Practicing Interdisciplinarity

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We explore the practical difficulties of interdisciplinary research in the context of a regional- or local-scale project. We posit four barriers to interdisciplinarity that are common across many disciplines and draw on our own experience and on other sources to explore how these barriers are manifested. Values enter into scientific theories and data collection through scientists' hidden assumptions about disciplines other than their own, through the differences between quantitative and interpretive social sciences, and through roadblocks created by the organization of academia and the relationship between academics and the larger society. Participants in interdisciplinary projects need to be self-reflective about the value judgments embedded in their choice of variables and models. They should identify and use a core set of shared concerns to motivate the effort, be willing to respect and to learn more about the "other," be able to work with new models and alternative taxonomies, and allow for plurality and incompleteness.

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Thinking collectively about complex problems requires crossing boundaries both horizontally (across disciplines) and vertically (across experts, policymakers, practitioners, and the public) (Klein 2004). Although the debates on climate change discussed elsewhere in this issue (Norgaard and Baer 2005a) exemplify strong boundary crossing in both dimensions, most scholars, when they venture into collective thinking, may begin with collaborations that stress the more academic, horizontal crossings. Much of the current interdisciplinary research on the environment is probably of this kind, and it also tends to have a smaller geographical focus than ongoing debates on climate change. Without gainsaying the need for crossings in the vertical dimension, an analysis of interdisciplinarity in this limited context can provide useful insights into the problems generated by researchers' disciplinary training and conditioning. In the context of working with a team of scholars from several disciplines on a regional-scale project, we explore the practical difficulties of participating in interdisciplinary research, drawing on our own experience in the fields of forestry, biodiversity, and hydrology, as well as other sources.

When scientists come together in such teams, it is usually around some shared interest, such as conserving biological diversity or improving the food security of the poor. These shared interests, however, do not translate into a research plan with predetermined bridges between the disciplines. Problems may show up early. When engaging with their colleagues in other fields, scientists typically find that their colleagues define the problem quite differently or seek different types of answers. For a few, this is an exciting discovery that energizes them to understand these differences. Many, however, decide that it takes too much effort to communicate and share knowledge within such a disparate group, and happily retreat to their own special fields, where all the participants use the same models of analysis, are comfortable with the assumptions they share as a group, and consequently "know" the same things. The purpose of this article is to help researchers who do choose to engage in interdisciplinary work by identifying the barriers to interdisciplinarity in a way that makes them easier to overcome. At the outset, we would like to point out that the term "discipline" is a little too slippery for a thorough analysis of the types of barriers that need to be surmounted (box 1). But given that most of us are brought up with these disciplinary labels, we will continue to use the major disciplinary categories or blocks (the "natural" and the "social" sciences) as a starting point, identifying the inconsistencies and subtleties as we go along. We should also mention that, for the sake of brevity, we use the term "interdisciplinarity" loosely to describe all types of crossings between or among disciplines, glossing over the subtle differences between multi-, inter-, and transdisciplinarity that are highlighted in more elaborate discussions on this subject (see, e.g., Kockelmans 1979).

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We begin by outlining a common set of barriers that scholars from different disciplines are likely to encounter when they come together to work on a project. Next, we discuss which barriers are most important and what shape they take when working within the natural sciences. Third, we address the more difficult problems of working across the natural and social sciences. One of the reasons it is so difficult for natural scientists to work with social scientists is because the latter themselves are divided, as we explain in more detail below.

Barriers to interdisciplinarity

We identified four major types of barrier to interdisciplinarity. First, there is the problem of values being embedded in all types of inquiry and at all stages: in the choice of questions, theoretical positions, variables, and style of research. But certainly natural scientists, and even social ones, are loath to acknowledge the presence of value judgments in their work. Furthermore, in the context of contentious social issues (e.g., sustainable development), decisionmakers call on scientists to provide "objective" advice, making such acknowledgment even more difficult. Consequently, the collective judgment required in interdisciplinary research is especially difficult. It is fraught with the possibility that scientists will "talk past each other" because of the ways in which the disciplines assert ethical neutrality and cast a blind eye to their own normative positions.

Second, researchers in different disciplines may study the same phenomenon but differ in their theories or explanatory models (and underlying assumptions). In the case of complex phenomena, it is not easy to prove the superiority of one theory over another in a particular case. Maintaining allegiance to one's school of thought may come to seem more important than openly exploring which explanation seems to work better in a particular context. This seems to be the case particularly within the social sciences, but it is also true for ecology. The level of complexity of ecological phenomena, and hence the underdeterminacy of the science, resembles the situation in the social sciences. On the other hand, sciences that have developed at the borders of the social–natural divide (e.g., agronomy in the natural sciences or agricultural economics in the social sciences) are required to make some assumptions about the processes that intrude from the other side (e.g., the decisionmaking process of the farmer or the nature of agroecosystems, respectively). These disciplinary assumptions about the "other" half of the system constitute simplistic models that must be abandoned and replaced by more complex ones.

The third type of barrier is the one that has been most emphasized in the literature on interdisciplinarity: the differences in epistemology and hence in specific methods, notions of adequate proof, and other fundamental assumptions of different fields. As Bauer (1990) puts it, "Scientists (and engineers) believe implicitly in certain absolute truths, and further believe that given enough time and effort the ultimate truth can be found, whereas for some philosophers, sociologists and other [social scientists] there is no absolutely determinable truth" (p. 106). These differences may exist even between disciplines within each disciplinary block. Certainly a major difference between the approaches of anthropologists and economists is their differing perception about the objective versus subjective nature of scientific knowledge and whether it is context specific or general. Within the natural sciences, although belief in the "knowability" of the world generally reigns supreme, scientists studying complex processes such as those in ecology have grappled with the question of how much we can know through reductionist models and experimentation (see, e.g., Botkin 1990).

Finally, the way in which society interacts with and organizes academia influences the production of interdisciplinary research. As Schoenberger (2001) and others have pointed out, the relative importance or validity of a direction of inquiry or approach is not determined simply by some objective recognition by academics of its ability to generate more valid knowledge than another approach. Forces at work in a larger society outside academia shape the perception of importance gained by a certain discipline, or by a particular kind of interdisciplinary crossing. This generates differences in the attention paid to (and resources commanded by) different disciplines, and consequently conditions behavioral patterns, such as arrogance or defensiveness, among their practitioners. Society also influences the institutional arrangements within academia that create incentives or disincentives for interdisciplinary knowledge production.

Below, we elaborate on these barriers to collective interdisciplinarity, and discuss more specific examples. We begin with a brief discussion of the smallest divides or barriers—that is, those within the natural sciences—followed by the big divide between the natural and the social sciences, and then the even bigger divide between the quantitative and the interpretive social sciences.

Divides within the natural sciences

Interdisciplinary thinking is easiest between disciplines within the natural sciences, but even in this context, it is not painless. The first kind of interdisciplinary barrier (difference in values) is neither directly discernible nor easily separated from the second (difference in theories, models, or worldviews). The judgment about what features of a natural phenomenon are important seems simply a subjective (individual-level) judgment about how to describe reality. But when this process is carried out in the context of applied science questions, it becomes clear that the question has two parts: a value judgment about what features are of ultimate concern or importance to society (such as productivity of useful plant species) and a more "scientific" judgment about what variables or features are most relevant in the effort to describe how these socially important features change (e.g., trophic structure of the community, species composition, or physiology of individual species). Answers to the first question are shaped by the individual's normative concerns, by the cultural trends within his or her subdisciplinary community, and also by the choice of the descriptive model itself

(Lélé and Norgaard 1996). The choice of methods, driven by different epistemological assumptions, also differs across subdisciplines within a particular subject area. These judgments and choices have different implications for work within and across disciplines.

When scientists from two different natural sciences try to work together, differences in value judgments and models manifest in the form of what we call "mismatched taxonomies." Scientists working in a subdiscipline often tend to believe that their particular way of categorizing phenomena (taxonomic system) is the best way of characterizing reality, rather than being open to different ways of representing reality that might be more or less appropriate in different applied contexts. For instance, for years soil scientists have been debating as to which system of soil taxonomy is the best. The US Department of Agriculture (USDA) soil taxonomy system appears to have won the battle and become the most commonly accepted classification. But if the purpose of soil classification is to relate soil types to forest vegetation types or agricultural fertility, the USDA soil taxonomy is not very useful. Indeed, when soil scientists shift from working on fertility questions in agricultural soils to working on sustainability questions in forests, they may have to change not only their taxonomy but also their methods (typical soil depths sampled, parameters analyzed, etc.). But once the problem of mismatched taxonomies is recognized and addressed, communicating across disciplines in the natural sciences becomes quite easy.

Collaboration between particular types of scientists within the same broad area can also be difficult. Within the biological sciences, in particular, there are significant differences in the models used to study the same processes. This is largely due to the difficulties of holding many factors constant in living systems and investigating particular factors in the mode of reductionist science. Thus, ecologists have to make some strong assumptions about how a system works, and the assumptions differ between approaches or schools. Energetics models and their underlying assumptions, for example, differ fundamentally from the models and assumptions in community ecology, akin to the differences among patterns of thinking in the social sciences. To some extent, these assumptions are adjusted through tacit knowledge gained from experience. Generally, natural scientists are fairly cognizant of and comfortable with their differences with one another, compared to their differences with social scientists. Natural scientists are relatively open to working with each others' judgments, and generally able to make the necessary conceptual adjustments.

The main barrier to interdisciplinary work—for example, to a collaboration between a botanist and a soil scientist—lies in the relative absence of motivation. This in turn is related to the last of the common barriers discussed in the previous section, namely, the link between science and society and the structure of academia. Most scientists do not see the low level of cross-disciplinary collaboration as a problem. Most are happily addressing the questions that have already been identified within disciplinary boundaries, in the belief that pushing the frontiers of each discipline will eventually lead to the convergence of all knowledge. Crossing boundaries to solve environmental and development problems distracts from pure research, where academic prestige is still highest. Some funding agencies are trying to break down the hierarchy of pure over applied science as they increasingly support applied research in their attempt to address pressing problems of environmental change and poverty. Nevertheless, we believe that the motivation for crossing disciplinary boundaries even within the natural sciences remains generally low.

Bridging the big divide: Linking the natural to the social

The divide between the two major disciplinary blocks (the natural and the social sciences) is large and multidimensional. All four of the types of barriers identified above have significant explanatory value.

The value-laden nature of science. What starts out in the pure sciences as only a problem of subjective choice of taxonomies or models burgeons into the issue of the value-laden nature of natural science when working on phenomena of social relevance. But most natural scientists have been brought up on the notion that science is value neutral. This belief proves to be a barrier both to working across disciplines and to doing good science.

Take the example of forest management. Tropical forests contribute a variety of benefits, but these benefits flow to different groups in society. Some of these benefits, such as fuelwood, fodder, leaf manure, timber, and minor produce, may flow to communities living close to the forests, while watershed services flow primarily to those living in the plains downstream, and carbon sequestration benefits accrue to the entire global community. Different ways of managing forests yield different mixes of benefits. Dense, undisturbed forests yield high levels of biodiversity and watershed services, but little by way of tangible products. Carefully managed, lopped forests might yield high levels of fuelwood, fodder, and leaf manure, but reduced levels of biodiversity and medium levels of watershed benefits. Monocultural timber plantations, on the other hand, would maximize timber production at the expense of most other benefits. Some of the benefits generated by forests, such as fodder or fuel, may also result from nonforest land uses, such as coffee plantations or croplands. Thus, prioritizing forests over other land uses, and certain forest management systems over others, means valuing certain benefits and certain beneficiaries over others. When one decides which mix of benefits is correct, one is deciding how the diverse needs of different sections of society and of present versus future generations should be valued. This decision is essentially a social or political one. Science can illuminate this social debate by generating a clearer estimate of the trade-offs and complementarities between different benefits, but science cannot settle the debate.

Furthermore, as noted earlier, judgments about what is socially valuable (what kind of forest should be sustained over what period of time) are almost inextricably linked to the subjective choices of the dependent variables, the likely set of independent variables, the functional form of the model, and the scale of analysis. That these are value-loaded choices becomes clear when one thinks of how different ecologists might respond to the question, "What constitutes a good forest?" The chances are that community ecologists might define this as a highly diverse forest, whereas energetics modelers might define it as a highly productive forest.

Unfortunately, debates in forestry have often been fruitless because they really are normative debates about what should be the goal of forest management, not scientific debates about which method of forest management will or will not achieve a particular goal (or mix of benefits) in a sustainable manner. For instance, in the Western Ghats region of India, colonial foresters in the late 19th century were up in arms against the local practice of lopping or pruning forest trees to obtain leaf manure and fuelwood, and predicted that "such land must become utterly barren" and that "ruin and desolation will be the outcome" (MacGregor 1894). Foresters and ecologists in postindependence India seemed to concur. However, rigorous measurements showed that even a century after these dire predictions, the extent of barren land was limited, and the productivity of the intensively lopped forests was much higher than estimated. Often (though not always) it was sufficient to meet the harvesting pressures (Lélé 1994, 2000). Rather than being a scientific judgment about what harvesting and management practices are sustainable, the foresters' criticisms seem to be driven by their underlying value judgment that such intensive use of forests was inherently undesirable.

Natural scientists are usually uncomfortable with the idea that "environmentally sound development" is not a self-evident, value-neutral concept. They have attempted to hang on to the cloak of value neutrality in different ways. For instance, in the context of ecosystems, some scientists try to argue that sustaining biodiversity automatically sustains all other products and services. Some try to portray ecosystem integrity, ecological health, natural capital, ecological footprint, or a green GDP (gross domestic product), for example, as objective measures. One can easily show, however, that the creation of new concepts and aggregate measures in response to a perceived problem does not get rid of value judgments. Each of these concepts is relevant only with respect to a particular choice of ultimate values or variables of interest, or to particular notions of how disparate values should be aggregated (Lélé and Norgaard 1996, Bowker and Star 1999, Rykiel 2001).

When we attempt to bridge the big divide, such hidden value judgments can cause serious problems. When social scientists are insensitive to this problem, they may take the natural scientists' assessment at face value, as an objective assessment of the quality of resource management, and end up taking their subsequent analysis further astray. For instance, in the case of the heavily used forests in the Western Ghats, Nadkarni and colleagues (1989) assumed that the forests were degraded (à la MacGregor 1894) and then tried hard, but with limited success, to explain why these individually controlled forests suffered a tragedy that is supposed to be restricted to the "commons" (Lélé 2000).

On the other hand, when social scientists do point out the possible ways in which natural science may be value laden, natural scientists are likely to become upset and defensive. For instance, in a workshop aimed at exposing economists to basic hydrology, the hydrology expert introduced the concept of "groundwater potential" and "sustainable utilization." The latter was defined as the situation in which groundwater extraction does not exceed the rate of groundwater recharge. At this point, an economist pointed out that this definition was debatable, because if communities living in the upper part of the watershed (typically where most of the rain falls and recharge occurs) were to extract the entire recharge, it would leave no water for downstream communities or for base flow in the river. The hydrologist took quite some time to understand the empirical point being made and, even then, insisted that the official definition of sustainable extraction was "correct."

Assumptions about other disciplines. Natural scientists tend to think of disciplinary differences as reflecting primarily differences in the subject matter studied (and hence to think of disciplinary perspectives as complementary). This means they are unprepared for the competition and even open hostility among social scientists from different fields. The various schools of thought in the social sciences address individual behavior and social interactions, but they do so using different assumptions. Furthermore, they may use the same words with different meanings, associated with different historical lineages. This makes it difficult for natural scientists to know which type of social scientist to work with. As a result, we have "interdisciplines" such as ecological anthropology and ecological economics. The ecological models in these interdisciplines may be the same, but the social science assumptions, models, and language differ. Natural scientists need to expect to take considerable time learning the cultures of the different social sciences if they are even to think about how to put together or join an interdisciplinary team, let alone actually work with the social science members of the team.

At the same time, natural scientists must unlearn their implicitly held social science theories. Natural scientists have often been the first to point out environmental problems of enormous social consequence. Naturally, they participate in, and often lead, societal efforts to address these problems. Charged with providing policy recommendations, they have to make judgments about how society works. They do not have adequate training to do this, but they are perhaps emboldened to do so by their position and are likely to adopt simplistic models of social dynamics. As a recent article in *Nature* put it, "Few of us know much about the dynamics of the cosmos, but we all know plenty about human nature—or at least we think we do" (Anonymous 2005, p. 1003). Thus, natural scientists have applied models of biological carrying capacity to human systems even though, unlike other animals, human beings constantly innovate and also respond to resource scarcity by varying their levels of consumption enormously. Natural scientists have used proximity analysis to assign blame for forest degradation, ignoring the fact that property rights may shape forest use much more than proximity. And of course natural scientists' quick recourse to ignorance as an explanation of unexpected or seemingly irrational behavior by poor communities ignores the logics imposed by poverty. In short, seeming familiarity with social issues can get in the way of recognition of the rigor and depth of the "other" that is necessary for a true cross-disciplinary collaboration.

Belittling the "other," however, is by no means the preserve of the natural sciences alone. Many social science theories and their adherents have tended to ignore or underplay the constraints imposed by natural resources and processes on human actions. Even today, many economists continue to use arguments based on economic models that assume an infinite substitutability among resources through technological change (Lomborg 2001). For others, such as hard-line Marxists, technology matters but is entirely determined by social factors, so it is not necessary to understand the relationship between technologies and environmental systems.

A first step in countering this problem may be to refer to the natural sciences as "unsocial" and the social sciences as "unnatural" as an interdisciplinary team is forming. Acknowledging what each side does not know may help promote the individual honesty and humility necessary for all team members to work together. A second step might be a careful choice of linking variables that simultaneously capture the critical social aspects of natural processes and the critical natural aspects of social practices. Forest ecologists studying the impact of fuelwood collection on forests should distinguish between differences in harvesting practices, such as the ratio of green wood to deadwood extraction or the girth of saplings felled, rather than simply focusing on tons of biomass (Lélé 1993). Hydrologists should identify exactly which portion of streamflow or infiltration is useful to which community, rather than giving gross values for these variables. And political scientists should be more sensitive to the ecological dynamics of a resource before trying to link group size or other variables to the presence of collective action. In the long run, one can expect this interaction to change the individual disciplinary models to some extent. For instance, detailed research on pastoral communities in the Sahel by ecological anthropologists has contributed as much to overturning the equilibrium model of grassland ecosystems in favor of the disturbance model as has research by ecologists (Mace 1991).

Epistemological and methodological mismatches. Much has been said about the epistemological differences between the two disciplinary blocks as well as those within the social sciences (Kanbur 2001). There is a general belief that natural science is quantitative and therefore rigorous, whereas social science is qualitative and therefore not rigorous. Most of the assumptions underlying this belief, however, are invalid. Not only has quantitative thinking been extensively adopted in the social sciences, but, more important, qualitative thinking can be as rigorous as quantitative thinking, and quantitative thinking does not prevent bogus rigor arising out of patently wrong assumptions (DeCanio 2003).

Of course, perceptions and preferences do not change easily. Thus, mathematical ecologists have shown a greater willingness to collaborate with mathematical economists than with other social scientists. But other approaches, such as political ecology and ecological anthropology, are also flourishing, suggesting that the qualitative–quantitative divide is not a fundamental barrier to integration across the divide between the social and natural sciences. Practical constraints might in fact turn out to be more important. Understanding environmental change caused by human actions (e.g., the effect of deforestation on hydrology) requires sampling across different intensities of human-induced environmental changes (e.g., watersheds with different levels of deforestation), keeping other variables (e.g., rainfall and soils) constant. But to understand how these environmental changes affect human communities and, more important, what factors influence human response to environmental change, researchers need samples wherein the extent of environmental change is similar (e.g., similarly deforested watersheds) and only one social factor varies (e.g., the strength of collective-action institutions). Finding adequate samples of such situations in the real world is virtually impossible, and studying even limited samples may require enormous resources, leading to tensions about which questions to prioritize.

The social standing of the social and natural sciences. There are significant differences in the manner in which society treats the social and natural sciences (and disciplines within them). These differences are reflected in the incentives and support provided for, attention paid to, and hence attitudes cultivated toward the two disciplinary blocks. In most countries, the natural science–social science divide is reinforced early on. India, where the first author is located, is perhaps an extreme case, where students are forced to choose between "science" and "arts" as early as the 11th year of schooling, and where the exposure to the arts, humanities, and social sciences in the undergraduate science-related programs is minimal and their status minimized. The undergraduate courses in the social sciences are completely bereft of the "natural." The liberal arts approach to education in the United States may be at the other end of the spectrum, but the divide is still present.

More than just lack of exposure to the "other," it is the clear signals of superiority or inferiority that are communicated to academicians (and by them to their students) that are a problem. Many societies, especially Asian ones, are constantly telling students that, when choosing between science and the arts and humanities, "science" is superior to "arts." This signal is reinforced at the undergraduate stage by the half-hearted manner in which the social sciences are taught in most professional courses. Naturally, the social sciences are seen as

Box 1. Forget disciplines, think scientific communities.

Disciplines are academic administrative artifacts. There is both a great deal in common across disciplines and much variety within them. In the social sciences, market economic models are used in economics, anthropology, history, sociology, political science, public policy, and even psychology; those from different disciplines who use these models may have more in common with each other than with those from the same departments who use Marxist perspectives. The biological sciences have reorganized over the past quarter-century, dropping the historic disciplinary distinctions, for example, between the plant and animal world and organizing more on levels of analysis from the gene to the organism to the ecosystem. Yet evolutionary biology cuts across all levels of analysis, and ecologists use genetic techniques to understand ecological systems and processes. Thus the structure of scientific knowledge and the differences in epistemologies, theories, and methods among scientists have little to do with what have historically been called disciplines. So, when approaching collaborative work between scientists, forget disciplines; think scientific communities.

A scientific community is a group of scholars who share a characteristic. The characteristic may be in one or more of the following epistemic categories:

- Subject focus (e.g., a species, economic systems, a region, or society and technology). Some universities have regional studies programs, society and technology programs, or other interdisciplinary institutions with faculty participating from multiple departments.
- Assumptions about underlying characteristics of the factors they study (e.g., the assumption that individuals are rational utility maximizers and a population can be understood as the sum of its individuals or, alternatively, that culture guides individual behavior and individuals can only be understood in the context of their culture).
- Assumptions about the larger world they do not study, and about how what they do study relates to the larger world (e.g., the assumption that the external environment is predictable because it is constant or exhibits regular patterns, or is unpredictable because it is complex or chaotic; the assumption that the long run is not important, or need not be considered, because technological progress is unpredictable or offsets resource scarcity). Such framing assumptions can serve as rationales for not considering more systemic questions.
- The models they use (e.g., mechanical, hierarchical, evolutionary, narrative). Note that, in the current climate of academia, formal models, especially mathematical models, give more credibility to a community.
- The methods they use (e.g., mathematical, statistical, interpretive, ethnographic).
- The audience they strive to inform through their research (e.g., other academics, policymakers, professional practitioners, a democratic public, corporations).

Holding a common characteristic in any of these categories can be a source of scholarly community. Scholars who use statistical techniques can share their statistical knowledge without having to share anything in the other five categories. Two scholars who work in the Amazon can usually talk for hours, even if they differ in the other categories. Of course, if the Amazon scholars start to argue over Adam Smith versus Karl Marx, their camaraderie can quickly break down. Clearly, sharing characteristics in more categories reduces differences and provides a stronger sense of community. Scholars within a tight community can work easily together because of all that they share, but the scholars who are most dependent on the security of sharing characteristics across the different categories are least able to work with scholars from other communities.

Note that not all combinations of characteristics across the categories are possible. Looking at a subject as a separate entity (individualism, atomism, or reductionism) and using mechanistic models are compatible with statistical techniques of analysis. Interpretive methods and storytelling are consistent with seeing everything as contextual (place specific), contingent (dependent on history), and interlinked.

(continued)

irrelevant, boring, and nonrigorous. Conversely, the social scientists, because they purportedly were not good enough to get into the "science stream," are often in awe of the natural sciences. The belief of the superiority of the natural scientists is so deep-rooted that whenever social problems have the slightest technical dimension, politicians have traditionally called on only technicians—the natural scientists—to help solve them. Social scientists were only invited into the US National Academy of Sciences in the 1950s, when natural scientists discovered they could use their help (Simon 1996). Until the latter half of the 20th century in the developed world, and more recently in the developing world, most governmental committees on natural resource management were constituted solely of natural scientists and engineers. The Intergovernmental Panel on Climate Change, or IPCC, was initiated by (and its leadership is dominated by) natural scientists, even though the origins and impacts of climate change are ultimately highly social. Not surprisingly, then, it is economics—the social science discipline that has modeled itself consciously on the natural sciences—that is considered by laypeople and politicians alike as superior to other social sciences.

Bridging the even bigger divide: Interdisciplinarity within the social sciences

We, the authors, have straddled the big divide between the natural and social sciences for some time and also have been involved in various efforts to promote interdisciplinary research on the environment. We can now attest that it is frequently harder to bridge deep divisions within the social sciences than between the natural sciences and particular social sciences. Economists, sociologists, and anthropologists, for example, may find it easier to interact with environmental scientists than to work with one another. When multiple

(Box 1, continued)

Understanding how the parts of the scientific endeavor do or do not fit together is another important concern for interdisciplinary communities. Some scholars are sure the sciences will unify; they seek that unity, and are convinced that the current disunity means some scholarly communities must be wrong. Other scholars are comfortable with the disunity of knowledge; they are methodological pluralists, and are not disturbed by competing, and sometimes contradictory, insights. Either type of scholar may be able to work with other scholars of the same type (unifying or pluralistic) on a problem that requires cooperation between other characteristics of communities, but there are serious tensions when scholars of different persuasions with respect to the unity of knowledge try to cooperate in an interdisciplinary effort.

These categories do not exhaust the criteria that define scientific communities. Scholars in the philosophy and sociology of science have developed a variety of insights into the ways in which personal networks, specific practices, and various forms of tacit knowledge characterize the organization of the modern scientific enterprise, as well as the ways in which that organization has changed over time (see box 2 in Norgaard and Baer [2005b] for some useful citations). Our point here is to highlight some of the most salient characteristics that facilitate or impede interdisciplinary communication.

Strong scientific communities actively demarcate and defend their boundaries. Most scientific communities are constantly defining themselves, reinforcing why their knowledge is credible, and seeking recognition, authority, and power. Such active communities tout the strengths of their approach to truth and reassert the superiority of their answers. Scholars who drift too far from commonly held characteristics of the community—perhaps in the assumptions they make or their orientation with respect to those they serve, and hence in the nature of the claims about truth that they make—are actively defined as being outside of the community. Praising the good work of those who best represent the community and what it has to say and weeding out those who stray is a part of the process of sustaining the identity and credibility of the community. This means that the social needs of the community can get in the way of openly acknowledging the limits of the particular assumptions or models favored by the community, impeding critical thinking and innovation.

Interdisciplinarity is about working across boundaries. The boundaries are those that define communities and that communities are constantly trying to enforce, so being aware of the different types of boundaries helps one see more clearly the ways in which scholars are different and the sorts of boundaries that need to be overcome, or at least recognized, to work together. Clearly, when there are many boundaries to overcome, it is especially hard to work together. It is also important to recognize the social dynamics of communities, the ways in which they reinforce their identity and credibility through boundary building and enforcement. When first trying to work with a scholar from another community, it is important to be respectful of that community's traditions and to be aware of the limitations of one's own perspective.

Although interdisciplinary scholars must initially learn how to cross boundaries, once there is a significant set of scholars crossing a common set of boundaries, or once a smaller number of scholars organizes themselves to encourage others to do so, they are subject to the same social needs to define the boundaries and assert the credibility of the new community. This may be academically necessary and even useful, but can also stifle attempts at new crossings in the long run.

In sum, it is crucial to recognize that while simple maps of the scientific enterprise still match the organizational charts of universities, these are far from the most important markers of difference and similarity that interdisciplinary scholarship must address. Commonalities exist at many different scales and in many dimensions; scientific communities are both nested and overlapping. Understanding these complexities can make the problem seem tougher at the outset, but should make it easier in practice.

strains of social scientists all work on the same topic, they seem to talk past each other. The reasons include all four of the main barriers to interdisciplinarity discussed above.

Hidden values. Of all the social scientists, mainstream economists are most prone to holding on to illusions of value neutrality, albeit in disguise. For instance, mainstream welfare economists aggregate costs and benefits across disparate sections of society to come up with a measure of net changes in aggregate social welfare. In virtually all valuation studies and cost–benefit analyses, this aggregation is done by simple addition (i.e., assuming that the effect of an additional dollar to the poor is the same as to the rich). When confronted, these economists acknowledge that this additive construction of social welfare function is not value neutral, but there are only a few examples of studies in which a social welfare function is calculated in different ways to represent different possible value positions (for an example, see Howarth 2001). The pervasive discourse about "getting prices right" is another illustration. The belief that there is one right price contradicts basic economic theory, because different distributions of rights, or income, result in different combinations of efficient market prices.

Other social scientists are less likely to insist that their position is value neutral, but they are nonetheless rarely explicit about what values they espouse, and thus end up talking past each other. In a detailed review of the literature on common property resources, Menon (1999) has pointed out how different streams in this literature talk past each other because their underlying normative concerns are different: the collective-action stream focuses on efficiency improvements in resource management, the environmentalist stream focuses on ecological prudence or sustainability, and the poverty stream focuses on the distributive impacts, that is, on impacts of common property resource degradation on the poor. One can detect a reasonably clear correlation between these three schools and their disciplinary roots: the collective-action approach is linked to the rational-choice ideas in mainstream economics and political science, the environmentalist approach has strong links with the natural sciences, and the poverty approach is closer to the anthropologists and sociologists. The correlation is certainly not 100 percent, but the fundamental problem remains. Much academic debate on the commons starts off on the wrong foot by not explicating what each participant's normative concerns and priorities are, and by failing to recognize how participants' individual models make it difficult to accommodate other normative concerns.

Competing explanations. The problem of interdisciplinarity within the social sciences cannot, unfortunately, be solved simply by choosing a common set of values or variables of concern. All social science disciplines are ultimately attempting to understand the same broad phenomenon, human behavior. At the cost of some simplification, one might say that each social science discipline (or subdiscipline) makes different assumptions about the key driver or drivers of human behavior. Mainstream economists believe the key driver is material benefits, certain schools within sociology believe it is power, and certain schools within anthropology believe it is cultural norms and value systems. These basic assumptions are not prima facie mutually incompatible, and no doubt different combinations of interactive phenomena are more important at different levels of explanation. They are, of course, incompatible within any simple model. Disagreements within the social sciences, however, are therefore extremely deep-rooted, in part because of a mistaken belief (left over from 19th-century physics) that social phenomena ought to be explained, or largely explained, by a few universal principles.

Different explanations of environmental degradation illustrate how social science disciplines compete. Neoclassical economists insist that the problem lies in missing markets or in the improper setting of prices of resources and pollutants. Political economists focus on the fact that different economic classes have different levels of access to natural resources, and the material consumption and pollution by the powerful classes comes at the cost of the less powerful. Institutionalists explain resource degradation in terms of the failure of institutions to properly assign rights and responsibilities so that market and other systemic failures do not occur. Ecofeminists have argued that environmental degradation is related to the domination of women by men, while anthropologists have argued that it is related to how human beings perceive their relationship with nature. Mahatma Gandhi pointed out that "there is enough for every man's need but not every man's greed," suggesting (somewhat like an anthropologist) that we have to look within ourselves and our value systems rather than the structure of society for the causes of environmental degradation. This is not to deny that some very interesting and fruitful disciplinary crossings are taking place within the social sciences. But they do not seem to have affected the mainstreams in the disciplines. The reason may be that the very identities of some of the disciplines or subdisciplines rest on the belief that their own explanatory model or method is the superior one. This is certainly true of the mainstream economists and their rational choice model, which has had a hegemonic position in the social sciences.

One approach to interdisciplinarity in the social sciences might be to assume that all these explanations have general validity, but that in specific cases one explanation may be superior to the others. Underlying this approach is a view of human beings as having multiple personalities: the economic personality asserts itself in the market, the political one in elections, and some other personality in the interaction between the genders. Sometimes human beings are driven by material considerations and sometimes by cultural factors. This may be related to the traditional idea that different disciplines explain human behavior at different levels: the household, the community, the nation, and so on. In this situation, one needs some kind of metatheoretical procedure for determining a priori which one of several possible explanations is likely to be appropriate in a specific context. To use such a procedure, researchers would need to train extensively in different social science theories, without absorbing the dogmas associated with each theory, so that they could pick and choose depending on the situation.

Eventually, social scientists need to figure out ways of working with several theoretical frameworks that may be simultaneously plausible. For instance, the failure of a particular institution of common-pool resource management may be rooted both in the norms inherent in cultural explanations and in the disproportionate distribution of power assumed in political economy explanations. Given the differences in scale of operation of these factors, testing such multicausal frameworks through some kind of statistically rigorous approach is an insurmountable task through formal analysis. This means that researchers who address multicausal, interacting phenomena must rely on an open discourse to take advantage of the different theoretical frameworks and tacit knowledge associated with different fields, and to come to a measured, qualified judgment.

The epistemological and hence methodological divide separating mainstream economists from anthropologists and other interpretive social scientists—with economists equating rigor with quantitative methods and mathematical models— is quite well known (Bardhan 1989). It explains why mathematical ecologists find it easiest to collaborate with economists (Perrings et al. 1995), whereas natural historians are perhaps more comfortable working with anthropologists (Maffi 2001). Sadly, this divide has even manifested itself within recent efforts to address environmental issues from within economics, with hard-nosed "environmental" economists (especially in the United States) finding it difficult to accept the contributions of the more pluralistic "ecological" economists.

The higher social standing of economics vis-à-vis other social science disciplines, and the consequent tensions between these disciplines, is also something that has been commented upon, with the hierarchy being strongest in developing countries such as India. This may be partly explained by the apparent quantitative rigor and exact prediction that economics shares with the natural sciences. But the main explanation may lie in the commonality of values and worldviews between a certain subdiscipline of economics (mainstream neoclassical economics) and those institutions that are currently setting the developmental agenda.

Concluding remarks

Doing collective interdisciplinary research, especially projects stressing the feedbacks between social and environmental systems, is difficult at the best of times. Yet surely most efforts fail before they get seriously under way because the participants from different intellectual communities never recognize the barriers created by their separate ways of understanding and approaching problems. We have provided a bird's-eye view of some of the important barriers scientists need to understand in order to overcome them.

We have argued that participants in interdisciplinary research projects must overcome various biases and prejudices that accompany disciplinary training. Contrary to their disciplinary training, participants need to be self-reflective about the value judgments embedded in their choice of variables and models, willing to give respect to and also learn more about the "other," and able to work with new models and taxonomies used by others. Even with apparently well-integrated models, the project team needs to keep thinking flexibly and allowing for plurality and incompleteness. In this sense, the collective judgments and synthetic interpretations made in interdisciplinary environmental research may have to be more interpretive, as in some social sciences, than the positivist approach of the natural sciences and mainstream economics. At the same time, there has to be a core set of shared socioenvironmental concerns—some ab initio, some negotiated—that would provide the motivation to sustain what can often be an exhausting effort.

This is not to suggest that shared concerns, greater self-reflectivity, and cross-disciplinary exposure will suffice. To promote interdisciplinary research at large, individual- and team-level must be complemented by strategies with major institution-level changes in curricula, incentives, evaluation criteria, and accountability. These may not be in the hands of individuals who seek to do interdisciplinary work; however, some of these constraints could be eased at the outset of major interdisciplinary projects (e.g., by getting parent institutions to agree that the outputs that emerge should not be weighed by conventional disciplinary or departmental standards). A better understanding of the barriers would also help better design interdisciplinary teaching programs. Reflecting on how to think across academic disciplines is only a first step toward bridging the various divides involved in collectively addressing complex environmental problems.

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