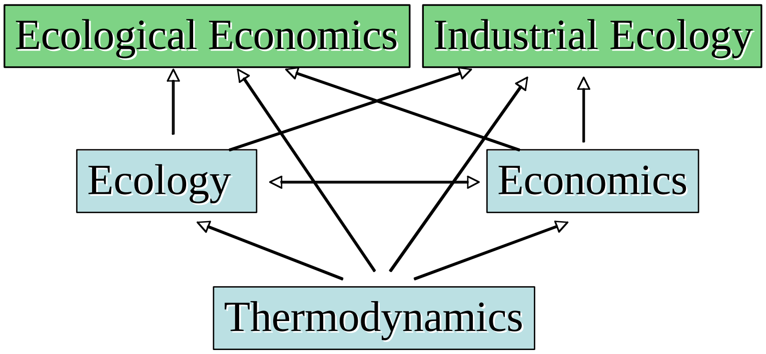

Figure 1. Influences between, and emerging integration of core disciplines in environmental research.

The development of ecological economics and industrial ecology are but two instances in which recent efforts to integrate disciplines have helped generate shared data sets and models. Examples include data sets and models used to value the contributions of ecosystems to economies (e.g. Farber et al., 2002; Boumans et al., 2002) and the vast range of life cycle inventories and analyses available to trace material and energy contributions associated with the production, use, disposal, and recycling of goods. Additionally, entire communities of researchers and practitioners developed who share tools, standards, agendas, and goals, and are becoming connected and visible through the establishment of their own societies and journals. While some of the work in these new fields remains heavily influenced by single disciplines, they distinguish themselves through an increasingly interdisciplinary character, and in some instances have created cross-fertilization among disciplinary approaches to the point that old concepts, tools and models have fused into new ones that can clearly be called integrated (see, e.g. Tiezzi, 2002; Jorgensen and Svirezhev, 2004).

2.2 Education

A second major opportunity for integration concerns the field of (environmental) education. To the extent that this means increasing the familiarity of students with the world views and tool boxes of multiple disciplines, it has been covered above. If the goal is to advance the development of communities of researchers that can effectively work across disciplinary boundaries, and who may even bridge the science-society divide, more is needed than simply exposure to what lies on the other side. Students will need the ability to translate knowledge from one field to another, immersion and hands-on experience in problem solving settings, as well as the prerequisite written and verbal communication skills. The integration of education with research and application itself is not new, though the intensity with which it is being pursued is.

As with environmental research, government agencies, funders and universities alike increasingly place emphasis on re-shaping environmental education. Major focal areas are multidisciplinarity and project-based learning. The latter often begins during the early undergraduate years, not just with work for distinction, but with entire research projects designed and carried out by groups of students under the supervision of faculty. Many large campuses have undergraduate research programs that span over several semesters, some of which regularly produce patent-disclosure applications and peer-reviewed publications by undergraduates and their mentors.

Interdisciplinary research-based education at graduate levels is much more common than for undergraduates in the US, though over the last three decades it, too, has received heightened attention through the creation of entirely new degree programs. Examples abound of joint degree programs that combine, for example, a life science with economics or policy. Fewer exist that merge engineering with policy. In all cases, educators and students alike find it both challenging, and often rewarding, to create a coherent course of study that meets disciplinary criteria and at the same time transcends disciplinary boundaries, creating something new and distinct, rather than simply an assemblage of existing courses. The challenges become even larger, and the success stories fewer, when the educational mission and plan include as a requirement clear practice-oriented elements, such as real-world problem solving exercises in the public, private or non-profit sectors.

Interdisciplinary environmental education has not only focused on college pre- and post-graduate education, but also begun to significantly influence doctoral-level and K-12 education. For a Ph.D., the efforts of redefining what constitutes a course of study worthy of a doctorate are often stymied by the very nature of a *uni*versity – diversity in approaches and integration of insights from across disciplines is often seen as an impediment to advancing discipline-specific knowledge. The traditional structure of universities, with their colleges and departments, is rarely amenable to relinquishing "quality control" as traditionally defined. Some institutions, though, have begun to loosen up that structure, for example, with the organization of "research groups" or "field committees" – faculty from different backgrounds coming together and declaring a new area of research as worthy a Ph.D. – as has happened, for example, at Berkeley, the University of Maryland and elsewhere.

Increasingly, government agencies and other funders of research ask that universities close the loop and contribute to education of K-12 science teachers and their students, as well as to curriculum development. This is one of the venues through which societal relevance of basic research is enforced – a topic which I discuss in some more detail next.

2.3 Science and Society

So far, I have talked about integration across two dimensions: integration of disciplines and integration of research and education. The third dimension across which we may want to achieve integration is across the science-society divide. One of the early proponents of actively closing that gap is Jane Lubchenco (1998), who forcefully argued that

"[a]s the magnitude of human impacts on the ecological systems of the planet becomes apparent, there is increased realization of the intimate connections between these systems and human health, the economy, social justice, and national security. The concept of what constitutes 'the environment' is rapidly changing."

Lubchenko calls for a new social contract for science, in which scientists actively seek out and address the most urgent needs for society, then communicate their knowledge and understanding widely in order to inform decisions of individuals and institutions, while all along exercising good judgment, wisdom and humility (Lubchenco, 1998). In this new contract, the privilege to seek answers to pressing problems is returned by "speaking truth to power", where it is acknowledged that the scientists' voice is only one of many in the societal discourse, that other "truths" may be contributed and deciding, and that the centers of "power" themselves may be defined in the process.

Others have followed, in their own ways, to place emphasis on the societal roles of their disciplines and professions. For example, a recent US National Academy of Engineering report on *The Engineer of 2020: Visions of Engineering in the New Century*, states that:

"Engineering will only contribute to success if it is able to continue to adapt to new trends and educate the next generation of students so as to arm them with the tools needed for the world as it will be, not as it is today" (National Academy of Engineering, 2004).

To the extent that this quote is representative, engineers may no longer see themselves as the drivers behind change, but as respondents. The change to which they see themselves respond is societal and environmental. Recently created degree programs in Engineering and Public Policy are very much in synch with this call for engineers to move beyond a reactive role of problem solving, where problems are defined by others, to a proactive role of participating in decision making processes.

3. Purposes of Integration

Now, that I have addressed the question of "Integration of what?", let me turn to the question about "Integration for what?". From the discussion above at least two goals for integration emerge – creating new knowledge about complex environmental systems and using this knowledge to stimulate debate about (past, current and potentially impending) environmental issues. Conversely, if the contribution of scientists to the debate indeed occurs in the form of active dialog, then that dialog itself may reveal issues and needs for knowledge that can stimulate new science.

Complexity may be defined as a property of a technology – broadly conceived – and measured by the information required to fully describe that technology, including its impacts on the environment (Ruth and Bullard, 1993; Ruth, 1995). For example, production and consumption processes transform energy in order to ultimately change the state of materials into forms that are valued by humans. Waste streams impact environmental processes, for example, by changing the structure and function of ecosystems. With the development of modern industry and consumer societies came an increase in the spatial and temporal extent to which technological consequences are distributed. For example, mass production of cars, chemicals and computers impact not only local environments but global resource availability and environmental quality, and affect the lives of current and future generations. As the spatial and temporal reach and the complexity of technology increases it becomes increasingly prudent that society foresees social and environmental problems arising from its technology (Bullard, 1988).

There are different ways to deal with complexity. One is to *reduce* the description of a system to linear, cause-effect relationships or by conducting static or comparative-static analysis. Often the two are done in conjunction with each other. The traditional economics approach to the internalization of externalities exemplifies such reduction. Environmental impacts of production and consumption are typically expressed in monetary terms, and models are developed to optimize the performance of the combined economy-environment system with respect to the social costs and benefits that occur under alternative internalization strategies (Baumol and Oates, 1988). The time-delayed, nonlinear feedback processes that often characterize economy-environment interactions at various levels of system organization are reduced to cause-effect relationships in an equilibrium domain. The debate over acid deposition that took place in the USA during the 1970s and 1980s, for example, has been plagued by linear, cause-effect thinking and has given rise to a set of mechanistic approaches to dealing with the problem. Among these approaches is an economic pollution-permit trading scheme that has fallen short of the expectations for increased cost-effectiveness in technology choice, increased decentralization of the decision making process, and improved environmental quality over levels that were likely to be achieved in the absence of pollution permits (Heinzerling, 1995).

An alternative approach to complexity is to *simplify* complexity by limiting the number of viewpoints while maintaining recognition of important feedback mechanisms among system components. The scientific and policy debate surrounding global climate change illustrates such an approach. While much effort has gone into the synthesis of diverse findings, the IPCC (1990, 1991) has been quite successful in conveying to policy decision makers the extent of the complexity and of the surrounding uncertainties. The ensuing policy debate has mirrored the debate in the scientific community about uncertainties, but more importantly it has begun to concentrate on the identification of policies that allow for significant flexibility both on the side of the policy makers who need to respond to changes in the economy-environment system and on the side of industry which needs to find effective strategies to comply with policies while maintaining their competitiveness.

The evolution of rules and rituals that govern society's relation to its technologies has frequently lead to a reduction rather than simplification of complexity by imposing a mechanistic approach to problem solving that inherently assumes direct cause-effect relationships or neglects the history of a problem. As a result, many of the rules that evolved may not be sufficient to deal with the complexity of modern technology (Wahlström, 1992), let alone to successfully manage the consequences that come from coupling diverse technologies and industries with each other.

The more widespread and long-term the implications of material and energy use, the more information is required to place bounds on the uncertainty surrounding the changes in the environment. It is in this sense that complexity can be considered also a measure of the human ability to identify and understand cause, and to expect and direct system behavior (Ahl and Allen, 1996). One could even go further, as Francisco Varela and his coworkers have done, and "... call into questions the idea that the world is pregiven and that cognition is representation" (Varela et al., 1991, p. 140). It is then the very process of interdisciplinary and social dialog that defines relevant system features, rather than the scientific approach to the "discovery of facts". Integration of knowledge from disparate disciplines, integration of research and education and integration of knowledge from the scientific and stakeholder communities are then a necessary, though not sufficient, condition for sustainable development.

The discussion above now leads to an extension of my questions about "Integration of what?" and "Integration for what?" into the realm of "Integration - how?". This is the topic of the following section.

4. Three Steps Towards True Integration

Integrative environmental research and education, if they are to be meaningful and effective, will require conscious efforts on the parts of centers of learning, and society at large. Neither is likely to emerge without a plan and purpose, but rather require active self-reflection among their members, motivation to embark on this journey, and consistency of what is preached and how it is lived.

4.1 Self-reflection

Self-reflection means asking questions of oneself and one's role in the larger intellectual enterprise of a university and society. If scientists subscribe to the notion that the science can be improved not just by learning from others within their narrow specialties but also from others outside their field, then they may begin to work on integrating that knowledge, rather than continuing to work side by side.

If scientists and (other) stakeholders understand that the complexity of real-world issues requires not just diversity in problem solving approaches but also some means of forging a synthesis among the proposed solutions, then generating more insights without much attention to how those insights can be reconciled may not be enough. Some of the pressing issues surrounding loss of species diversity, proliferation of invasive species, habitat fragmentation, and genetically modified organisms, are not well-served, for example, when insights from biology remain disconnected from knowledge in other natural sciences and from knowledge in the public health, engineering, business and policy realms.

How well the integration actually works can often only be known after the fact. To ensure opportunities for effective learning along the way, any effort at integration must be accompanied by post project evaluation. Much like the adaptive management in environmental decision making (Holling, 1978; Gunderson et al., 1995; Ruth, 2006) the scientific endeavor itself must become adaptive by asking questions, such as:

- What new insights have been generated that explicitly required integration across disciplines? How, and how well, was integration achieved?
- What were the communication barriers among contributing disciplines? How, and how well, were they overcome?
- How responsive was the science to societal needs and concerns?

Rarely do the resources exist to create the freedom in science to address such questions.

4.2 Motivation

One underlying hypothesis of this paper is that society makes better policy and investment decisions, at least in the long run, if one gets the science right. Likewise, one may presume that – once scientists recognize how privileged they are that society provides them with opportunities to explore answers to the questions they contemplate – they derive more of a "warm inner glow" if they know that socially desirable outcomes result. Contribution to problem solving may become a (non-monetary) reward and motivator for scientists.

Conversely, if one is not interested in drawing on the knowledge available outside one's field, and if one is not interested in providing contributions for the common good, few obstacles exist to conduct the science one wishes to carry out. Each and every individual in the scientific community is entitled to make those choices. Those individuals, though, may be surprised if, one day, they find themselves at the sidelines of their discipline and society. A lot of attention, action and fun - let alone funding - are found where the sciences collide and where they address issues of broader social concern.

Consistency

A third step towards integration requires that environmental research and education must be consistent with the issues that are studied. Specifically, a university's strengths in various environmentally-related areas, combined with society's changing needs for focus on specific environmental issues, will make it necessary to lay out a versatile research agenda. All too often have universities created environmental programs with narrow focus and designed them around the expertise and interests of a core group of people, then later found that the ideas, once petrified, were soon outlived. In efforts to contribute to such noble causes as sustainability, resilience and adaptability, centers, institutes and programs were set up to be unsustainable, highly vulnerable and unable to adapt.

Instead, one may want to think about research agendas in flux. The role of institutions would be to bring together, and rotate, players to effectively play a game who's rules evolve. In concrete terms, a university may want to establish networks of self-reflective, motivated researchers and students who come to collaborate with people outside their research labs, departments and colleges. While they contribute to a common cause of integration, they benefit for their own activities in the smaller units in which they are appointed and the subfields within which they build their careers. At the same time, universities may wish to revive their roles as meeting grounds for societal discourse. While this may be easier for some, such as large land, and sea grant universities who historically have developed strengths in these areas through outreach and extension programs, important niches may be filled, and new ones defined, for others as well.

5. Summary and Conclusions

As environmental research and education has progressed from discipline-specific investigations to multidisciplinary and interdisciplinary endeavors, many participants have remained dissatisfied by the fact that the relevant discourses in the various sciences and in society have progressed often in parallel. While not inherently problematic – after all there are good reasons to keep disciplines distinguishable from each other and to keep science as much as possible shielded from special interests – there are opportunities to inform and improve each through active integration of knowledge across the disciplines and across the science-society divide. Mutual education of the participants and of the next generation of scientists and decision makers will be key to the success of integration, and thus to adequate use, valorization and regeneration of resources – natural and human-made. Other important ingredients include the generation of flexible institutional arrangements that foster integrative environmental research and education – within universities and through the mandates and actions of government agencies and funders. Last but not least, integration will live and die with the motivations of the researchers and stakeholders involved. Most of them are new at this business, and all will need to be able to learn through an iterative process of experimentation, observation and evaluation. In this process, the scientific enterprise itself will need to be adaptively managed, making it in turn a formidable case study for social science research that integrates the knowledge of its participants.

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