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Authors: EIGENBRODE, SANFORD D., O'ROURKE, MICHAEL, WULFHORST, J. D., ALTHOFF, DAVID M., GOLDBERG, CAREN S., et al.

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Employing Philosophical Dialogue in Collaborative Science

SANFORD D. EIGENBRODE, MICHAEL O'ROURKE, J. D. WULFHORST, DAVID M. ALTHOFF, CAREN S. GOLDBERG, KAYLANI MERRILL, WAYDE MORSE, MAX NIELSEN-PINCUS, JENNIFER STEPHENS, LEIGH WINOWIECKI, AND NILSA A. BOSQUE-PÉREZ

Integrated research across disciplines is required to address many of the pressing environmental problems facing human societies. Often the integration involves disparate disciplines, including those in the biological sciences, and demands collaboration from problem formulation through hypothesis development, data analysis, interpretation, and application. Such projects raise conceptual and methodological challenges that are new to many researchers in the biological sciences and to their collaborators in other disciplines. In this article, we develop the theme that many of these challenges are fundamentally philosophical, a dimension that has been largely overlooked in the extensive literature on cross-disciplinary research and education. We present a "toolbox for philosophical dialogue," consisting of a set of questions for self-examination that cross-disciplinary collaborators can use to identify and address their philosophical disparities and commonalities. We provide a brief user's manual for this toolbox and evidence for its effectiveness in promoting successful integration across disciplines.

Keywords: interdisciplinary research, collaborative research, philosophy

Increasing human populations and per capita resource consumption have engendered pressing problems that threaten ecosystem function, ecosystem services, the sustainability of production, and the health and well-being of human populations. Solutions to these problems require the expertise of biologists, but their complexity necessitates integrated efforts involving other disciplines. For example, research to improve sustainability and biodiversity conservation involves ecology, agriculture, sociology, soil science, hydrology, and economics (Palmer et al. 2005). In public health, issues such as AIDS prevention require the collaboration of sociology, anthropology, behavioral science, clinical medicine, bioinformatics, and evolutionary biology (Stillwaggon 2005). Research that crosses traditional disciplinary boundaries (described here as "cross-disciplinary") poses challenges that can be new to scientists, depending on the depth and breadth of integration among disciplines.

First, collaborators must determine the appropriate level of cross-disciplinary integration, from a continuum that includes multidisciplinary, interdisciplinary, and transdisciplinary work (box 1). A suitable level of integration will depend on the problem to be addressed and on the mutual understanding of the disciplines involved. If interdisciplinary or transdisciplinary efforts are required, participants must work together from problem formulation and hypothesis development to data analysis, interpretation, presentation, and application. An emerging literature addresses the obstacles and challenges to integrated, cross-disciplinary research, which include delineating social, biological, and physical aspects of complex problems; identifying commensurable spatial and temporal scales of measurement; identifying interpersonal and group-related dynamics that affect cross-disciplinary collaboration; and adjusting institutional and educational structures to facilitate such collaboration (Benda et al. 2002, Giampietro 2003, Heemskerk et al. 2003, Rhoten 2003, Jakobsen et al. 2004, Lélé and Norgaard 2005, NAS 2005).

In addition to these formidable operational difficulties, cross-disciplinary collaborations entail combining the some-

Sanford D. Eigenbrode (e-mail: sanforde@uidaho.edu) and Nilsa A. Bosque-Pérez are professors of entomology, and Leigh Winowiecki is a graduate student in soil science, in the Department of Plant, Soil, and Entomological Sciences; Michael O'Rourke is an associate professor, and Kaylani Merrill and Jennifer Stephens are graduate students, in the Department of Philosophy; Caren S. Goldberg is a graduate student in the Department of Fish and Wildlife Resources; Wayde Morse is a graduate student in the Department of Conservation Social Sciences; Max Nielsen-Pincus is a graduate student in the Department of Forest Resources; and J. D. Wulfhorst is an associate professor in the Department of Agricultural Economics and Rural Sociology, University of Idaho, Moscow, ID 83844. David M. Althoff is a research assistant professor in the Department of Biology, Syracuse University, Syracuse, NY 13244.

Box 1. A primer on collaborative research.

Although much scientific progress has been made through the efforts of individuals, as exemplified by prominent single-authored works (e.g., by Isaac Newton, Charles Darwin, Albert Einstein, Nikolaas Tinbergen, Sewell Wright, and Ernst Mayr), solutions to complex problems are often best identified through collaboration. Collaborative science allows the integration of the skills, knowledge, and perspectives that pertain to a complex issue. Operationally, disciplines are bodies of knowledge addressing a domain of objects investigated and a vernacular to describe them, an evolving set of problems and methods to determine solutions, and a theoretical framework that explains and predicts associated phenomena (Mitchell et al. 1997; see also Klein 1996, 2004, Naiman 1999, Schoenberger 2001, Rhoten 2003). As such, they tend to be protean, engendering subdisciplines, some of which mature into recognizable disciplines in their own right (e.g., biochemistry, microbiology, and neurobiology), or synthetic disciplines through collaborative combination (e.g., landscape genetics and chemical ecology). Although this plasticity has been perennial, many scientists consider themselves practicing members of specific disciplines, which have been codified through formation of professional societies and academic units.

Effective collaborations differ in breadth and depth. The breadth of collaboration can range from shared work within recognized disciplines to combinations spanning disciplines as disparate as sociology and molecular biology. The depth of collaboration can range from post hoc synthesis of disparate kinds of research results to thorough theoretical and methodological integration. Both the breadth and the depth of collaborations have implications for the methodological, intellectual, and philosophical issues that can arise. Although collaborative breadth and depth exist on a continuum, distinct categories can be recognized. We offer a summary of the most widely applied categories as a frame of reference for examining their philosophical dimensions. For thorough expositions of this classification, readers should consult Klein (1996, 2004).

Disciplinary collaboration
Collaborators may identify with a single scientific discipline, but bring different strengths to their shared work (e.g., empirical versus theoretical versus instrumentational emphases; see Galison 1997). Such research is guided by the metaphysical and epistemological traditions of its discipline, relying on its theory, methods, and interpretive standards.

Cross-disciplinary collaboration
Broader collaboration that spans disciplines can take different forms, typically classified as follows:

Multidisciplinary collaboration. Multidisciplinary research is conducted by scientists from different disciplines but is designed to address a question or problem pertaining to a single system. Theory, methods, and interpretive standards of the different disciplines are employed. Interpretation of the results from different disciplines typically occurs post hoc, often from the perspective of one discipline that may emerge as dominant within the project.

Interdisciplinary collaboration. Interdisciplinary research requires a greater degree of coordination among disciplines than multidisciplinary research, from problem formulation through analysis and interpretation. Research questions often span several spatial and temporal scales, such as those germane to interacting human and biological systems. Methods and analytical approaches may be synthetic. Collaborators accept, understand, and sometimes apply one another's disciplinary methods and approaches. More than multidisciplinary coordination, interdisciplinary integration can lead to new questions and new methodologies.

Transdisciplinary collaboration. Transdisciplinary problems are uniquely formulated and cannot be captured within existing disciplinary domains. Collaborators accept and adopt epistemological perspectives unique to the collaborative effort and distinct from those of any of the cooperating disciplines. The term *metadiscipline* can be applied to an emergent and sustained epistemological framework spawned by persistent transdisciplinary effort.

In practice, these classifications are divisions along a continuum, as are the criteria that define them. Some epistemological synthesis or compromise, for example, occurs in many collaborative endeavors. Moreover, heterogeneous collaborative teams are possible in which some team members engage in interdisciplinary activity but the larger project is better defined as multidisciplinary. Finally, collaboration is becoming so prevalent in some fields that some critics assert the notion of distinct disciplines is outmoded (Lélé and Norgaard 2005).

times disparate methodological and conceptual traditions of several disciplines. These can include different views concerning the role of stakeholders in identifying and refining research objectives (Anonymous 2004, Pretty and Smith 2004), the integration of societal values into the scientific process (Wallington and Moore 2005), and the validity of qualitative versus quantitative data (Lélé and Norgaard 2005), reductionist versus holistic methods of study (Holling 1998), and frequentist versus Bayesian methods of statistical inference (Taper and Lélé 2004). Scientists collaborating within disciplines tend to share fundamental assumptions and values concerning the scientific process and, habitually, may discuss them little, but the failure to understand and address these fundamental differences can impede progress in cross-disciplinary efforts (Jakobsen et al. 2004, Campbell 2005). For example, Stokols and colleagues (2003), reviewing experiences of Transdisciplinary Tobacco Use Research Centers at major universities, report that the collaborative efforts involving the biomedical, social, and behavioral sciences were often slowed by protracted phases of conceptual disagreement among participants. They refer to divergent "worldviews" of social and behavioral scientists and biologists as being at the heart of these difficulties. In their analysis of the cross-disciplinary US Interior Columbia River Basin Ecosystem Management Project, Jakobsen and colleagues (2004) found that project participants perceived interdisciplinary illiteracy as a barrier to successful collaboration. This team worked for 1.5 years in disciplinary component teams, but encountered difficulties when trying to integrate the results as an entire project. In attempting to address this problem after it arose, participants found that understanding "other disciplines' methods, traditions, terminology and underlying assumptions...was a facilitator of communication" (Jakobsen et al. 2004).

Exploring fundamental assumptions about the scientific process

We contend that effective cross-disciplinary research entails deliberately identifying and exploring differences in the assumptions fundamental to science that are held by collaborators and are implicit or explicit in their disciplines. We find that the literature on cross-disciplinarity underemphasizes the importance of the collaborative examination of these assumptions. Our goals in this article are (a) to review the frequently cited difficulties faced by cross-disciplinary collaborators; (b) to show the extent to which these difficulties arise from differences in fundamental assumptions, and hence are philosophical in nature; (c) to provide an overview and classification of the underlying philosophical structure of the research enterprise; (d) to outline an approach to help cross-disciplinary collaborators identify and explore the philosophical structure of their research; (e) to describe the application and expected outcomes of this approach throughout the collaborative research process; and (f) to detail results gleaned from the application of our approach in pilot tests. We submit this analysis and approach as aids to currently active collaborators, to students interested in developing as interdisciplinary scientists, and to institutions seeking to promote effective integration across scientific disciplines.

The approach we have developed is an outgrowth of our own efforts as an interdisciplinary team (comprising biologists, physical scientists, sociologists, and philosophers) and of the issues encountered by our colleagues working on such teams, with whom we have had extensive discussions. Our interest in developing a deeper understanding of the interdisciplinary process arose out of our involvement in an NSF-IGERT (National Science Foundation, Integrative Graduate Education and Research Traineeship) project at the University of Idaho aimed at integrated research and education to address biodiversity conservation and sustainable production in fragmented landscapes, and out of the campuswide dialogue on interdisciplinarity of which this project continues to be a part. (N. A. B.-P. is the project director; S. D. E. and J. D. W. are faculty steering committee members; and C. S. G., W. M., M. N.-P., and L. W. are graduate fellows in the project.)

The challenges of cross-disciplinary research

Cross-disciplinary collaborators must address several challenges in addition to those encountered by collaborators in a single discipline. Here we organize these challenges into six categories and briefly describe them as a basis for examining their philosophical dimensions.

Level of integration. The appropriate level of integration (box 1) can depend on the scope and scale of the problem being addressed and on the knowledge and applicability required. Although interdisciplinary integration is widely regarded as an ideal (NAS 2005), less integrated cross-disciplinary science can be effective. An understanding of the fundamental assumptions of collaborating disciplines and their compatibility in an interdisciplinary context can aid collaborators as they search for the proper level of integration.

Linguistic and conceptual divides. Disciplines employ specialized terms that can bewilder the uninitiated; perhaps more vexingly, the same terms can have different connotations across disciplines (Naiman 1999, Heemskerk et al. 2003). For example, the term "guild" has acquired different meanings within ecology, in addition to its applications in human societies. Moreover, specialized terminology can represent subtle disciplinary concepts, perspectives, standards, and worldviews (Schoenberger 2001). The term "triangulation," for instance, refers to a procedure in the social sciences for combining several research methodologies when studying the same phenomenon (Miller and Salkind 2002). Biophysical scientists collaborating with social scientists must learn this sense of the term "triangulation" as distinct from its senses concerning measurement in navigation and surveying. More important, they must also understand social triangulation as an accepted means for validating knowledge in social sciences, distinct from the standard of replication regarded as essential in some other disciplines.

Validation of evidence. As Schoenberger (2001) notes, "The nature of meaningful evidence and how it registers is quite divergent [among disciplines]: in some, evidence is what we can see and hear around us, in others what appears in documents, in still others what can be measured with instruments or what is counted by machine even if it cannot be seen" (p. 367).

A commonly cited obstacle to successful interdisciplinary research is disparity in methods for acquiring and validating information (Klein 1996, Benda et al. 2002, Stokols et al. 2003, Jakobsen et al 2004, Lélé and Norgaard 2005). Disciplines can differ in specific measurement or analytic approaches, and in their reliance on and interpretation of quantitative and qualitative information. These differences reflect scientific, cultural norms that have developed around the practices that generate reliable knowledge in specific fields of inquiry. Well-trained disciplinary scientists are likely to view approaches outside their discipline's cultural norms with discomfort, if not suspicion (Holling 1998).

Societal context of research. Social and governmental entities have a stake in the definition and resolution of many environmental problems (Klein 1996, 2004, Rhoten 2003). Nonetheless, cross-disciplinary collaborators may disagree about how to incorporate the views of stakeholders in defining the research agenda. For some scientists, stakeholder inputs are essential, whereas those working in basic or pure research traditions will have less experience with and appreciation for this contemporary dialogue. For example, sociologists from agricultural or natural-resource academic units may be motivated to delineate or facilitate social change, while other sociologists focus on developing a theoretical understanding of why social change occurs.

Perceived nature of the world. Many scientists view the world as an objective place that is investigated by researchers who are independent of it, although other scientists see the world as more subjective and possibly in part as a human construction (Loux 2002, Giampietro 2003). Related to this is the issue of values: Do values (e.g., moral, aesthetic, cultural) exist as an objective part of the world, or are they something we, as investigators, impose on it? If investigators perceive the world as an objective place, they can pursue the ideal of objectivity in science (Douglas 2004). On the other hand, if they assume that values are a part of the world they investigate, researchers should deliberately examine and respond to the values that drive their science, acknowledging that they *choose* what evidence they think counts, how to find that evidence, and how to transmit that evidence in an acceptable manner to others (Schoenberger 2001, Machamer and Wolters 2004). Although an ongoing dialectic has sought to resolve these dichotomies (Giampietro 2003, Douglas 2004, Klein 2004), disciplinary science tends to pick sides. Individual scientists, on reflection, may differ with their colleagues about the roles of objectivity and values in science (e.g., Wallington and Moore 2005); but in practice they seldom are required to resolve these differences. Within cross-disciplinary collaborations, however, some accord on these issues is required.

Reductionistic versus holistic science. Scientists differ in their attitudes toward the effectiveness and suitability of reductionism versus holism in science. Reductionistic approaches isolate and analyze elements of a system and then use them to construct comprehensive models, whereas holistic approaches examine emergent properties of complex systems that are considered irreducible (e.g., de Rosnay 1979, Holling 1998, Silberstein 2002). Participants in cross-disciplinary collaborations may have different levels of experience with and appreciation for reductionism or holism.

An analysis of the philosophical aspects of cross-disciplinary research

The challenges to cross-disciplinary research outlined in the previous section arise out of conflicting assumptions about the nature of the world, the development and verification of knowledge, and the role of values in the scientific process. These are essentially philosophical challenges, rooted in the conceptual divides that separate disciplines. We contend that a philosophical analysis can help researchers identify these conceptual roots. Philosophy applies methods of conceptual analysis to foundational concepts (e.g., knowledge, evidence, causation) that frame the acquisition and interpretation of empirical data (Rescher 2001). In this section, drawing primarily on the philosophy of science, we provide an analysis of the philosophical dimensions of cross-disciplinary research that will guide us as we develop a response to the distinctive challenges to this type of research.

Many cross-disciplinary collaborators are disciplinary specialists, having received research training in a particular field. Such training instills specific research approaches and techniques that constrain questions, frame observations, and determine methods of interpretation and standards for validation; that is, it instills a complex, distinctive way of perceiving and investigating the world that we will call a *conceptual scheme* (Galison 1997; cf. Lélé and Norgaard 2005). Conceptual schemes are networks of (a) concepts that frame an investigator's pursuit of knowledge about the world and (b) concepts that represent the inherent nature of that world. Philosophical analysis of the concepts that frame the pursuit of knowledge is considered *epistemology* (Greco and Sosa 1999), while analysis of the concepts that represent the nature of the investigated world is considered *metaphysics* (Loux 2002). For example, riverine ecologists combine epistemological elements. such as measurements (e.g., of channel morphology and biological populations) and qualitative concepts (e.g., the river continuum concept), in pursuing knowledge about their metaphysical concerns, namely, the distribution of species and the transformation of nutrients and energy in riverine ecosystems (Benda et al. 2002). Another type of philosophical analysis, *axiology,* concerns concepts that represent values, but as these also admit of epistemic and metaphysical analysis, we classify them under metaphysics in the interest of streamlining our framework.

Each challenge reviewed in the previous section has epistemological and metaphysical aspects. For example, a traditional reductionist approach to research questions is epistemological in assuming that higher-level phenomena can be understood by elucidating elements at a lower level of organization, and metaphysical in assuming that complex objects and events are composed out of simpler objects and events (Silberstein 2002). We have structured our presentation by treating philosophical aspects of two of the above-listed challenges to cross-disciplinary science as primarily epistemological and two as primarily metaphysical, recognizing that, on scrutiny by collaborators, both metaphysical and epistemological aspects of each of the challenges will be revealed.

We treat the challenges involving inputs from society and policymakers and the validation of evidence as primarily epistemological, because they relate directly to the kind of knowledge sought and the research methods employed in its production (Greco and Sosa 1999). Inputs from stakeholders bear on how investigators approach their research, that is, their research motivation. Validation of evidence embodies two epistemic concerns, namely, the research process—including what investigators regard as evidence and their methods for gathering it—and the knowledge confirmed by this process. Thus, the two challenges put in play three epistemic categories: *motivation, methodology,* and *confirmation.* These categories can be understood as follows:

- Motivation: This concerns the tendencies and aims brought to research by investigators, especially insofar as these relate to people who might be affected by their work. For example, a rural sociologist might be interested in pursuing theoretical (i.e., basic) knowledge about the impact of large resource extraction projects on small communities, or applied knowledge that solves immediate problems for those communities.
- Methodology: The research process involves identifying goals, gathering data, and then interpreting the data relative to those goals. Research goals differ across the disciplines, depending, for example, on whether strict hypothesis testing is feasible and whether predictive accuracy or descriptive adequacy is achievable. Approaches to data acquisition also differ. For example, quantitative statistical analysis, qualitative textual analysis, and local beliefs can all be counted as evidence by social scientists, depending on the study. The field of ecology includes physiological ecologists who rely on replicated experimental data and frequentist inference for validation, and ecosystem ecologists who are constrained by lack of available controlled replication and who rely on separating multiple competing hypotheses using Bayesian inference (Holling 1998, Lélé and Norgaard 2005).
- Confirmation: Researchers may differ in the type and amount of evidence they require for knowledge. In addition, questions can be raised about ways of validating the accuracy of findings. *External validity* (i.e., transferability or generalizability) consists in the successful application of results to new settings or samples, *internal validity* in the confidence that the suggested causal links are the actual ones, and *measurement validity* in agreement between what was measured and what the researchers intended to measure. All of these pertain to the main question, namely, When in the process of research do investigators believe themselves to have knowledge (Miller and Salkind 2002)?

We treat challenges to cross-disciplinary research involving the reductionism–emergence debate and the question of how investigators perceive the world as metaphysical, because they direct us to the nature of the investigated world. Researchers typically take the investigated world to be uniform, supporting certain interpretations while disallowing others; that is, they take the world to be structured in a systematic way (Loux 2002). Our primary metaphysical focus is on the ontology of these structures (i.e., on the constituent parts and the relations among them). Our review of the challenges associated with how investigators view the world prompts us to ask two questions about the constituent parts. First, do the parts have an objective existence, or are they more subjective and investigator dependent? Second, are values included among the parts? The second question is related to the first but remains importantly distinct, since, even in an independent world, values might be imposed from without by scientists. As introduced in the preceding section, reductionism and emergentism are ontological because they concern structural relations among parts of the investigated world. Disciplinary traditions recommend different attitudes toward each of these three metaphysical categories: *objectivity, values,* and *reductionism–emergence.* We understand them as follows:

- Objectivity: The concept of objectivity is complex, related in intricate ways to knowledge through research methods, human judgment, and social institutions (Douglas 2004), but it is also related to ontology through the objects that give it its name. Conflicts can arise over whether a fully objective world exists independent of any perspective, or whether the world is to some extent constructed by those who investigate it. Those who cleave to the former view believe that "objectivity lies in the objects and how they affect us, whether we understand them or not," and that any deviation from objective research invalidates the conclusions of the study (Machamer and Wolters 2004). Others regard objectivity of this sort as an illusion, and believe that scientific progress requires a recognition of the subjective, constructed nature of the world we experience (Giampietro 2003). Friction can arise when one type of researcher assumes that another type of research is less constrained by an objective world, as when biologists expect social scientists to use their research to solve socioeconomic problems (Campbell 2005).
- Values: Science is infused with values, but some scientists operate as if these are not a part of the investigated world and so are irrelevant to the practice of science. Many values do concern issues external to the content of specific research projects—for example, the values that influence researchers' motivation for doing science, or the social values that influence the application of results—but others bear on central matters, such as the degree of evidence required for confirmation. This produces disagreement about whether science can or should be conducted without values. As Lélé and Norgaard (2005) note, "Most natural scientists have been brought up on the notion that science is value neutral" (p. 969); others, however, argue that value neutrality is an obstacle to scientific progress and that values have a place in "objective science" (Wallington and Moore 2005). In fields of study that interface with economics and social policy, such as medicine or ecology, these disagreements can hinder collaboration and undermine progress (Machamer and Wolters 2004, Lélé and Norgaard 2005).
- Reductionism–emergence: It is possible to view the world as decomposable (i.e., reducible in its entirety to simple parts) or as dependent to some extent on emergent properties and so not decomposable. These are distinct ontological perspectives, with implications for how science should be conducted (Mitchell et al. 1997, Silberstein 2002). For example, collaborations involving physical and social scientists can include members who strongly believe that only strict reductionism is viable for establishing knowledge, and others who believe as strongly that studying system components in isolation

> is useless for answering important questions (Giampietro 2003). It is also possible to adopt an intermediate position that is reductionist about the world but accepts pragmatically that certain aggregates are appropriate units of study because their emergent properties are predominant (Silberstein 2002). For example, many biologists who think of themselves as reductionists nonetheless regard certain aggregates (e.g., organisms) as entities with properties that cannot be studied solely in terms of component genes or molecules.

These epistemological and metaphysical categories are interrelated and interdependent. For example, a reductionist worldview validates and privileges experimental research methodologies that emphasize replication, and success in employing such methodologies reinforces a scientist's commitment to reductionism (Holling 1998). Similarly, acceptance of the world as inherently emergent requires and reinforces the validity of systems-level descriptive methods (Giampietro 2003). Rejection of the ideal of objectivity calls for qualitative methods that can incorporate subjectivity into the analysis of complex phenomena (Mitchell et al. 1997, Machamer and Wolters 2004). These interdependencies are reciprocal and comprehensive. In practice, disciplinary scientists tend not to reflect on them because their metaphysical and epistemic traditions are ingrained and tacit. Cross-disciplinary collaboration, in contrast, can bring very different conceptual schemes into conjunction, revealing their metaphysical and epistemic aspects in ways that demand attention.

A toolbox for philosophical dialogue

According to the recommendations of a recent National Academy of Sciences study on facilitating interdisciplinary research, "Researchers...desiring to work on interdisciplinary research, education, and training projects should immerse themselves in the languages, cultures, and knowledge of their collaborators" (NAS 2005, p. 81). We have argued that philosophical assumptions are implicit in this list. Interdisciplinary or transdisciplinary efforts that involve the synthesis of conceptual schemes may require substantial interactive exploration of these assumptions (Mitchell et al. 1997, Rhoten 2003), but less integrated efforts should still benefit from an understanding of the philosophical perspectives of collaborators. Under the pressure and heat of day-to-day effort, collaborators at any level of integration are exposed to the philosophical assumptions of their partners, but in a piecemeal and uncoordinated way, rarely deliberately. At the very least, exploration of these assumptions requires conversations with collaborators, for "at the heart of interdisciplinarity is communication—the conversations, connections and combinations that bring new insights to virtually every kind of scientist and engineer" (NAS 2005). Other reports corroborate the importance of communication in cross-disciplinary collaboration (Heemskerk et al. 2003, Rhoten 2003, Stokols et al. 2003, Jakobsen et al. 2004, Campbell 2005, Lélé and Norgaard 2005). We agree, but contend that communication structured in a way that ensures the discovery and exploration of key philosophical assumptions is preferable to unstructured conversation that varies widely in degree.

To address this need for philosophically informed communication, we designed a "toolbox for philosophical dialogue" (table 1). We present this toolbox, which reflects the epistemological and metaphysical categories introduced above, as an aid to scientists who wish to initiate philosophical self-examination as part of their collaborative effort.

The toolbox consists of a set of questions designed to draw out a scientist's views on philosophical aspects of his or her work. It is intended to be employed in group discussion by current or potential collaborators. The questions address different philosophical issues and are organized within the two principal areas (epistemological and metaphysical) into the six categories introduced in the preceding section (motivation, methodology, confirmation, objectivity, values, and reductionism–emergence). The core questions broach the characteristic issue associated with each of the categories, and the subquestions elaborate these issues and point to salient interdependencies with other categories. The toolbox is intended to structure group discussion by enabling participants to connect their responses to one another and to philosophical assumptions that can complicate cross-disciplinary research; however, it is not intended to be restrictive. Indeed, as we have seen, many of the questions relate to more than one philosophical issue, and all of the issues can be addressed from different philosophical perspectives (e.g., values are involved in the process of knowledge formation, and one's methods can influence what one finds in the world, i.e., one's ontology).

Implementation of the toolbox

Our experience shows that the toolbox is most effective when used with the following general protocol. First, the participants review the philosophical structure that underlies the toolbox. The preceding sections in this article can be used for this purpose. Second, team members reflect on the questions and their individualized responses to them. Third, the team meets as a group to discuss the questions in the toolbox for one to two hours. The discussion can begin with any of the questions and progress to other questions in any order. The interdependencies among categories, the unique concerns and backgrounds of the team members, and the particulars of their project should be allowed to determine the trajectory of discussion. At the same time, digressions from the philosophical issues the exercise is designed to examine should be minimized. In our experience, it is useful to assign or enlist a facilitator to help keep the discussion focused on the toolbox questions. It is also important to assign someone to record the entire discussion so it can be reviewed later. Copies of the toolbox with space for notes are available online (*www.class.uidaho.edu/toolbox*).

Assessments of the toolbox

To examine the effectiveness of the toolbox, we tested it with four collaborative teams during the period from June 2005 to

Table 1. Toolbox for philosophical dialogue, consisting of a set of questions designed to draw out collaborating scientists' views on philosophical aspects of research.

Principal philosophical domain (entry point)/specific philosophical issues	Core question	Probing questions
Epistemology		
Motivation	Is applied research or basic research more important to you as a researcher?	Is basic research inherently disciplinary research, or can cross-disciplinary research address basic research questions?
		How do basic and applied research relate to each other in the traditions of your discipline and in the current team project?
		Should your collaborative research project emphasize applied over basic research?
		Is there a role for advocacy in research?
Methodology	In your typical disciplinary research, what methods do you use, and which are most appropriate for your collaborative study (e.g., quantitative, qualitative, experimental, case study, observational, modeling)?	What kinds of data constitute scientific evidence?
		In your research, do you combine different types of research approaches?
		How are your methods related to those used by other members of your team?
		Is a hypothesis required for research to be considered science?
		How does the spatial or temporal scale of your research approach compare and interact with the scales of your team's research approaches?
Confirmation	What type and amount of evidence are required for knowledge in your work?	What is required to ensure that measurements are valid?
		What is required to ensure that empirical data confirm a theoretical proposal?
		Is replication necessary for confirmation?
		Can unreplicated results that are confirmed by a combination of methods qualify as knowledge?
		In what ways do your research conclusions address or incorporate uncertainty?
Metaphysics		
Objectivity	Must scientific research be objective to be legitimate?	In what way or ways is your research objective?
		Can one integrate values into research and still remain objective?
		Do you think it is valid to use one's personal perspective to frame a research question or hypothesis?
		Can subjective research be scientific?
Values	Is value-neutral scientific research possible?	If it is possible to conduct scientific research without values, how is that accomplished?
		Do you consider questions about when hypotheses count as knowledge to be value questions?
		If you regard values as an ineliminable part of scientific research, how can they be managed to avoid biasing research results and interpretations?
		Does the introduction of values into the research process amount to advocacy?
Reductionism and emergence	Can the world under investigation be fully reduced to individual, independent elements for study?	Are there emergent properties of the system or subject of study, or is it reducible?
		Is the context in which a subject is investigated important (i.e., is the subject of study part of a larger system that should be considered)?
		Are multiple-scale (spatial, temporal) interactions important? To what degree can and should these be addressed?

September 2006. Two of the teams were from the University of Idaho NSF-IGERT project. One was a team of students comprising a plant ecologist, an entomologist, a soil ecologist, and a sociologist. The other was a team of students and their faculty mentors, including two landscape ecologists, a population geneticist, a conservation biologist, and two sociologists. Both IGERT teams were engaged in interdisciplinary projects related to bioregional planning. The third team comprised faculty members of an interdisciplinary project on water management science and policy. Disciplines represented included agricultural engineering, environmental management, hydrology, law, and political science. The fourth team comprised colleagues from several educational institutions in Idaho and a national laboratory, and included physicists and engineers, organizational management specialists, policy analysts, and social scientists.

For the toolbox assessment, each team self-administered the toolbox, with one or two members of our group attending to observe and to serve as note takers. After the toolbox exercise, the transcript of the session was distributed to the teams, and individual members were asked to complete an evaluative instrument. This instrument consisted of eight questions concerning the introspective, interactive, and evaluative effects of the philosophical dialogue generated with the toolbox. Introspective effects were probed through questions concerning (a) individual experience with cross-disciplinary collaborations and (b) the effectiveness of the toolbox in improving one's understanding of the philosophical aspects of such collaborations. Interactive effects were examined through inquiry concerning the change in the team's understanding of its own dynamics. Evaluative effects were revealed through inquiry into whether the toolbox was perceived as a useful element in cross-disciplinary collaboration.

The results of assessments of the toolbox exercise are summarized in table 2. Entries in this table are organized according to the three categories (introspective, interactive, and evaluative) and four themes (question and method development, collaborative relations, team cohesion, and philosophical issues) that emerged in the responses and team discussions. In the introspective category, the responses indicate that the exercise prompted personal insights into factors that promote effective cross-disciplinary collaborative work. Participants also noted that an understanding of philosophical aspects of collaboration is facilitated by personal and professional compatibility and pragmatic flexibility among the team members.

At the interactive level, participants focused on the importance of establishing a "culture of commitment" and open communication early in the collaborative process, noting that the toolbox facilitated this.

At the evaluative level, participants noted that the toolbox exercise enabled them to identify potential barriers and facilitators to cross-disciplinary collaboration. The exercise can improve team cohesion and reduce the risk of dominance by a single member or disciplinary perspective. Participants emphasized the importance of mutual trust, respect, flexibility, and communication for effective collaborations.

In summary, feedback about the toolbox was generally positive (table 2). A few participants doubted its value. Two noted that discussion reveals certain issues but does not help solve them. One team felt that a pragmatic, goal-directed effort can override the potential philosophical barriers. Most participants did not find the exercise motivated them to engage in more cross-disciplinary collaboration, but our sample is biased toward scientists already participating and committed to such research.

Applications

Mutual understanding of disciplinary approaches and good communication are widely recognized as requisite for effective cross-disciplinary collaboration (Galison 1997, Benda et al. 2002, Heemskerk et al. 2003, Rhoten 2003, Stokols et al. 2003, Jakobsen et al. 2004, Campbell 2005, Lélé and Norgaard 2005, NAS 2005). How to achieve this is less clear. The toolbox for philosophical dialogue has been developed to promote structured discussion that facilitates cross-disciplinary understanding by exposing its philosophical dimensions. We use the term "dialogue" to imply our expectation that the toolbox exercise will facilitate a continuing exchange of ideas at the philosophical level among collaborators.

Although conceived for teams addressing problems with interacting human and ecological systems, the issues explored are relevant to any group of collaborating scientists; and although intended for early stages in the collaborative process, toolbox discussions should also have value for more mature teams. We stopped short of suggesting how collaborative teams might grapple with philosophical divides, or how best to capitalize on useful synergies or other insights once they are discovered. Nonetheless, our view is that the toolbox exercise establishes a stronger foundation for addressing these issues. Most of our participants indicated that they found the toolbox exercise rewarding and that the experience has improved their understanding of the collaborative research process and their professional roles as cross-disciplinary collaborators. Biologists and other scientists addressing the emerging complex social and ecological problems will need to excel at collaboration, and a better understanding of the philosophical dimensions can help ensure this.

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Table 2. Summary of results from collaborative team discussions employing the toolbox for philosophical dialogue (a set of questions that cross-disciplinary collaborators can use to identify their philosophical disparities and commonalities) and feedback from team members about the toolbox exercise.

Category of response	Responses (organized by theme)			
	Question and method development	**Collaborative relations**	**Team cohesion**	**Philosophical issues**
Introspective	An objective process improves collaborative research. A practical, pragmatic, and goal-directed approach reduces difficulties in reconciling disciplinary approaches.	The success of cross-disciplinary research depends on the compatibility of collaborators. Individual effectiveness in cross-disciplinary research can improve with experience. Commitment to the principle and value of cross-disciplinary facilitates collaboration.	Awareness of differences in others' philosophical perspectives is important for team function. Openness to, and interest in, other disciplinary approaches improves cohesion. Identifying shared ideas, regardless of disciplinary differences, improves cohesion.	Individual clarity about and ability to express philosophical viewpoints improves the collaboration. Preconceptions about the differences in social versus biological sciences are prevalent.
Interactive	Discussion of philosophical aspects of research is useful prior to trying to address a research problem. Although discussion can clarify disparate views about validation of knowledge, it does not necessarily help resolve them.	Prejudice and misunderstanding concerning the social sciences can be a significant issue. Discovering shared motivation and perspectives provides a support for exploring differences.	Discussion of philosophical issues early on can facilitate later stages of projects. Group interactions and discussion create a culture of commitment, mutual respect, and working partnerships. Communication is key to the success of any collaborative effort.	Different disciplinary research approaches and conceptual schemes can be applied as required to address specific aspects of a cross–disciplinary project.
Evaluative	The toolbox exercise revealed colleagues' reluctance to state opinions on "how science should be done." The toolbox exercise revealed the importance of personal commitment to overcome barriers to collaboration. The toolbox exercise catalyzed paradigm shifts and encouraged risk taking.	The toolbox exercise improved mutual understanding of philosophical orientations, helping the team to function. The toolbox exercise reinforced a sense that mutual respect, communication, and the ability to trust that collaborators are competent and committed are most important.	The toolbox exercise reveals issues, but does not provide solutions to substantial practical challenges of cross-disciplinary research. The toolbox exercise helped prevent a single discipline from predominating. The toolbox helped make explicit the areas of agreement and disagreement within the team.	Agreement on the metaphysical aspects facilitated discussion of epistemological ones. Epistemological questions improved the functionality of participating teams. The toolbox exercise revealed underlying impediments to combining data from different methodologies. The toolbox exercise revealed that philosophical differences were at the root of some disagreements between researchers from different disciplines.

Note: Entries synopsize comments made during the discussions and on evaluation questionnaires prepared by participants afterwards. Four different teams used the toolbox (see text). Responses are classified as introspective (insights gained or articulated pertaining to individual participation and involvement in cross-disciplinary research), interactive (insights gained or articulated pertaining to the performance of cross-disciplinary teams), or evaluative (assessments of the usefulness of the toolbox for philosophical dialogue as a part of cross-disciplinary research).

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