

Global Environmental Change Science: Education and Training

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Education and Global Environmental Change

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Causes of Global Environmental Change fall into two major categories: natural variability and anthropogenic contributions, the human component arising largely as a result of vast numbers of people demanding high standards of living and using technology and resources to support their efforts.

An understanding of the processes leading to global change requires detailed knowledge of the natural and social sciences, and a systems approach. This in turn requires cooperation amongst teachers and researchers across the traditional boundaries in education. These boundaries are between subject areas, and because global environmental change is a multidisciplinary problem, a range of potential solutions and an understanding of the complex issues often spring out of the interface of knowledge among the disciplines.

Further, not only must the traditional boundaries of the subjects be broken down, so too must those boundaries between school, undergraduate, and postgraduate education and training.

It will be seen that these two themes are emphasised many times during this book, in terms of the training of global change scientists, in educating school and university students and in providing the public with the knowledge essential to an understanding of the environment. While earth and physical sciences serve as the information and research base, the nature of the issues in global change bridge nearly every component of the curriculum. Thus, the issues in global change require an educational structure that integrates the natural and social sciences, as well as the humanities and professional studies such as business, law, and medicine.

Why this workshop?

Global change problems are an important and timely focus for research and education and they are indeed being tackled urgently. However, the training brought by most scientists to global change problems consists of first - and often second - degrees in a single scientific discipline, so that the global perspective must be picked up on the job. There are few opportunities for formal training. This problem was recognised during the initial workshop of the NATO Special Programme for the Science in Global Environmental Change (Corell *et al.* 1991), which recognized that the multidisciplinary nature of global change science was a significant obstacle and that NATO had a rôle in assisting with the training and education of the coming generation of global change scientists. The panel in charge of the Special Programme proposed that conversion courses at the masters degree level could be a possible way forward to provide conventionally trained scientists with the necessary global outlook.

A preliminary step prior to holding the workshop was to gather information on existing courses in NATO countries. Enquiries were addressed to research and educational agencies, and centres were visited. From this survey emerged a list of potential participants. However, it was soon apparent that, although there was healthy activity in specific subjects, there were few interdisciplinary systems-oriented scientific research activities or educational programmes. There was, however, an encouraging sign that at least some educational programmes were emerging which attempt to provide students at many levels with a familiarity of the "earth-as-a-system" concept.

These preliminary enquiries also revealed that there was a large measure of interest among educators in having information brought together in a reference volume, which outline global change curricula and resources and experiences of course-providers.

Following detailed correspondence with global science educators over a period of 18 months, it was decided that it was time to bring some people together to share experiences and to chart ways in which global science education at undergraduate and postgraduate levels could be enhanced, and, through this book, to share experiences with others.

The Workshop

Twenty five scientists and science educators from 11 countries agreed to participate in the Workshop. Although the original aim was for the first workshop to identify some of the resources in university postgraduate courses, it was soon apparent that we needed to look at the educational issues below the masters degree level.

During the workshop, it became apparent that in many countries environmental concerns have had little impact on school and first degree science courses. Problems associated with global change education in degrees in single subject disciplines are exacerbated by courses at school and pre-doctoral level, which in many countries are taught in terms of specialisms defined by boundaries set a century ago. This led workshop participants to widen their brief because the training of global change scientists, who have the necessary global perception or requisite combination of knowledge, needs underpinning during first degree courses. With no introduction to the bigger picture of the environment and its relationship to humans, students are not excited about the relevance of the study of science, and we as a society are losing opportunities to further the pursuit of science careers. Getting students interested and committed will in turn contribute to increasing the supply of global change scientists, who have the necessary global perception or requisite combination of knowledge. Further, the lack of a broader science education exacerbates problems associated with a public ill-equipped to face the rapidly changing environment in which we live and is antipathetic to solutions proposed for global change problems. Increasing science literacy through the use of environmental issues will enhance the abilities of the public to understand and participate in environmental policy-making efforts. This broader perspective is reflected throughout the report.

Members of the group had a very wide range of experiences in the education and training of both scientists and non-scientists at university level in various aspects of global change science. They addressed the problems of introducing new and modifying existing courses by having a series of plenary sessions with inputs from participants who outlined the work done in their own institutions and regionally. These are described in Section 2.

Earth System Science and the Science of Global Environmental Change

The fundamental concept is that of the earth as a dynamic system which has experienced change over all timescales. This is studied as *Earth System Science*. It has been shown that man's activities have the capacity to perturb this global system, so the *Science of Global Environmental Change* is the study of the natural global system focusing on anthropogenic influences and their environmental and societal consequences. This is often shortened to *Global Change Science*.

At present, scientists are focussing on subjects such as climate change, ozone depletion, the loss of biological diversity, degradation of terrestrial and marine environments, and desertification, but the workshop participants were aware that these are but some examples of current and fundamental concern. There are two terms used in the discussion of earth-systems which need defining. These are *linkages* and *interaction*.

Linkage refers to connections among various sub-elements of a system. For example, the ocean provides a heat source for the atmosphere and thus air and sea are linked. *Interaction* implies linkage in both directions among sub-elements of a system. For example, the ocean provides a heat source for the atmosphere, but, for time scales longer than weeks, atmospheric winds and transparency to solar heat feed back on ocean temperatures. Thus, on these scales, there is an air-sea interaction.

Finally, two terms are used to describe the way global change scientists are educated and trained. These are multidisciplinary and interdisciplinary. We distinguish between these in the following way: *Multidisciplinary* refers to knowledge from multiple disciplines derived from disciplinary methods, practices, and paradigms, independent of problems such as global change. *Interdisciplinary* is used to denote the integration of knowledge from multiple disciplines combined in an original synthesis, in order to explain the behaviour of a complex system or to address a problem of practical significance.

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Evolutionary Organizational Models for Interdisciplinary Research and Teaching of Global Environmental Change

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Environmental science, technology, and policy studies require an integrated, interdisciplinary approach that needs to draw together talents from diverse academic disciplines, and from industry, government, and non-government organizations (NGO's) (mostly non-profit advocacy groups), and must offer incentives to participants to produce team-oriented, problem-driven, interdisciplinary research and teaching. The challenge, of course, is how to encourage this and maintain high quality standards, given the traditional disciplinary and/or departmental structures at most universities, national laboratories, and funding agencies. Some individuals have thus suggested that we need to re-examine and modify these traditional structures to ensure they are not impediments to quality, integrated global environmental systems studies.

Linear versus "Organic Systems" Structure for Academic Institutions

Figure 1 is my "cartoon" of the typical academic research and teaching paradigm, a linear progression of "knowledge flow" (represented by the arrows on the figure) from disciplinary and multidisciplinary (but rarely integrated) natural scientific work fed into social sciences for impact assessments which may spawn isolated efforts at policy analysis, sometimes by interdepartmental institutes. Humanities expertise enters sporadically, usually in the form of an interested scholar or two becoming involved with a team of global change natural or social scientists. By "multidisciplinary, I mean specialists from various disciplines applying their respective disciplinary paradigms and methods in parallel on restricted aspects of some broad systems problem. By "interdisciplinary" I refer to individuals or teams of diverse specialists which learn enough - individually or collectively - about a range of relevant disciplinary methods and content to combine such multidisciplinary knowledge into an original synthesis that helps to raise understanding of systems phenomena or to solve a real problem (Schneider, 1977). Interdisciplinary work is often at the intersection of disciplines; multidisciplinary work is usually centered within several traditional disciplines. Government agencies and private foundations largely fund the

spectrum of such research, but, like other "users" of the research who often have to make policy decisions despite the uncertainties, they largely sit on the sidelines once the grant is given and academic research is undertaken.

Teaching is typically concentrated in disciplinary departments, but a broadening of this discipline-oriented approach has long been undertaken at many institutions. There are many examples described in this volume. This approach will be discussed in depth shortly. Outreach of new knowledge from the academic community to the media, the public, and policy makers is sometimes handled institutionally by extension officers, but, as Figure 1 suggests, it is more often provided by mediaskilled entrepreneurs: an unorganized, ad hoc minority the members of which are selfselected "outreach agents" who interpret and "spin" the academic knowledge-base. Such people are typically disciplinary specialists, and, with a few rare exceptions, offer their interpretations and advice from the narrow perspective of their disciplinary paradigms. What is needed, I believe, is to find an organizational vision that leads to institutions which inherently will immerse such specialists in a systems perspective, an experience that could well substantially alter their interpretations.

Figure 2 is a contrasting organic systems paradigm stressing the integrative or "center-like" aspects of global environmental change problems. This figure illustrates the integration and organizational concepts I wish to discuss here. Rather than a linear, disciplinary organization in which knowledge typically flows from physical to biological to social scientists, and eventually to policy assessment teams, Figure 2 offers a circular, problem-oriented, interconnected structure, or an interactive or organic systems approach. The global environmental change issue is subdivided into three primary subsets: (1) the functioning of the global environmental system, (2) disturbance of the environmental system, and (3) the response of the environmental system to global change disturbances. There is feedback among these subsets and a central entity responsible for integration, which is a group also responsible for feeding back to the three sub-problem groups new scientific problems to work on. An input from many traditional disciplines is necessary for describing the functioning of the global environmental system, and likewise for the other two subsets.

Many gaps in disciplinary knowledge will be uncovered by such a problem oriented approach. Thus, rather than competing with disciplinary research

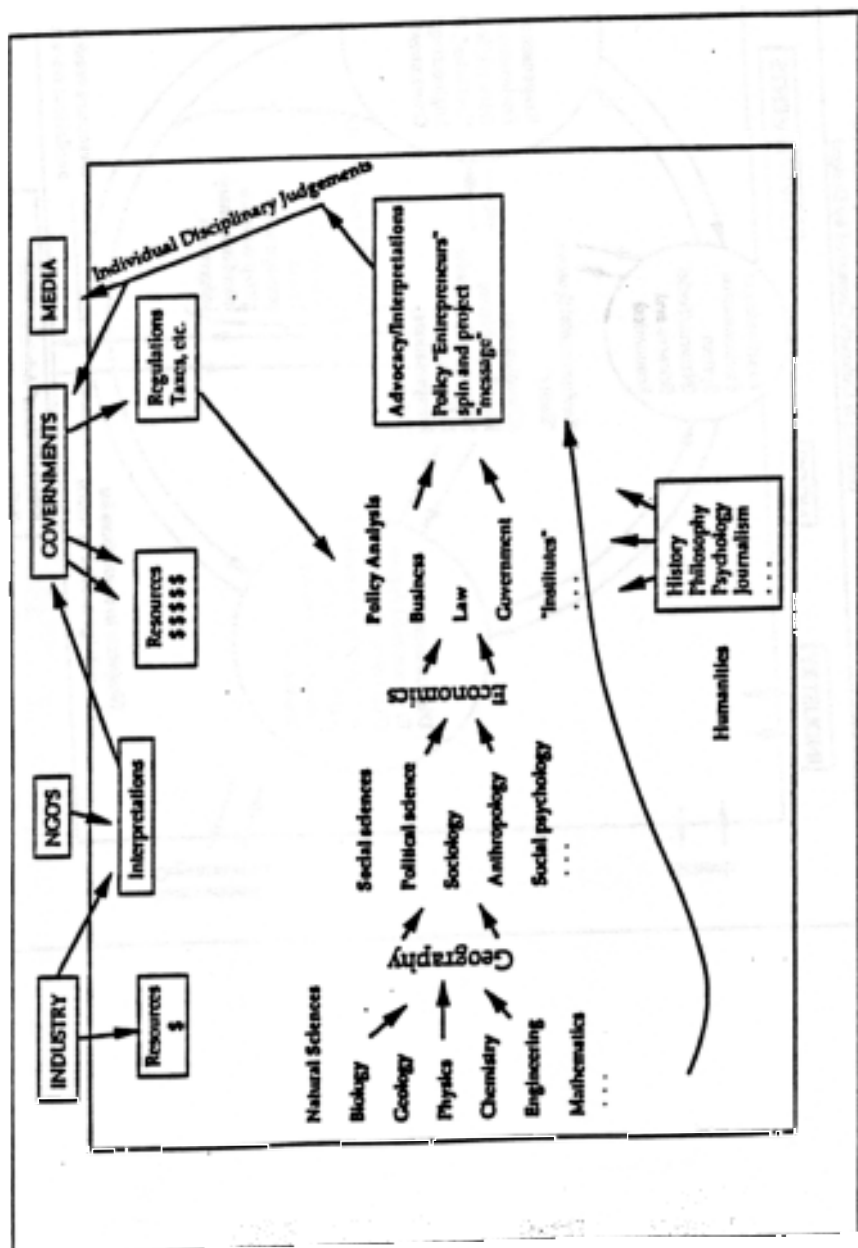


Figure 1

INTEGRATED MODEL OF ENVIRONMENTAL SYSTEMS
 (Multi-disciplinary to Inter disciplinary Research,
 Teaching & Outreach Connected by Design)

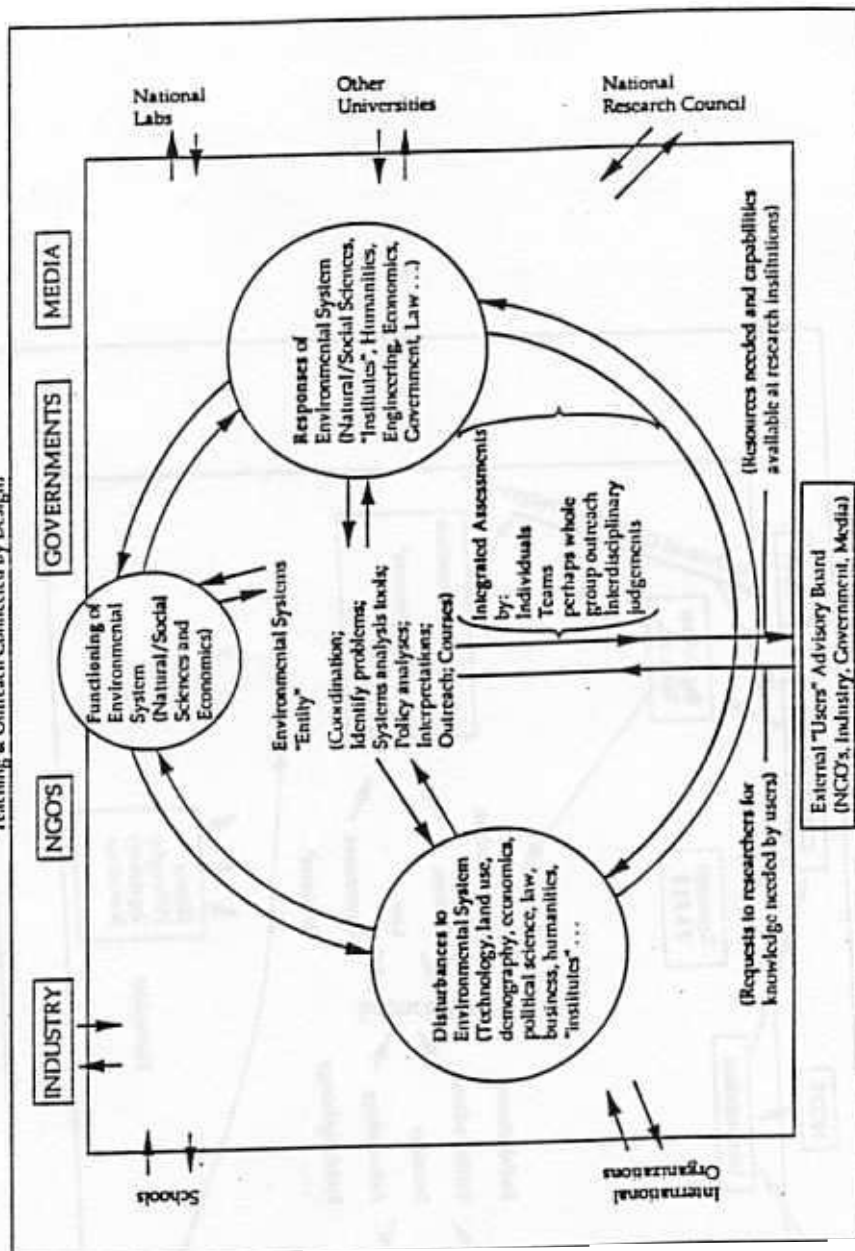


Figure 2

progress, such a systems organization could very well augment it by providing new discipline-oriented tasks for disciplinarians to work on, that are based on overall problem needs and not simply research agendas established in the judgment of disciplinarians as to what is most important for that discipline.

This organic systems structure is designed to unite, evaluate, and reward high quality interdisciplinary research, teaching, and outreach; to coordinate exchanges from multiple disciplines so that an interdisciplinary perspective is facilitated; and to set up formal mechanisms to encourage individuals, teams and (perhaps) whole groups to communicate with the "real world" actors represented on Figure 2 in the "picture frame" margin in the diagram. The three circles reflect a problem-oriented administrative disaggregation of intellectual talent based on environmental systems phenomena, rather than on disciplinary tradition or historic bureaucratic boundaries. Typical disciplinary specialties needed in each sub-problem area are listed in the circles. However, how to organize existing people or groups at an academic or laboratory institution into teams suggested by the circles in Figure 2 is a formidable challenge. In this article discussion will be focused on the intellectual question of whether we would *want* to do this, rather than on the potentially divisive political question of how to effect the transition.

Instead of having practitioners of one discipline pass on their partial view of a systems phenomena to the next discipline, and eventually have the policy implications reported largely ad hoc by disciplinary or special interest-driven policy entrepreneurs (Figure 1), my replacement concept is to evolve a central Environmental Systems Entity (e.g., an integrated department, institute, or some other administrative taxon) to help ensure that actual problems are addressed by having high-quality disciplinary knowledge (available from traditional departments) collected, combined, and focused on problems by the "entity" faculty/staff. Such personnel would include world-leading specialists in the integration process itself. Such scholars may well come from specific disciplines, or be graduates of interdisciplinary programs. Regardless of their origin, they should have demonstrated an ability to seek out specialists with appropriate disciplinary knowledge, and they should help survey and integrate such knowledge in order to enhance understanding of systems phenomena and/or to help solve actual problems.

Evaluating Interdisciplinary Quality

One constraint facing universities considering such a systems approach involves the issue of evaluating interdisciplinary quality. While I could hardly argue with the proposition that researchers should always pursue high quality, it must be recognized that quality evaluation consists of value judgments. Within a university setting, quality generally is defined as any significant quantity of original work that advances the discipline. This definition is perfectly appropriate for disciplinary specialists, but too narrow for evaluation of integration experts. Members of the academic community who define quality under this traditional, narrow definition of disciplinary originality often argue that interdisciplinary programs compromise worth (e.g., Chen, 1981).

I believe that interdisciplinary quality, although substantially different from the disciplinary notion of the concept, is intellectually as viable. Interdisciplinary quality, too, must possess originality. This requirement can be accomplished through an innovative method of combining known materials from various fields rather than within the confines of one field. The materials from various disciplines needed to address a particular interdisciplinary problem must be combined in an original manner that helps to enhance understanding of a systems phenomena or to solve an actual problem. All disciplinary materials used must be up to date and accurate. Furthermore, specialized concepts or jargon must be presented with great clarity to promote cross-disciplinary communication. (These, in fact, have been the criteria for interdisciplinary peer review for the journal *Climatic Change* since its inception [Schneider, 1977]).

Such quality standards can be evaluated, can be enforced, and should be rigorously tested through the peer process - although no individual peer may have the capacity to fully judge the entire nature of the work, nor is that a necessary or a fatal obstacle. The creation of a peer review group for interdisciplinary environmental studies is itself an evolving process, and models of this process will be explored later on in the discussion of Tables 1 and 2. Interdisciplinary work is inherently team-oriented and requires multiple inputs from many quarters. However, over time individuals who become increasingly knowledgeable about the content and paradigms of several disciplines can themselves become interdisciplinary, or in essence, integration experts. These are the kinds of people for whom reward systems are generally not well developed in academe, and for whom funding is often difficult to obtain from traditional sources.

Problem-driven research doesn't exclude disciplinary originality, rather it emphasizes the reverse, requiring more, though problem-focused, disciplinary knowledge. Since that knowledge can be focused on practical problem solving, it should entrain new "customers" for the research products. Thus, this systems model should also provide nontraditional sources of resources to disciplines, that would not likely have been available to curiosity-driven disciplinary researchers from most granting agencies. In short, participation of disciplines in interdisciplinary systems research need not be a threat in the sense of losing out in a zero-sum game, but rather a way of expanding overall support for intellectual activities.

User Interface

In an organic systems model, mechanisms are also built in for interactions with users of research products (for example, environmental activists, industries with environmental connections, elected officials, agency workers, and the public at large) to examine research products and suggest just how these products could - or could not - contribute to improving the knowledge base needed for analysis and ultimate policy choices. In this manner, research relevant to user needs could evolve as an integral component of the center or entity concept. To me, bringing users into research planning is not merely putting "amateurs in charge of disciplines," but rather putting professionals in information use in charge of determining what kinds of information they think they need. Then integration experts at the interface of the user communities and the disciplinary academic and laboratory communities can help to translate what is needed at the policy end into what should be produced at the science end. Quite bluntly, most disciplinary investigators are not qualified by themselves to make that judgment without the input of broader groups, particularly those at the front lines of problem solving. Neither are the problem solvers qualified to dictate the details of what disciplinarians should do, but certainly the former should point out what policy questions are in need of more scientific information, from which integrationists and disciplinarians together could work out focused research agendas that are appropriately multidisciplinary and/or interdisciplinary.

Another vital function that an environmental systems entity could perform would be to establish a place for summer studies, for regional field work, for research fellows to congregate, for media interested in covering global change topics to be put in touch with individuals knowledgeable in various aspects of the issues (rather than the random and/or biased coverage typical of most

polarized global change debates), and in which public outreach could be advanced.

Evolution, Not Revolution

In essence, what I am calling for is not the wholesale replacement of the disciplinary paradigm, or its traditions of strict quality review standards for disciplinary research, with something different, but rather the augmentation of standard practices to include problem-driven, interdisciplinary integration as part and parcel of the total academic/laboratory research enterprise. I believe that this evolution toward broader research and teaching paradigms will *not* reduce the quality of disciplinary work. On the contrary, I think that it will expand the opportunities and funding sources, and that evolution of systems organization will not necessarily replace most disciplinary departments, just as biological evolution does not necessarily replace some existing species. Rather, such an evolution will allow analysts and synthesists to address global change problems at the scale they exist (the "problem scale"), a scale not constrained by boundaries and methods that happen to fall into historic entities or disciplines that were created for different purposes.

None of this obviates the need for disciplines. I envision that only a small percentage of overall academic activities would be in the integrationist category, because integration expertise is hard to find, will take time to develop, requires reorganization of training and rewards systems, needs to evolve a peer group, and simply isn't ready to take over a very large fraction of the effort, if quality is to be maintained. Interdisciplinary work cannot function without a high quality base of disciplinary knowledge, but an institution of higher learning cannot efficiently contribute to the solution of pressing environmental problems by retaining a discipline-only, traditional organization and rewards structure. We need both, and there is no time to waste. We simply cannot afford the luxury of waiting for such new structures to emerge bit by bit out of present institutions over the next century, just as specialized disciplines replaced classical training and organizations a century or two ago. We need to be creative and active in accelerating that evolutionary process by perhaps an order of magnitude to address pressing environmental problems whose solutions are already overdue.

Evolution of Global Change Research Organization

Most academic or laboratory research is not organized like the systems model proposed in Fig. 2. However, organizational changes have evolved at academic

institutions in an attempt to encourage multidisciplinary and sometimes interdisciplinary activities to take place. Table 1 offers an example of typical organizational issues involved in enhancing global environmental change research activities.

Table 1

Organizational Steps or Issues for Global Environmental Change Research	
•	Multidisciplinary seminar - to learn who is interested and in what
	Multidisciplinary committees - plan more formal integrative activities and supervise Ph.D. students
	Interdepartmental Institutes (typically not permanent)
	- Multidisciplinary faculty with partial appointments in disciplinary departments and institutes
	- Senior fellows: non-tenure track but full-time institute appointees
	- Development of peer groups capable of evaluating interdisciplinary quality

This NATO volume is dedicated primarily to educational rather than research problems encountered in global change activities. However, research activities typically are given higher priorities than global change educational activities in most of the more prestigious universities, so experience gained in analyzing problems and in finding solutions to interdisciplinary global change research aspects should carry over to dealing with global change educational improvements. Furthermore, the best global change teachers are probably close to evolving research findings.

Returning to the organizational steps in Table 1, the process of using organizational change to encourage global change activities typically begins with the creation of a multidisciplinary seminar. Since the process of establishing networks of multidisciplinary scholars, students, and staff to form multidisciplinary research teams requires a progressive recognition of the problems, practices, and ideas from a variety of disciplines, the formation of multidisciplinary seminars is one of the best ways to build that community of scholars. Talks given by faculty from various departments or from visiting faculty, scientists, decision makers, or people from business and environmental groups from the outside, often serve as a focal point for this activity. Frequently, as interpersonal relationships build around multidisciplinary problems like global change, some subset of faculty, visitors, students, and staff often form the

next element on Table 1, multidisciplinary committees. Such groups often plan for more formal integrative activities or can supervise Ph.D. research, evolving to become part of the peer group needed to sustain interdisciplinary quality, as discussed earlier. Such activities could include joint proposal writing, summer studies in multidisciplinary problems, planning for new courses, development of an interdepartmental institute or center, and ultimately, attain a vision for more permanent new departments and/or schools, whose focus would be, in our example, interdisciplinary global environmental change efforts.

Interdepartmental institutes typically are not permanent, hard-money-funded organizational entities at most universities, because they do not have the historical or administrative clout of schools or disciplinary departments. They are typically staffed by multidisciplinary faculty, most of whom may have partial appointments in such institutes, but most of whom have permanence or tenure status in disciplinary departments. Sometimes institutes hire full-time staff, such as senior fellows or research professors, but in many - probably most - current cases such positions are pejorative in the sense that they are not tenure-track faculty slots with full security, privilege, and influence associated with tenure status. In some cases junior faculty (those not yet tenured) are often nervous about participation in such interdepartmental institutes, particularly if their work is interdisciplinary. Such activities can reduce the likelihood of promotion to tenure for junior faculty whose peer evaluation may be made solely on disciplinary standards. Furthermore, they often will be compared to the productivity and disciplinary originality earned by colleagues who may not be splitting their efforts among both disciplinary and interdisciplinary activities.

The tenure issue is explicitly raised next on Table 1. Most tenure-track appointments in academe, or so-called "senior scientist" appointments without term in research laboratories, largely reside in disciplinary departments. Sometimes creative, interim solutions have been attempted across organizational sub-units, such as that at Penn State University, in which the Earth Systems Science program controls the funds for new appointments in global change studies, while the departments retain the legal power to advance or deny a candidate achievement of tenure status. Because of the difficulty in modifying existing legal or traditional appointment practices at academic institutions, such "joint implementation" compromises are often important evolutionary steps of organizational change needed to enhance the tractability and quality of interdisciplinary work.

Another proposed solution to this difficulty was developed in 1969 at Stanford University in its interdepartmental Human Biology program, and is informally known there as "elastic slots." The logic is that research activities and tenure would remain in traditional departments on the grounds that such departments were best qualified to evaluate research quality, but that multi- or interdisciplinary teaching could be carried out in an interdepartmental program or in institute organizations which do not have permanent or tenure granting status. While elastic slots may be a potentially useful interim step, I believe this is not an optimal - or even appropriate - long-term solution, since the highest quality problem solving or interdisciplinary research will require the integration of research, teaching, and outreach in the same organization; and with quality review being applied to both teaching and research, based on how well the candidate performs in the interdisciplinary context, not how well the candidate performs solely in disciplinary research. Rather than seeing departments as best qualified to evaluate research quality, the opposite is more likely: departments are usually not well qualified to judge the interdisciplinary originality or importance of such research activity, and the basic premise behind elastic slots and the assignment of tenure to departments and teaching to programs, is fundamentally flawed with respect to encouraging sustained, high-quality interdisciplinary activities.

The most difficult organizational change for most current institutions would be the creation of new interdisciplinary departments or schools whose prime activity is research, teaching, and outreach on interdisciplinary, systems-oriented problems like global environmental change. To attract the best faculty (especially at early career stages), such an environmental studies entity needs to be backed up with sufficient funding to offer prospective staff the opportunity of permanence on an equal footing with tenure-granting schools and departments. But a new permanent entity is especially hard to create when the overall institution is not growing, let alone when it is undergoing cutbacks. Such new interdisciplinary departments of environmental science and/or management hardly need to add this fiscal obstacle to the many other associated problems of new paradigms, such as evaluating interdisciplinary quality, providing adequate rewards or reprimands based on quality evaluations, and expecting some measure of effective public outreach or technology transfer as part of the job. The suggestion to obtain hard money to support a new interdisciplinary department (which could mean earmarking a fraction of the endowment of a private university for it or becoming a permanent line item in the budget of a

large laboratory) is likely to run into a storm of academic opposition from already established organizational sub-units, each of which is trying to hold on to its share of what it perceives as the stable or shrinking pie. Of course, such opposition is usually couched in terms of quality concerns, not competition for scarce resources.

Support for the program, faculty, and staff of a new environmental entity could also be obtained from federal and local grants, as in the case of disciplinary departments and schools, and perhaps could also, particularly in the early phases, get a major boost in support from private foundations. The latter often like to fund new initiatives, particularly for problem-oriented organizations, but do not typically like to be committed to long-term support programs. The creation of new interdisciplinary, permanent organizations would be the ultimate institutional evolutionary step. Most institutions are more realistically described in terms of the activities distributed across the earlier entries on Table 1, but there are some outstanding examples of interdisciplinary environmental studies organization that are already established, (such as the Energy and Resources Group (ERG) at UC Berkeley and the Earth Systems Science Center at Penn State University). At a 1977 symposium on the interdisciplinary process co-organized by the author, the late anthropologist, Margaret Mead, was invited to comment on this question. She characterized three elements she believed were in common to the creation and sustenance of most interdisciplinary ventures: (1) a charismatic leader with sufficient disciplinary credentials to maintain credibility of the enterprise in spite of doubters from disciplines and with sufficient intellectual clout and appeal to procure the next two ingredients; (2) a group of young, dedicated researchers, who are "analogical" rather than "digital" thinkers: or people who at the margins of their intellect like to make connections; and (3) an identified primary funding source for the activities. (Mead's remarks are described in Chen 1981). When pressed by a panelist who was concerned by how difficult these three criteria are to maintain, I recall her replying simply that two out of three of these characteristics needed to be maintained at all times by successful interdisciplinary groups and all three for some of the time, particularly criterion 1 at the outset of the venture. I think her model fits well the ERG and Earth Systems Center examples given above, my former affiliation with the Interdisciplinary Climate Systems Section at the National Center for Atmospheric Research in Boulder, Colorado, and, on a larger scale, the International Institute for Applied Systems Analysis in Laxenberg, Austria.

The Margaret Mead model for interdisciplinary group creation and survival has been closely matched many times and in many types of institutions, but, distressingly, I have also witnessed the withering of such interdisciplinary activities, particularly when the charismatic leader moved on before the unit could become sufficiently established. Thus, such a model implies a burdensome set of hurdles for new interdisciplinary units that most disciplinary groups do not need to address. It is essential for high quality and sustained integrative activities required by such subjects as global environmental change, that support for the activities and staff be institutionalized and put on a par with traditional disciplinary departments. That means having fair access to funding resources, and not being required to maintain indefinitely and continuously either extraordinarily unusual leadership or outside resources as a prerequisite to continued existence. During the transition from initial establishment of interdisciplinary units to more permanent status, it is probably not unreasonable that Mead's model should apply, but eventually a progression through the steps outlined on Table 1 should lead to a more permanent state .

Successional Model of Organizational Changes to Sustain Global Change

Let us turn now to the question of improving education and training of global environmental students, scientists, professionals, and the public at large. Table 2 summarizes my experience with the teaching of cross-disciplinary subjects at universities and laboratories. The Table suggests a typical progression or successional model for organizational changes in response to the special demands for interdisciplinary teaching. It is a model of a typical successional pattern in which increasing degrees of integrative activities are encouraged and institutionalized. Like a real biological succession, from which this analogy is inspired, sometimes particular examples do not conform with the usual successional sequence (for example, following an intense forest fire ecosystem recovery typically proceeds from grasses to shrubs followed by rapidly colonizing "pioneer" trees and eventually ends up with a final or "climax" state of succession: a mature old growth forest with a stable mix of species). Sometimes standard successional steps are skipped or the order of progression of changes depends on additional factors that range from the scale or intensity of the initial disturbance up to human interventions, such as replanting a certain set of species and eliminating others. The latter could entirely overwhelm the normal successional pattern. Likewise, some educational institutions may have opted for permanent rather than term appointments for an interdepartmental institute's non-faculty staff, contrary to the more usual situation anticipated in

Table 2, in which such permanence for integration experts does not normally occur until the late successional stage when the group becomes a full interdisciplinary department or school. The model in Table 2 is offered simply because this progression seems to capture many typical situations in academe or laboratories, even if individual examples do vary.

Table 2

"Successional" Model of Organizational Steps for Global Environmental Change Teaching	
•	Multidisciplinary Seminars (get to know the players and rules of their games; typically takes years for individuals or groups to become interdisciplinary)
	Announce Program and Initial curriculum
•	- Form multidisciplinary committee to define program goals, participants, and to define core curriculum and electives
	Curriculum Development
•	- "Staple-gun" courses (require some half-dozen pre-existing multidisciplinary courses for students to become an "environment major" by displacing similar number of required/elective courses otherwise needed to be a disciplinary major)
	- Tracks (discipline-like course options for upper undergraduates using pre-existing courses)
•	- Team-taught, first course (Cameos by major members of staff with interdisciplinary, problem-oriented context emphasized over the disciplinary content)
	- New (or modified) core courses (multidisciplinary core knowledge, with content from various disciplines emphasized over integrative, interdisciplinary context)
•	- New tracks (add multidisciplinary course options for upper undergraduates)
	- Senior seminar (to reacquaint content-oriented tracked students with integrative interdisciplinary problem context)
•	- Co-Terminal Masters allows enough disciplinary content to be equivalent to a B.S. in a major discipline, but with interdisciplinary context of global environmental change problem solving added on)
	Create Environmental Systems Entity with permanence (new department, center or school with tenure-track faculty; research, teaching and outreach are combined and their quality evaluated on interdisciplinary systems or problem-oriented criteria)
•	PhDs (see Table 1)
•	Career change programs
	- A largely multi-disciplinary M.S. program to acquaint already trained disciplinary students and/or practicing professionals with the content of relevant disciplines and the broader context of environmental problem solving
	- Special post-doctoral or mid-career fellowships for senior scientists to retool in an interdisciplinary department, institute, or school.

The successional teaching model in Table 2 is very similar in its basic features to the research steps suggested in Table 1. Both begin with multidisciplinary seminars and progress toward some kind of integrative, systems-oriented environmental science, technology, and policy entity, that could be a center or institute with permanence, a new department, or a school. However, the steps inbetween are somewhat different, with Table 2 chosen to match the typical experience academic institutions have in developing interdisciplinary teaching programs.

Personal and professional relationships often develop at multidisciplinary seminars - seminars that may initially have been organized for building a peer group for research purposes but which also serve to develop relationships necessary for interdisciplinary teaching. At such seminars faculty, students, staff, and other professionals from the region learn enough about each others' interests and abilities to desire further development of a teaching program in global environmental change. The second step often is the formation of a multidisciplinary committee, which tries to define an appropriate curriculum, identify student interest and possible placement of students after completion of courses; and decides who could bring the program both credibility and official status by carrying it through appropriate channels, such as the university management, an academic senate, or governmental officials. Such a committee often writes proposals to help fund or initiate the program and/or tries to attract charismatic leadership either from within the institution or from outside it.

In some cases the multidisciplinary committee might comprise of faculty not only from disparate departments, but from different schools; whereas in other cases faculty might come from different areas of the same department, but be assembled to fashion a new, broad program within that department. Regardless of which model applies, a typical product of such committees is to define a curriculum for a departmental or interdepartmental program related to global environmental change. As the successional model of Table 2 suggests, there are some common stages in the development of such curricula. In the earliest phases after the program is announced, requirements for a core curriculum, required of all students, and/or electives open to upper-class students, are often listed. The courses involved are often already in the institution course catalog and lead to what I have referred to in Table 2 as "staple gun courses", whereby the multidisciplinary program simply "staples" together existing courses in unique combinations not typically open to disciplinary majors. For example,

students enrolling in the new environment program either as a major or a minor (depending upon institutional options) might substitute for disciplinary major requirements, several courses from a variety of departments that involve relevant multidisciplinary global change questions. These substitutions would thus displace a similar number of core courses or electives that otherwise might have been required in order to receive a degree in a specific discipline. The obvious advantage of such an approach is that it allows the student and his/her advisor flexibility in putting together an individualized curriculum which more closely matches his or her perception of what constitutes the knowledge base needed to deal with particular aspects of global environmental change, than might be available in a traditional discipline. The disadvantage is that the "stapled" courses themselves are often aimed at discipline majors, and may provide more detailed or peripheral material than is really necessary for the interests of the global environmental change student. For example, an atmospheric science student wanting to learn enough about leaf physiology to understand how to incorporate biophysical processes into a climate model might wish to have some detailed information on leaf physiology, photosynthesis, and perhaps only a few disciplinary lectures would be sufficient for this interdisciplinary purpose. Yet, the staple gun approach would require the student to take an entire semester or more of a botany class to gain the information legitimately. Likewise, a student trying to understand the development process in China and wishing to compare it to the Victorian Industrial Revolution in Europe or North America might register for a history, economics, or political science course that deals with Western industrial development in the late 19th century. Once again, it is possible that the knowledge needed by that student would be sufficient with half a dozen lectures summarizing the highlights of the issues. It may not be efficient to have the student learn in full semester's depth all the labor relations, social and political conditions, innovations in industrial technology, and other details that appropriately belong in the disciplinary courses dealing with that time of Western industrial development.

In view of the demands for multidisciplinary training and the limitations of a four-year bachelor's degree, it may not be practical for a program to strive for full depth in several relevant global change disciplines, and also adequate breadth by exposing the student to a vast array of unmodified physical, biological, and social scientific courses; as well as policy, history, and values studies - all in a standard bachelor's or master's candidacy! This suggests that in the best teaching

programs attempts will be made to try to create new core courses and eventually new electives, the latter to be specifically designed to meet the needs of global environmental change students. This could be done by selecting representative samples of material from existing disciplinary courses and combining them, perhaps in an original way, in specially focused global change classes. Of course, such new courses will require staff to teach them, but sometimes difficulty is encountered because the breadth of expertise to teach these "environment" courses is not resident in the department or even in the program. With luck, such expertise is available somewhere across the university, but then getting people to participate can be a problem, especially if there are few rewards for participation, and frequently multiple instructors are needed. This has the advantage of comprehensiveness; the disadvantage of choppiness. One solution is a single course coordinator whose job it is to smooth the edges between jumps, as lecturers dealing with different disciplines follow each other in sequence.

A first course in global environmental change is an example of this issue. First of all, such a course could satisfy the science requirement for non-science majors in a given university. Recent experience at a number of institutions suggests that vast numbers of students are interested in a comprehensive global environmental change course for their general science education requirement. Such a course could also be a springboard for someone in the program planning to take further courses. Cameo appearances by a multidisciplinary set of top faculty typically dominate such a course, but alternatively, visiting scientists, policy leaders, or industrial representatives can be guest lecturers, and together with program staff provide the breadth needed at the introductory level. Such a course stresses the context of global environmental change and its broad multidisciplinary nature over the content that would be more typical in first disciplinary science classes.

I strongly believe that at the outset of learning about global environmental change, students need a sense of how physical, biological, and social sciences all contribute to understanding global change problems. Beyond that, students need to be aware of the policy making process and understand that human values lead to policy choice. Environment programs that have just begun may have no more than one such new course, but more developed programs often attempt to fashion new (or modify existing) courses as part of the environment core. Occasionally, new electives in the global change program may be offered.

The Stanford University Example

Earth Systems Undergraduates. My own experience at Stanford University provides an example. The Earth Systems (ES) program at Stanford was initiated by biologist Jonathan Roughgarden and geologist Gary Ernst. ES is an inter-faculty, inter-school program managed by a committee of some 18 professors from all across the campus. A beginning course, affectionately called the "grabber," is offered as a core requirement for earth systems majors as well as being offered as an option for fulfilling science requirements for all students at Stanford. Its first year saw an enrollment of about 20 students, second year 40, and third year over 100. In 1994, in less than three years, there were nearly 90 majors in this program, attesting to its strong popularity with the students. The Stanford program leaders believe that physical, biological, and social sciences all must be included in a core curriculum taken by all earth systems majors. This core goes beyond the grabber course taught by "cameos" given by half a dozen highly visible professors and a few outside visitors. Three multidisciplinary courses which stress content over context in three physical, biological, and social scientific areas are required. One deals largely with geology (the "geosphere" course), one with biology (the "biosphere" course), and one with economics (the so-called "anthrosphere" course). These courses are cross-listed between Earth Systems Science and the relevant disciplinary departments, and the syllabus has been modified by compromise arrangements with the professors, his/her department, and the earth systems leadership to try to meet the needs both of disciplinary students taking the course and not involved in the earth systems program (who typically request more depth), and earth systems science majors who want to cover more topics in that sub-discipline than might be typical of the major. Stanford has also required calculus, physics, chemistry, economics, and biology background courses from the catalogue (i.e., the "staple gun" approach). The ES requires the students to take those courses (e.g., physics, economics, and biology) that have more mathematical prerequisites, thereby stressing methodological rigor, regardless of whether the subject is economics or ecology. At Stanford, five "tracks" are available to students (Appendix A). These are discipline-like programs for upper undergraduates, that provide depth and content equivalent to roughly two-thirds of the content that might be obtained by a disciplinary major who had not had the benefit of the added breadth associated with the earth systems program. Currently, the tracks at Stanford are "staple gun-like" in that few new courses have been specifically developed for Earth Systems beyond the grabber and the three crosslisted core courses - although a few special topics classes have been offered on land use problems and the

management of energy efficiency. However, should the ES program gain permanence and therefore have the capacity to hire tenure-track faculty directly into the unit, it would be desirable to create new courses and even new tracks. (An energy track would be a high priority in the opinion of this author and member of the ES Steering Committee.) However, such events are later stages on the successional model of Table 2, at least so far at Stanford.

Another element to the Stanford program common to a number of other institutions is a senior seminar. Here, the attempt is to reacquaint students with the interdisciplinary context they learned in their first course but moved away from in discipline-like tracks. Such seminars involve outside speakers, faculty members, or, preferably, detailed presentations by the tracked students themselves that are subjected to the comments, criticisms, and perspectives of their multidisciplinary student colleagues.

Senior Honors. Another approach to dealing with the senior level interdisciplinary integration need is a "senior honors" program in environmental science, technology, and policy. Based on recent Stanford experience (Appendix B), this has been run through the Institute for International Studies (IIS), which is an institute consisting largely of a multidisciplinary faculty with half-time, tenured appointments in disciplinary departments and half-time, non-tenured Senior Fellow appointments in the Institute. Institute Fellows, as well as faculty with full-time appointments in departments, make up an interschool faculty committee to oversee the program. (Such a committee helps to advance the process of peer group formation mentioned earlier.) A few full-time institute staff with non-tenure "Fellow" status are also involved. External funding for the honors program was obtained for several years of operation. A competitive application procedure has produced a remarkably diverse and high-quality set of students for the honors program (Appendix B). After the first year's experience, the four faculty involved (with only a dozen or so students each year) recognized that even after three years of multidisciplinary training, Stanford students still needed more hands-on experience with the integration process, particularly for the policy aspects of environmental issues. Thus, the first quarter of the IIS honors program is now devoted to the analysis of practical case studies of environmental science, technology, and policy problems (e.g., acid rain, global warming, etc.). Lectures on risk analysis, cost benefit methods, the regulatory context, and communicating complicated issues into the political process

through the media were all included. Students are expected to know the difference between "facts" and "values," what testimony is given, and to be familiar with the nature of the decision making process in industrial, federal agency, and legislative bodies.

The next two quarters are devoted to student presentations on the ideas behind their theses, preparation of interim drafts, and ultimately their final defense before faculty and student colleagues. Simply put, as the year goes on, questions and comments from the faculty at honors sessions are deliberately restrained and the students themselves, with diverse background (Appendix B) begin to take over the job of melding themselves into an interdisciplinary unit capable of penetrating analyses of their colleagues' work.

As one of the four faculty in this experimental program, I can attest to the high degree of satisfaction personally derived from association with these hard working and dedicated students, and the amazingly high quality of their work. (Several of their projects already are being considered for formal publication.) On the other hand, in all candor, it is extremely expensive to have student-to-senior faculty ratios like the one in this program (12 to 4), so this model is simply not feasible for the vast majority of students at most educational institutions. That would have been true at Stanford, too, had not a charismatic leader here secured a generous, but temporary, externally funded gift. Nevertheless, what can be readily generalized from this experience is the important need to bring "tracked" students back together on real world problem-solving exercises, and for them to have multidisciplinary contact with their colleagues that will hopefully lead to some interdisciplinary rapport and understanding.

Co-terminal Masters in Earth Systems. One potential drawback of the successional model in Table 2 or of the Stanford examples presented so far is that by the end of the bachelor's program, an earth systems graduate would typically have had less in-depth training than a disciplinary major graduate, although the environmental change student's training would provide a much broader context in which to place environmental problems. In order to increase the competitiveness of such environment program graduates with disciplinary graduates in job markets, Stanford recently created a "CoTerminal master's degree." This option allows a student to receive both bachelor's and master's degrees in earth systems in five years. The master's has rigorous requirements (Appendix C) for basic, multidisciplinary methodological training in physical,

biological, and social sciences, and math. However, a student is then free to pursue further course work in his or her specialized track. Thus, upon graduating in five years, he or she could have depth in disciplinary content roughly equivalent to a B.S. in a discipline, but the ES student likely would have much greater understanding of the interdisciplinary context of global change problem solving. Preliminary experience suggests that this not only puts the "environment" students on equal footing for disciplinary jobs with bachelor's degree disciplinary majors, but gives them a distinct advantage if they choose to work in a variety of environmental fields.

A Permanent Environmental Unit: The Environmental Educational Climax

On Figure 2 an "entity" was proposed in the center of the diagram to house on a permanent basis the integration experts who serve the purpose of being an interface among scientists from different disciplines, and the outside "user community" which needs emerging global change information for practical decision making. Such an entity could be a new department and/or school, or perhaps even an existing institute or center. The factor that puts it at the "climax end" of the successional model on Table 2 is that it would have permanence, with the capability of granting tenure to deserving and quality reviewed staff (with quality review standards based on interdisciplinary rather than disciplinary criteria, as outlined earlier), and would be an institutional home where research, teaching, and outreach can all be practiced and evaluated as a whole. With regard to outreach, it is my belief that scientists involved in global environmental change studies have the obligation to inform their colleagues and society at large in clear and understandable terms about the emerging state of the art in this field. While not all scientists are equally skilled at public presentation or technology transfer, nor do all desire to be involved in the policy process, at a minimum I believe that students trained in global change science should be given some instruction in techniques for clear communication, the nature of media coverage, the use of metaphor, and the need for public information in this area. Then, they, as well as faculty residing in some global environmental change organizational entity, can choose to what degree they wish to emphasize public outreach in their career; but at least they will be informed of the context and have some skills in this area. At a minimum, I would hope that all global change professionals and students would be receptive to the different outreach styles of their colleagues, including those who invest great efforts at this - provided those outreach activities are of high quality and are responsible representations of often confusing and contradictory results.

At this stage, I might add a personal prejudice: that the best teachers of global environmental change will probably be those who are either themselves researchers immersed in interdisciplinary problems, or who are intimately familiar with research and researchers who pursue this kind of work. For this reason I believe that new organizational entities, which are dedicated to integrative activities that unite research, teaching, and outreach, will have the highest quality global environmental change activities.

Post Graduate Training

Finally, two additional categories appear at the end of Table 2 and deserve brief mention. One is Ph.D. education and the second is career change programs for existing professionals or students who are already trained. With regard to Ph.D.'s in global environmental change, there is legitimate debate among those who believe that global change Ph.D.'s should be problem solvers pursuing interdisciplinary research according to the three *interdisciplinary* quality criteria mentioned earlier; and others who feel it is still in the best interests of students to pursue a more narrowly focused, discipline-like thesis, and then to become increasingly broad in the next phases of career growth 'or perhaps to defer such breadth until after tenure. While there are pro's and con's to both positions, my belief is that institutions should not rigidly adhere to either model, but should make flexible decisions based upon faculty and student interests and abilities, and individuals' willingness to take risks. However, in all cases a Ph.D. candidate in global environmental change needs to recognize that there may be suspicions about his/her capacity to do in-depth work. Thus, regardless of whether the originality of the thesis is in the disciplinary component, the interdisciplinary component, or both, a Ph.D. candidate would be well advised to be particularly careful to produce a substantive, useful, and original piece of work.

As for the retraining of working professionals from industry, government, or individual disciplines, who wish to pursue a career shift into global environmental change areas, a number of institutions have already created master's degree programs for such students. What seems essential in these programs is to have a core set of courses that insure that the student has adequate depth in physical, biological, and social sciences to understand the global change context, while at the same time having the opportunity to pursue special topics in more depth. With regard to the Ph.D. program again, there are many examples in many institutions of individual faculty members who work across departmental or institutional lines doing multi- or occasionally interdisciplinary

environmental research. Such faculty also are often willing to fund and train a few graduate students on such projects. However, as laudable as this activity may be, I must ask: How many of these still unusual interdisciplinary Ph.D.'s would be hired as entry level faculty members by a university, whose departments are structured by discipline, given that the disciplinary contributions of these young scholars may not be as weighty as other recent Ph.D.'s who stayed fulltime within the traditional disciplinary boundaries and/or published single-authored, basic research papers rather than team-authored, problem-driven publications?

This raises for me an ethical issue: Should we in academics be training such interdisciplinary doctorates if we wouldn't hire them as colleagues? Furthermore, can we do a truly fine job of integrated interdisciplinary teaching when so few of us have become adequately knowledgeable in three or four environmentally-connected, but still distinct disciplines - disciplines that are needed to do interdisciplinary research that is quality evaluated on interdisciplinary rather than disciplinary criteria?

Advocacy Conclusion

It is my belief that only through the ultimate creation of new, permanent, interdisciplinary environmental organizations within academic institutions can such high quality programs be pursued on more than a piecemeal or temporary basis. It seems unimaginable to this "global changeologist" that universities, or other research and educational institutions claiming a significant share of public resources, could willingly turn down the opportunity to examine both intellectually interesting systems problems and socially important questions, such as understanding, predicting, and managing global environmental change, simply because it demands modification to existing institutional structure or because peer prejudice is in the way. Solutions to the formidable obstacles outlined in this chapter and elsewhere in this volume are given throughout the book. Hopefully, models such as those presented here and in other chapters can help managers, scientists, legislators, and educators to develop or expand research, teaching, and outreach efforts in global environmental change. I do not believe that these models necessarily fit all situations, nor should they be rigidly followed. The essence of the development of global environmental studies entities is flexible institutional change fashioned to meet the specific needs of a wide variety of actors and institutions. But the one thing of which I am certain is that current institutions are not remotely adequate to the task of producing

sufficient numbers and quality of students, scientists, managers, and environmentally literate citizens to match the urgent needs of a world undergoing rapid and potentially serious global environmental changes.

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