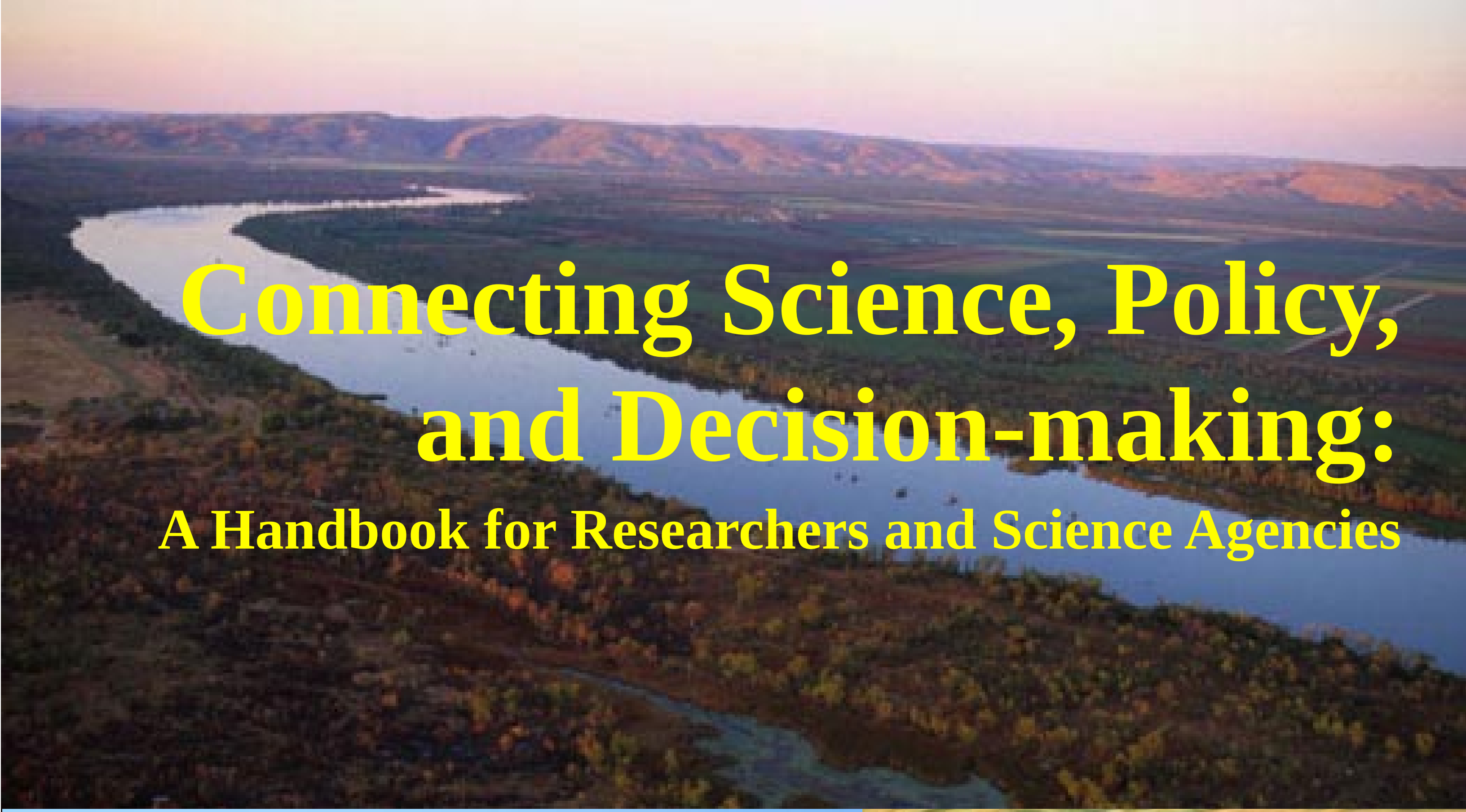
Connecting Science, Policy, and Decision-making:

A Handbook for Researchers and Science Agencies



Cover photo credits:
Lower left hand corner photograph courtesy of Andrea Ray, NOAA Climate Diagnostics Center, Boulder, CO.
Other photographs are courtesy of ArtToday.com

Produced by the NOAA Office of Global Programs

Connecting Science, Policy, and Decision-making:

A Handbook for Researchers and Science Agencies

Katharine Jacobs[1]

[1] The author has been employed by the Arizona Department of Water Resources since 1981 within the Tucson Active Management Area (AMA). She was director of the Tucson AMA from 1988 through 2001. This work was completed through a 2001-2002 academic year contract with the National Oceanic and Atmospheric Administration, Office of Global Programs.

Introduction: Strategies for Integrating Research and Practice

There is a well-documented need to improve the flow of information in both directions between scientists and decision-makers (see for example, National Research Council, 1995, 1998, 1999a,b). Improved access to scientific information and to the hands-on experience of decision-makers has multiple benefits from the perspective of developing new management options and adaptive capacity. At present, it is clear that many of the products and tools scientists have developed for water managers are not as fully utilized as they might be (Rayner et. al, 2002). This is at least partly because the scientists who have developed them do not fully appreciate the institutional, economic and cultural circumstances within which decisions are made. It is also partly because decision-makers frequently do not actively seek new sources of information or initiate contacts with experts who could be helpful to them in making more informed decisions.

It is common for researchers to develop products and tools that they believe will be useful, then make them available for use without verifying whether these are really the products needed. This "loading dock" mentality is generally the result of one-way communication, without sufficient evaluation of the needs of stakeholders. The result is that, at least in the context of federal agencies, millions of dollars are being spent on research that has the potential for utility but in fact may currently have little tangible societal benefit.

This handbook provides practical, hands-on suggestions for researchers and science agencies about ways to improve the focus of scientific research that is intended to be useful to decision-makers (as opposed to more basic research that is not intended for immediate application). These suggestions are based on interviews with researchers who study science and decision-making, federal agency science and policy personnel, and decision-makers and stakeholders. This report uses the applications (or lack thereof) of climate science to water management as an example, but is intended to be applicable to other types of science and other resource sectors.

A number of scientists have recognized the need to achieve more integration among disciplines in order to address emerging social and environmental problems. In fact, there is general acknowledgment that decision-making in the context of an increasingly complex and inter-related global system will require more interdisciplinary research and more involvement from decision-makers and stakeholders (NRC, 1999a,b). Amplifying the need for improved information and predictive capacity is the probability of increasing climatic variability associated with global change, and the related needs for adaptation (US Global Change Research Program, 2001; US Dept. of Commerce, 1999).

Attempts to bridge the gap between those who generate information and those who use it have not always been successful. There are certainly cases in which academics and scientists from multiple fields have successfully worked together on interdisciplinary problems. An early example is the Tropical Oceans–Global Atmosphere Program (TOGA) of the 1980's, in which oceanographers and atmospheric scientists worked together to identify the El Nino-Southern Oscillation (ENSO) signal. However, a true dialog between end users of scientific information and those who generate data and tools is rarely achieved. The Regional Integrated Science and Assessment (RISA) teams that are sponsored by NOAA and activities sponsored by the Environmental Protection Agency's Global Change Research Program are among the leaders of this investigation, and represent a new collaborative paradigm in which decision-makers are actively involved in developing research agendas. The U.S. Geological Survey (USGS) has also been actively investigating ways to enhance the use of USGS science through its recently initiated Science Impact program.

The RISA teams, which are located within five universities, primarily in the western US, are focused on stakeholder-driven research agendas and long-term relationships between scientists and decision-makers. Lessons learned within the RISAs have been incorporated in this document to the extent that they have been identified.

It is hoped that this handbook will be useful in a number of contexts, and for that reason some of the considerations are identified through questions rather than answers. **The handbook is intended to assist physical science researchers in developing successful relationships with stakeholders and decision-makers,** but is deliberately not prescriptive in terms of providing answers to many of the important questions. Because this handbook is being designed for use in a broad range of applications, and each application should be context-dependent, it would be inappropriate if not impossible to develop the answers to the questions identified here. However, answering these questions is likely to help researchers internalize a broader perspective and thereby increase the utility of their work.

This report focuses on the ingredients of successful interaction from multiple perspectives and identifies:

- **Conditions for providing useful services and products**
- **Keys to communication and collaboration**
- **Incentives for change**
- **Mechanisms for evaluation and feedback**
- **Measures of success in collaboration**

I. Conditions For Providing Useful Services and Products

There has been much documentation of the reasons why decision-makers and scientists rarely develop the types of relationships and information flows necessary for full integration of scientific knowledge into the decision-making process (Graffy, 2002; Kirby, 2000; Pagano et al, 2001; Pulwarty and Melis, 2000, Rayner, et al., 2002). The primary reasons are problems with relevance (are the scientists asking and answering the right questions?), accessibility of findings (are the data and the associated value-added analysis available to and understandable by the decision-makers?), acceptability (are the findings seen as accurate and trustworthy?) and context (are the findings useful given the constraints in the decision process?). The differences in perspective of scientists and decision-makers are more fully described in the table in Appendix 1.

Fostering relationships that cross cultural and professional barriers requires effort and incentives. Financial incentives do exist, and there are private sector "integrators" who specialize in translating scientific information for particular applications. However, most "cross-cultural" relationships are fostered within certain universities that value and encourage interdisciplinary work with stakeholders, and within parts of agencies that have recognized the need to establish connections with users of their data and research tools.

Step 1: Understanding the Context

A first step in developing useful products and services is understanding the **context** in which they will be used. **Scientists, whose world view is strongly influenced by the boundaries of their own research, may not recognize that the new information they produce may be a very small consideration in the manager's "decision space".** As used here, the term "decision space" means the range of realistic options available to a given manager to resolve a particular problem. New tools and information may have obvious applications from a theoretical perspective; however, most resource managers work within highly complex environments that are constrained by external factors.

Context Checklist

- How do laws and regulations limit the range of options available to the decision-maker? How difficult is it to change the institutional context?
- Within the institution, what are the policies, procedures, and precedents relative to this type of decision or activity? Are there defined decision rules, etc., that cannot be changed by the manager?
- How are the decision-makers affected by their training, their peers, and their supervisors in terms of expectations of behavior? Is there a disincentive to "break ranks" and use techniques that are without precedent in the institution?
- Does the decision-maker have sufficient resources (time and money) to properly integrate the scientific information into decision-making and operations procedures? If not, is this a real or a perceived problem?
- Is there a personal or institutional history of interaction between the scientist and the decision-maker?
- Is the range of options that is technically possible significantly different from what is practically possible?
- What are the key questions faced by this type of decision-maker on a daily, weekly, monthly basis?
- Is the range of options that is technically possible significantly different from what is practically possible?
- What are the historical roles of politics and the media in this decision space?

Step 2: Defining the Users/Clients and Understanding their Perspective

The potential to use particular data sets or decision-support tools depends in large part on what kind of individuals might be interested in using the information. Some time spent on defining the likely candidates for use of a potential product is appropriate, since it will affect the types of collaboration that may be necessary, the sophistication of the products, and the ways in which they will be distributed.

Short-term Versus Long-term Information, Skill, and Applications

The information needs of decision-makers are influenced by the time frame of their decisions. NOAA researchers commonly make a distinction between weather prediction information, which is produced on an hours to weeks time frame, and climate predictions, which may be on a seasonal to inter-annual time frame. The majority of decision-makers are likely to focus primarily on shorter time frames, though as longer-term predictions gain skill, this may change, particularly in areas with economic applications. Understanding the frame of reference of the decision-maker and the types of decisions he or she makes will help the researcher focus on products that are most useful. It should also be noted that short-term decisions also have long-term consequences, so identifying the information needed to make better decisions in all time frames is important.

Because of the focus on short-term information and quick results, it is difficult to get political support for research that focuses on long-term, incremental increases in knowledge that are the key to significant policy changes (Kirby, 2000)[2]. This is a symptom of today's societal preferences, which generally do not support current investments with long-term or uncertain future payback. This presents obvious policy and priority issues for researchers and decision-makers who are concerned about global change and adaptation.

Who is the audience?

- Is the potential user involved primarily in day-to-day operational decisions or longer-term policy decisions?
- Are the users researchers themselves, or are they primarily focused on the development and implementation of policy?
- Is there real potential for improving decision-making associated with new scientific information and understanding?
- Should the products be designed for particular types of users, or should the products be general in nature?
- Is there an expectation of direct use by decision-makers (or the public), or are intermediaries (integrators) likely?
- Are the users likely to be government employees or within the private sector?
- Is there a potential role for public interest groups or NGOs?
- Is the equipment (computer capacity), platform, etc. for this information generally available, or will specialized equipment or organizations be required to make it useful?

Step 3: Understanding the Credibility/Value of Information Needs in Particular Applications

It is important for scientists to think about how accurate and credible the information being produced is, compared to how accurate a decision-maker needs it to be in order to be useful. An evaluation of this may be highly subjective, but researchers need to think about the degree of certainty needed by decision-makers, what the potential benefits of using the information are, and what the risks associated with failure are.

> *Uncertainty is not the hallmark of bad science, it is the hallmark of honest science…This perennial question "Do we know enough to act?" – is inherently a policy question, not a scientific one"* (Hon. George Brown, 1997).

How much do decision-makers need to know in order to know enough to act?
(Note: A decision not to act also has consequences…)

- In the context of the type of information produced, how much risk and uncertainty is acceptable to practitioners? Is this a broad spectrum of acceptability, or do most decision-makers in this area agree about the levels of risk that are acceptable? Is there a safety net, for example, FEMA floodplain insurance if there are failures?
- Do the managers discuss uncertainty, probability and risk when describing their daily decisions?
- Is skepticism about value of climate products (or other science products that involve use of models) well founded? Given that people are already making inherently probabilistic decisions (particularly in agriculture) now, is concern about such products overblown? Should a threshold for utility of probabilistic information be developed for particular applications?
- What constitutes credible information? Is it intrinsic to the agency that produced it? Is it dependent on the individuals who worked on it or disseminated it? How are accuracy and credibility related? How can information about credibility be conveyed most easily?
- When evaluating probabilities of extreme events, statistics and probabilities may not help predict future events if the event is outside of previous experience, extremes are "too extreme". How can this be addressed?

[2] A reviewer of this document pointed out, however, that it has recently been asserted that focusing on the uncertainties of long-term global warming impacts has been used as a stalling technique in avoiding politically hazardous shorter-term steps.

Communication of Uncertainty

Although great progress has been made in projecting climate conditions up to a year in advance, the accuracy of predictions varies tremendously from year to year, season to season, and location to location (Hartmann et al., 2002). Some economic sectors (such as agriculture) are much more vulnerable to climate influences, especially extreme events, than others. An assessment of the accuracy of predictions for the southwestern U.S. and their utility has been produced by Hartmann et al., 2002, who show that providing skill scores (evaluations of the accuracy of past predictions) to potential users of climate information helps managers make better informed decisions, even in cases where the skill scores are low. This is because the skill score provides an evaluation of the accuracy of the forecast, and allows the decision-maker to assess the utility of the information for his or her own situation. If this type of evaluation can be shared with potential users, it greatly enhances the utility of the tools produced.

The value of information to a particular decision-maker also relates to how much difference the information could make in a particular outcome. In some cases, even a perfect prediction of future conditions may not make a significant difference, because there is very little that the decision-maker can do to respond to the information.

Understanding/Responding to Types of Uncertainty in Particular Applications

Understanding the types of uncertainty in the decision-making environment will help researchers work within the policy context better and design products that may have more immediate utility. In some cases uncertainty is created because the problem faced by the decision-maker has not been properly diagnosed; for example, estimates of the potential for extended drought may be based only on recent experience in a relatively wet climatic regime, while a review of the historic record could provide a broader view of the potential for future droughts. In other cases, uncertainty is caused by a changing regulatory environment, changes in economic conditions or inadequate information.

Types of Uncertainty in the Decision-making Environment

- Regulatory uncertainty is often an important component of the uncertainty in resource management decisions. In addition to changes in the regulations themselves, differing interpretation of regulations causes uncertainty. Interpretations may change based on directives (politics) at any level in the chain of command or the perspectives of individual regulators.
- Uncertainty may result from inadequate data, poor access to data that do exist, or data quality problems.
- Changes in climate forecasts throughout the season or year are common, and the regular updates of predictions may cause uncertainty.
- Incorrect conclusions from premature or inadequate data analysis may result in decisions that increase risk or have other negative consequences.
- Changing environmental, social and economic conditions mean that decisions are made against a shifting backdrop, increasing uncertainty.
- Public perception and politics affect all decision-makers, and in some cases may outweigh facts and professional judgment. The effect of media interpretations and political pressure is particularly acute when there is great risk and inadequate information. Fear of controversy severely limits the chances for innovation in many water management organizations (Rayner et al., 2002).

Step 4: Getting the Scale and Timing Right

Utility of information for decision-makers relates to whether the information is relevant to the particular region being managed and whether it is timely. A frequently cited problem in use of climate information by water managers is that the scale of the information that is available is too large to be useful. Global circulation models now do a relatively good job of predicting average conditions over broad areas, but do not take into account the particular topography and microclimate within regions, particularly as they relate to precipitation and streamflow. Although downscaling from large-scale climate models to local hydrologic models has now been successful in multiple locations, the models are not based primarily on an understanding of the physical processes within basins but rather on assumptions about runoff, soil moisture, groundwater inflows and outflows, etc. that are adjusted to match historic runoff measurements.

Because large surface reservoirs allow for regional averaging of precipitation conditions, management decisions related to reservoirs may be better suited to the use of climate predictions than other types of resource management decisions. Other examples, such as management of large groundwater basins, drought and wildfires may also lend themselves to use of large-scale predictions. Despite the adage "think globally, act locally," many people have conceptual difficulty translating between different scales of information. Developing products that match the boundaries of areas of interest to potential user groups will improve the utility of a given product.

Accuracy vs. Precision

In the example above, downscaling for local or regional applications results in an overall loss of accuracy, even though the information is more "precise". If decision-makers understood that there is a tradeoff between accuracy (how close to the truth you are) and precision (whether the information is specific to the area of interest), which would they choose?

Timing is Everything

Information must be timely to be useful. This requires that the researcher understand and be responsive to the time frames during the year for which specific types of decisions are made and entry points for information into the process. Pulwarty and Melis (2001) and Ray et al. (2001) have developed the concept of "decision calendars" in the context of the Western Water Assessment in Boulder. Failure to provide information at a time when it can be inserted into the annual series of decisions made in managing water levels in reservoirs, for example, may result in the information losing virtually all of its value to the decision-maker. Likewise, decision-makers need to understand the types of predictions that can be made and tradeoffs between longer-term predictions of information at the local or regional scale and potential decreases in accuracy.

II. Keys to Communication and Collaboration

An important starting point is the recognition that all individuals perceive themselves to be "stakeholders," meaning that they have a strong interest in outcomes that are related to their areas of professional and personal interest. When relationships are initiated, acknowledgment of the validity and importance of the perspectives of those individuals needs to be an underlying premise of the conversation. Emphasizing from the beginning an expectation that information will flow both from the researcher to the decision-maker and back to the researcher may allow for a more constructive approach.

Strategizing Prior to Contacts with Stakeholders and Decision-makers

- How can the strategy for approaching particular users or decision-makers be tailored to their interests?
- What is the role of the private sector, as opposed to government, in providing specialized science products for particular applications?
- How can local knowledge and the decision-maker's hands-on experience be used to improve outcomes?
- What are the messages that will result in long-term trust-building?
- Are there individuals within the system who can help provide orientation about decision-makers and institutional context? Can they provide introductions and other ways of getting to the right people? Can they suggest good ways to communicate effectively with these people?
- How vulnerable is the decision-maker within his/her own institutional context? How much personal or professional risk is involved in changing historical ways of doing business? Will the decision-maker's job be on the line if he/she uses a new approach that is not perceived as successful?
- To get a busy decision-maker's attention, the risk needs to feel tangible to him/her or he/she won't prioritize the issue. Short of waiting until a disaster is already imminent (or has already struck), how can this be accomplished?

Education and communication go hand in hand with scientific advancements to bridge the space between climate science and the potential benefits that societies can derive from it.
(The International Research Institute for Climate Prediction, Columbia Earth Institute)

There are multiple facets to communication, some of which require common sense while others require concerted efforts to overcome barriers caused by different training and context. First impressions are very important, so thinking about how to structure initial encounters with potential stakeholders and decision-makers is always worthwhile.

Communication Strategies

- Emphasis on two-way communication between groups that develop products and tools and those who use them implies an evolving relationship. An iterative approach, involving testing of products and services and feedback over time, may be useful.
- Working through and within existing professional organizations is often a good way to introduce new ideas and concepts to a group of users or decision-makers. By gauging the reaction of the group, it is possible to identify those who are more open to new ideas or are more interested in the topic and may be early adopters.
- Working with early adopters within organizations or user groups may provide an inside contact who can facilitate information flows, set up meetings, provide a sounding board for alternative approaches, or demonstrate how science products can be used.
- Trust-building with groups of stakeholders requires long-term, sustained efforts. The resources to support this type of activity are frequently not available, but sustained contact may be more important in the long run than specific product characteristics.
- Summarizing key points to facilitate efficient communication can be very helpful. Short, highly graphic products that summarize conditions for decision-makers may pique their interest in more in-depth products.
- Matching the individual to the task helps pave the way for others to interact once initial barriers have been overcome. Different kinds of people excel at communication with different user groups or stakeholders (government officials, farmers or private sector companies, for example) and different group sizes.
- Planning meetings so that there is an appropriate ratio of stakeholders/decision-makers to scientists/researchers can improve the comfort level of participants.
- Soliciting and responding to input from user groups or stakeholders, even if it is relatively minor in nature, is likely to lead to buy-in for the final outcome and may lay the groundwork for future collaboration.
- Working with the press can have multiple advantages in disseminating information and encouraging interest of stakeholders. However, it is important to cultivate relationships with individual reporters who appear to have technical competence. Substantial benefits can be gained by distributing key points to the press in a briefing page prior to an event to be publicized.
- Intensive training workshops and short courses have been found to be effective catalysts for change, particularly involving role-playing with groups that have different backgrounds.

There is a natural tendency for groups to create special forms of communication, such as acronyms, that help define the "insiders." Overcoming this tendency, developing a common language and avoiding jargon and acronyms are very important for meaningful communication between scientists and decision-makers. A common problem for researchers is to lapse into their own jargon and use of acronyms. Most practitioners also have their own jargon.

> *The use of information in organizations is inextricably bound up with creating collective meaning and identity, as well as servicing implicit goals of organizational maintenance…*(Rayner et al., 2002).

The Changing Role of Information

The worldwide web plays an increasingly important role in the dissemination of information. Communication can be enhanced by carefully designing web sites that guide people to the appropriate data or analysis.

> *The increased emphasis on decentralized decisions and improved data accessibility greatly broadens the potential impact of science. The need for information on the consequences of decisions expands beyond traditional decision-makers. This is manifested by the active participation of citizens in advisory committees…and by the proliferation of stakeholder groups…*(US Dept. of the Interior, Science Impact – Enhancing the Use of USGS Science, April 4, 2002)

Ideas for Improved Websites

- Design websites in consultation with a group of potential users.
- Design cover pages for websites for ease of access by uninitiated users (see equity considerations, below) particularly focusing on the kinds of questions they may be interested in answering.
- Provide descriptions of links that focus on the utility of the information provided, rather than just describing the information itself.
- Provide information on how the data were developed, how they were intended to be used, and the current state of the science (particularly regarding certainty of results).
- Develop an information clearinghouse that provides multiple avenues for access, through mail-out brochures, fact sheets, development of generic powerpoint presentations that can be used by people accessing the website, contact people with phone numbers and email addresses, access to a speaker's bureau, video and CD data summaries and explanations.
- Provide opportunity for feedback so that users can comment on the website, including what is useful, how they used it, and what improvements they would like to see, rather than just counting "hits" on the website.
- Devote resources to regular updates of the website, including highlighting new information.

To increase the impact of scientific information, there should be a focus on usability, not just availability of information. This means moving to "value-added" products, where findings are provided in a format that allows for policy applications. (Note: working with potential users in development of a website would be good "neutral" territory for establishing relationships).

Equity Considerations

Knowledge creates wealth as well as power, and there are multiple examples throughout the world of scientific information being used as a tool without a full appreciation of the potential to create winners and losers (see. for example, Pfaff et al., 1999; Broad and Agrawalla, 2000; Broad et al., 2002). Access to information is an equity issue; for example, large water management agencies can usually afford sophisticated modeling efforts, consultants to provide specialized information, and a higher quality of data management and analysis, while smaller or less wealthy stakeholders generally do not have the same access or the consequent ability to respond (Hartmann, 2001). Understanding this point, those who develop products and services can make program decisions that either increase or decrease access to information for less sophisticated or wealthy users. This is of particular concern in developing countries, where access to information could have the greatest impact due to the high vulnerability of significant portions of the population to environmental hazards (T. Finan, personal communication). (Of course, providing access to information is not sufficient to ensure adaptation, there must also be resources and institutional support available to benefit from the information).

Equity and Economics: Impact of Information

- Who is paying for particular information and services, and who benefits? These questions may not always be answerable, but are well worth thinking about.
- Who (what groups, agencies or stakeholders) benefit from the changes in policies and programs that may result from improved access to data?
- How do public values like habitat and environmental quality, aesthetics, needs of future generations, etc., get incorporated into cost-benefit analyses and other forms of decision systems? If they are not formally incorporated, is there a way to recognize and respond to these values through other mechanisms?
- Are new tools such as hydrologic models, climate forecasts, and improved water quality monitoring really transparent, or are they enhancing technocratic control because only very sophisticated people can use the information? (A particular concern in developing countries, M. Lemos, personal communication.)
- What makes some agencies and institutions more likely to use new sources of information than others? How is the information used? Is it generally available or difficult to access within the organization or agency? Does availability of improved information always enhance democratic processes, or is the information controlled in ways that concentrate the benefits?
- Does better information lead to better decisions? Is there any way to monitor this?

Platforms for Collaborative Processes

Universities are good locations for development of new ideas and applications, but they may not be ideal for sustained stakeholder interactions and services. Many user groups and stakeholders either have no contact with universities or may not encourage researchers and academics to participate in or observe decision-making processes. University reward systems rarely recognize inter-disciplinary work, outreach efforts, and publications outside of academic journals, which limits the incentives for academics to participate in real-world problem solving and collaborative efforts.

In the international context there are numerous protocol and political considerations regarding the willingness to cooperate, and underlying agendas of existing national/regional players and organizations to be evaluated. It is important that institutions and individuals within them participate for long enough to accomplish the goals of a particular project, establish trust in the people and the products, etc. What are the options?

- Within the agricultural extension programs of universities are large networks of people who interact with local stakeholders and decision-makers within certain sectors (not limited to agriculture) on a regular basis. In other countries this agricultural extension work is often done with great effectiveness by local government (e.g., Department of Primary Industries, Queensland, Australia).

- In some states, watershed councils and other local planning groups have developed, and many are focused on resolving environmental conflicts and improved land and water management. Watershed councils have been particularly successful in the State of Oregon.

- Natural Resource Conservation Districts, within the US Department of Agriculture, are highly networked within agriculture, land management, and rural communities.

- Some non-governmental organizations (NGOs) and public interest groups focus on information dissemination and environmental management issues within particular communities. They are good contacts for identifying potential stakeholders, and may be in a position to collaborate on particular projects. Internationally, a number of NGOs have stepped forward and are actively engaged in working with stakeholders to advance use of climate information in decision-making (e.g., Asian Disaster Preparedness Center (ADPC), in Bangkok, Thailand).

- In the US, research is currently conducted primarily with federal government funding, in federal agencies or universities. Expanding the types of research conducted within management institutions and local and state governments is an option to be considered—the stakeholders can then have greater influence on ensuring that the research is relevant to their particular concerns.

III. Incentives for Change

Understanding what motivates the people who are potential users of information is important in meeting their needs and expectations. Because there is reluctance to change behavior, particularly within agencies and other hierarchical organizations (Rayner et al, 2002), an assessment of the potential to provide incentives of various kinds may be appropriate. In some cases, an explanation that the person or agency could improve performance if improved information were used may be persuasive. In other cases, decision tools, i.e., models that simulate climate/hydrology/management options to produce scenarios will help identify benefits of changes in management. Explicit examples of the economic benefits that may accrue are likely to provide incentives, and such situations may lend themselves to encouraging the involvement of private sector consultants.

The existing incentive systems within most public sector agencies, many private sector organizations, and even universities may work against innovation. A major consideration is developing policies for mentoring, promotion and tenure for academic researchers working in integrated/applied science. This applies to both social scientists and bio/physical scientists.

Identifying ways to provide special recognition, nomination to advisory groups, awards or thank-yous that are visible to the supervisors and peers of the stakeholder/decision-maker may help. Opportunities for stakeholders to jointly present findings along with the scientist/researcher through publications or conferences may be appropriate in some cases. Innovation within agencies is often discouraged, which means that truly innovative people find employment elsewhere, generally in academia or the private sector.

Incentives and Motivation

- What will cause agencies, scientists or individuals to work together or change their mode of operation, other than direct orders from a superior or an outright emergency? How can the needs of all participants be incorporated into a perceived “win-win” situation?
- New techniques generally don’t get applied until managers get involved. How can the self-interest of managers be best served? For academics and government scientists who have secure jobs, what is the incentive to move outside their current comfort zone?
- For stakeholders and decision-makers, what are good reasons to participate? What is the “hook” that will pique their interest?
- If it is clear that there are potential economic benefits involved, working with private sector innovators and translators in the research design and potential transition to operations may speed adoption of new techniques.

The Role of Leadership

Causing change to occur in operational or policy environments, especially where there is substantial precedent, requires people working in these environments who are willing to move away from the status quo. This implies some willingness to take personal and professional risks, and some ability to get others to follow. Particularly in federal agencies, many people who make policy decisions are appointed and may not have the opportunity to develop long-term relationships with those who generate scientific information. This represents a particular challenge in getting scientific information used in high-level policy decisions. In contrast, operational policy staff and research staff are likely to be in place for longer periods of time in agencies, providing better opportunities to develop the relationships necessary to integrate research and decision-making. Presence or absence of leadership or a "champion" within stakeholder groups or agencies may make the difference in successful integration of new information. Identifying people with leadership qualities and working through them will facilitate adoption of new applications and techniques. The importance of leadership in initiating change cannot be overestimated, though connections with on-the-ground operational types and data managers are also important to facilitate information exchange. New (recently hired) professional water managers have been found to be more likely to take risks and deviate from precedent and "craft skills" that are unique to a particular water organization (Rayner, et al., 2002).

Crisis as Opportunity

Many changes in policy and use of technology occur in response to actual or perceived crisis, when there tends to be greater investment in adaptation or at least political pressure to respond. Since it is virtually inevitable that there will be future droughts and floods and other environmental hazards that affect decision-makers, stakeholders, and the availability of money for mitigation and adaptation, preparing to use these situations to best advantage is a useful strategy. This could mean having constructive alternatives or proposed legislation ready for a future "opportunity." In addition to crises caused by natural hazards, crises can be caused by regulatory changes and abrupt changes in funding. For example, in the Pacific Northwest, California and New Mexico, Biological Opinions associated with implementation of the Endangered Species Act (ESA) have significantly impacted existing water allocations, in some cases by trumping existing priority water rights and causing major economic dislocation. In other cases, habitat conservation plans developed under the ESA have derailed potential crises and provided an avenue for constructive evaluation of options that would not previously have been considered.

It is widely known that there will be increasing pressure on water supplies, particularly in the western US, due to population changes, habitat and recreation needs, Native American water rights settlements, water quality concerns and drought. It is relatively well known what the vulnerable regions are (Gleick, 2000), and preparing for these almost inevitable future conflicts can be used as an opportunity to insert new decision tools into the mix. To the extent that researchers can proactively help develop local consensus approaches to handling future conflicts, the region may be in an advantageous position in applying for funding and implementing solutions prior to the onset of crisis conditions.

Role of Social Science

One intended audience for this handbook is physical science researchers. Historically, such researchers may have had an unnecessarily limited view of the role of social science in integrating their own brand of science with decision-making. Social scientists, working as team members or consultants in projects, can help with identifying stakeholders' needs and perspectives, suggesting ways to encourage and facilitate interaction and sustain relationships, characterizing uncertainties faced by decision-makers, helping develop products that are more usable and useful, and providing input on project evaluation and dissemination of products. Social scientists can help characterize sensitivity, evaluate risk under various kinds of perturbations, and identify adaptation strategies that may be workable. These roles expand the traditional view of social science and are legitimate parts of the research agenda for science applications. However, social scientists are also affected by disciplinary boundaries and are not always focused on policy-relevant solutions, so finding a willing collaborator with good communication and policy skills is important.

Many of the challenges in linking scientific information with decision-maker needs are in fact social science questions. This is the reason why the "Human Dimensions of Global Change" program was established within various federal agencies, including NOAA, and why continued funding of the social and economic investigations of the use of scientific information is important.

Integrators

The wide array of technical inputs in many decisions requires translators of scientific information to assist in interpretation and tailoring for specific uses. Currently there is widespread use of private sector and academic consultants in agricultural and energy applications of climate and weather information, and limited use of consultants in water resources management applications. In some cases, communication between scientists and decision-makers would be enhanced by expansion of the types of professionals (integrators) who specialize in translating information (NRC, 1995; Hartmann, 2001, Kirby, 2000; Jacobs and Pulwarty, in press).

There are currently few training programs that are explicitly oriented toward developing the capacity to integrate climate science for particular applications, though there are a large number of universities that sponsor interdisciplinary environmental research. A broader range of integrators could be developed through short courses and certification programs as well as through degree programs. Regular refresher courses, such as those available for doctors and lawyers, for example, could be useful. A skill that could be incorporated into such a program is assistance with developing and encouraging new relationships between stakeholders and scientists in particular sectors, to encourage collaborative learning and jointly developed research agendas.

Integrators are commonly self-selected; they may be managers and decision-makers with particular aptitude or training in science, or they may be scientists who are particularly good at communication and applications. Many current integrators have evolved as a result of doing interdisciplinary and applied research in collaborative projects, and some have been encouraged by funding provided by NOAA's Office of Global Programs.

Qualities of Good Science Integrators and Translators

- Outside the box mentality.
- Willingness to work across disciplines and think creatively.
- Credibility in the science community, capability of understanding and translating complex information correctly.
- Expertise in a particular sector (e.g. energy, agriculture).
- Understanding of the institutions and cultures of the particular country/region involved.
- Ability to facilitate, rather than replace, relationship building between the principals (scientists and user groups).

Where will an expanded group of integrators with special skills in integrating science and decision-making come from? Some suggestions for expanding the range of translators and integrators appear below.

Ideas for Developing Integrators

- Incentives for including integrators in research projects can be provided by the agencies that fund science projects—either in the project review criteria or through separate direct funding for the participation of integrators.
- Educational institutions can be encouraged or funded to set up programs to develop integrators in various environmental applications, perhaps at the Master's level.
- The American Academy for the Advancement of Science Fellows program is an excellent example of encouraging integration of science into agency activities at high levels, by providing post-doctoral fellowships to work for a year within agencies. The Sea Grant program also provides fellowships that may result in placement of recent science graduates in policy areas.
- Cross-training within and between agencies and public universities can be accomplished through Intergovernmental Personnel Agreements and less formal mechanisms.
- New programs can be developed to place government and academic scientists in policy and decision-making arenas, and to bring stakeholders and decision-makers into research arenas for specific time periods of a month to a year to elicit interest in and understanding of each other's agendas.

Ideas for Developing Integrators (cont.)

- Mediators and facilitators who already focus on environmental conflict resolution are likely candidates for further training in specific disciplines to enable them to expand their areas of expertise. A directory of these facilitators is available through the U.S. Institute for Environmental Conflict Resolution, a program of the Morris K. Udall Foundation in Tucson, Arizona (www.ecr.gov/roster.htm).
- Focused training seminars that provide hands-on practice with interpreting data and using existing tools can be very helpful in expanding the capability of integrators and potential users of data.
- Programs that are intended to link decision-makers with particular researchers, students and faculty with potential applications areas for their research, etc., can help build a network of people focused on integration.
- Integrators can be required as a component of research that is intended to involve stakeholders/decision-makers.

IV. Mechanisms for Evaluation and Feedback

Assessments

Assessments of social and physical conditions are not always viewed as original research, and they may not get the respect they deserve from academics or scientists. However, assessments of physical conditions within regions, the institutional capacity to handle change, and the expertise and involvement of decision-makers are the most useful way to focus scientific research that is directed toward applications. Assessments also cause integration of science into society, as a by-product of the required interaction between physical and social scientists and the players in a particular area. The National Assessment of the Impact of Climate Change and Variability in the United States, which established regional and sectoral assessments throughout the U.S. (see Scheraga and Furlow, 2001), was possibly the most ambitious step yet in “use-inspired basic research” (L. Gilbert, personal communication, citing Donald Stokes, Pasteur’s Quadrant). Although the process followed for the Assessment varied substantially from region to region and between sectors, varying degrees of true engagement of stakeholders did occur. Encouraging on-going activities of this nature, which result in networks of scientists and stakeholders within communities, has benefits that are difficult to quantify but important for collaborative learning.

Follow-Through

Failure to adequately synthesize and disseminate the lessons learned in collaborative projects has reduced the value of some research and application activities. This is particularly problematic within and between federal agencies, where regular changes in personnel and changing areas of emphasis result in fragmentation of efforts and loss of institutional knowledge. For relatively little additional effort, results of research in applications could be more widely disseminated and useful.

The final product of research that is intended for applications is not a journal publication, but the development of operational products. There is a need for a more robust system to evaluate utility of products and to provide more "value-added" products. This framing of the research findings is critical to whether the products are truly useful.

Developing and documenting demonstration projects, where the utility of particular tools can be tested and potential benefits identified, is a useful way of following through on new ideas that show promise. A good example of this technique is work by K. Georgakakos et al. (the INFORM project) in northern California, where real-time monitors will be set up to show water managers the impacts of using climate prediction information in reservoir management as an alternative to depending on existing rule curves based on historical climate and runoff data. The key to this project is that there is no commitment made by the manager to change operations – they can operate for seasons or years with side-by-side systems, and evaluate benefits of changes in approach, while making no "risky" commitments.

Special Project Management Considerations in Science Applications

- Establish milestones (intermediate goals) and measures of success before programs begin.
- Collect data in an accessible (to all participants) and preferably standardized way, articulate quality control expectations.
- Provide opportunities for decision-makers and stakeholders to manipulate data and test applications of tools themselves.
- Document interactions between scientists and stakeholders, observing ways in which they change over time and why.
- Develop iterative feedback and response mechanisms.
- Require assessments of success from participants, including feedback from participants regarding conclusions.
- Identify lessons learned and ways to improve the approach in subsequent applications.
- Develop and maintain an up-to-date contact list for interested parties in both the research community and the applications community.
- Distribute regular updates on the status of currently funded projects and findings.
- Find avenues for sharing results outside of traditional academic journals, produce derivative "value-added" products that move beyond data sharing to a discussion of policy implications.

V. Measures of Success in Collaboration

> *Measures of success must be in the context of an objective and a strategic plan. They need to be identified in the context of the project itself. Participatory research as an end in itself is too process-oriented. You need an end condition that you will really know when you see it.* (M. Dilley, personal communication.)

Success in Collaboration is in the Eye of the Beholder

Success from the perspective of a social scientist might be development of sustained relationships between scientists and stakeholders and decision-makers, an open and participatory process, incorporation of risk assessment in prioritizing research activities, better scientific understanding of the decision-making process, etc. Success from the perspective of a physical scientist might be an improved understanding of physical processes that results from working with decision-makers who have years of hands-on experience managing resources. From the perspective of a stakeholder, success might be measured in terms of dollars earned from improved crop management decisions, or reduced losses from flooding or fire hazard. All of these measures of success are legitimate, though some are more difficult to document than others. The following table provides suggestions for potential measures of success that can be included in the articulation of expectations for future research activities.

MEASURES OF SUCCESS**

- **In Stakeholder Interaction/Collaboration**
  - Did participants modify behavior in response to information?*
  - Did participants initiate subsequent contacts?*
  - Were contacts/relationships sustained over time and did they extend beyond individuals to institutions?*
  - Was the information received integrated into the user's "world view"?*
  - Did stakeholders invest staff time or money in the activity?
  - Was staff performance evaluated on the basis of quality or quantity of interaction?*
  - Did the project take on a life of its own, become at least partially self-supporting after the end of the project?
  - Did the project result in building capacity and resilience to future events/ conditions rather than focus on mitigation?
  - Were quality of life or economic conditions improved due to use of information generated or accessed through the project?
  - Did the stakeholders claim or accept partial ownership of final products?

MEASURES OF SUCCESS** (cont.)

- **In the Use of Science in Decision-making**
  - Was the process representative (all interests have a voice at the table)?
  - Was the process credible (based on facts as the participants knew them)?
  - Were the outcomes implementable in a reasonable time frame (political and economic support)?
  - Were the outcomes disciplined from a cost perspective (i.e., there is some relationship between total costs and total benefits)?
  - Were the costs and benefits equitably distributed, meaning there was a relationship between those who paid and those who benefited?

- **In Interdisciplinary Work**
  - Are there regular contacts with colleagues in other disciplines?
  - Have inter-disciplinary programs and lecture series been established within agencies or institutions?
  - Are participants publishing integrated analyses in multi-disciplinary journals or journals from other fields?
  - Are participants cited in journals from other fields?
  - Are research projects jointly funded with other agencies or disciplines?
  - Is there a professional reward system (such as merit pay review) that encourages activities outside of the discipline?

* From both the scientist's and the user's perspective
** This table incorporates significant input from B. Morehouse and D. Liverman, personal communication.

VI. Conclusions

There are multiple opportunities to improve the utility of scientific research through developing new kinds of relationships with stakeholders and decision-makers. These efforts to work with stakeholders should not be perceived as being in conflict with the current research agenda of the federal science agencies; rather, relatively minor changes in process and expectations can make a significant difference in utility of products and result in more constituent support for the program. Likewise, there is no need for all scientists to directly engage with stakeholders. The key is developing an appreciation of the constraints and opportunities associated with working in the context of the "real" world, and establishing two-way flows of information with true engagement of stakeholders at one end of the flow, and the researchers at the other. Expanded use of intermediaries and translators can enhance the flow of information where scientists and/or agencies do not engage directly with decision-makers. Additional suggestions for increased integration of science and decision-making include:

- Understanding the context in which decisions are made
- Expanding the range of professional integrators
- Developing and documenting cooperative demonstration projects
- Encouraging institutional change, focusing on interdisciplinary research and applied knowledge (including changing the academic incentive system to reward applied and interdisciplinary work)
- Articulating clear expectations from the beginning and measuring success based on those expectations while providing for iterative learning
- Developing ability of practitioners to manipulate data themselves
- Facilitating long-term relationships and trust between scientists and decision-makers
- Developing synthesis products and mechanisms for evaluation and feedback
- Having people representing different backgrounds and perspectives in the same room

These efforts are important and necessary, and require both financial and institutional support. Evaluation of ways to improve the utility and communication of scientific research is itself a legitimate research objective that will significantly enhance the societal benefits of investments in science. An expanded focus on useful science is likely to result in increased support from constituents, an important outcome for government agencies.

Appendix 1. Differences in Perspective on the Use of Climate Information Between Scientists and Water Managers

(From Jacobs and Pulwarty, in press)

Factor	**Scientist's Perspective**	**Water Manager's Perspective**
Identifying a critical issue	•Based on a broad understanding of the nature of water management	•Based on experience of particular system
Time frame	•Variable	•Immediate (operations) •Long-term (infrastructure)
Spatial resolution	•Defined by data availability, funding, modeling capabilities	•Defined by institutional boundaries, authorities
Goals	•Prediction •Explanation •Understanding of natural system	•Optimization of multiple conditions and minimization of risk
Basis for Decisions	•Generalizing multiple facts and observations •Use of scientific procedures, methods •Availability of research funding •Disciplinary perspective	•Tradition •Procedure •Professional judgment •Training •Economics •Politics •Job risks •Formal and informal networks
Expectation	•Understanding •Prediction •Ongoing improvement (project never actually complete) •Statistical significance of results •Innovations in methods/theory	•Accuracy of information •Appropriate methodology •Precision •Save money, time •Protect the public •Protect their job, agenda or institution
Product Characteristics	•Complex •Scientifically defensible	•As simple as possible without losing accuracy
Frame	•Physical (atmospheric, hydrologic, economic, etc.) and societal conditions as drivers •Dependent on scientific discipline	•Safety, well being •Profit •Consistency with institutional culture, policy, etc.
Nature of Use	•Conceptual	•Applied

References and Suggested Reading

Broad, K., A. Pfaff and M. Glantz, 2002, Effective and Equitable Dissemination of Seasonal-to-Interannual Climate Forecasts: Policy Implications from the Peruvian Fishery During El Nino 1997-98. Climate Change 00, pp 1-24.

Broad, K., 2000, Practical and Conceptual Challenges to Climate Forecast Applications. International Forum on Climate Prediction, Agriculture and Development, IRI 26-28 April, 2000.

Broad, K. and S. Agrawalla, 2000, The Ethiopia Food Crisis—Uses and Limits of Climate Forecasts. American Association for the Advancement of Science, Science Reprint 289, pp 1693-1694.

Brown, G., 1997, Environmental Science Under Siege in the U.S. Congress. Environment, 39, pp 13-30.

Glantz, M., ed., 2001, Once Burned, Twice Shy? Lessons Learned from the 1997-98 El Nino. United Nations University, Hong Kong.

Gleick, P. and D.B. Adams, 2000, Water: The Potential Consequences of Climate Variability and Change for the Water Resources of the United States. US Global Change Research Program, Water Sector Report.

Graffy, E., 2002, Using Functions of Information to Guide and Improve Science Communication in the Policy Arena (unpublished manuscript).

Hartmann, H., 2001, Stakeholder Driven Research in a Hydroclimatic Context, Dissertation, Dept. of Hydrology and Water Resources, University of Arizona.

Hartmann, H., T. Pagano, S. Sorooshian, and R. Bales, 2002, Confidence Builders: Evaluating Seasonal Climate Forecasts from User Perspectives, Bulletin of the American Meteorological Society, May 2002, pp 683-697.

Jacobs, K. and R. Pulwarty, Water Resource Management: Science, Planning and Decision-Making, American Geophysical Union Monograph, in press.

Kirby, K., 2000, Beyond Common Knowledge: The Use of Technical Information in Policymaking. Dissertation, University of California, Davis.

National Research Council, 1995, Science, Policy and the Coast. National Academy Press, Washington, DC.

National Research Council, 1998, Future Roles and Opportunities for the Geological Survey. National Academy Press, Washington, DC.

National Research Council, 1999a, Making Climate Forecasts Matter. National Academy Press, Washington, DC.

National Research Council, 1999b, Our Common Journey: A Transition Toward Sustainability. National Academy Press, Washington, DC.

Pagano, T., H. Hartmann, and S. Sorooshian, 2001, Using Climate Forecasts for Water Management: Arizona and the 1997-98 El Nino, Journal of the American Water Resources Association 37, No. 5, pp 1139-1153.

Pfaff. A., K. Broad and M. Glantz, 1999, Who Benefits from Climate Forecasts? Nature 397, pp 645-646.

Pulwarty, R. and T. Melis, 2001, Climate Extremes and Adaptive Management on the Colorado River: Lessons from the 1997-1998 ENSO event. Journal of Environmental Management 63, pp 307-324.

Ray, A., R. Webb and J. Wiener, 2001, Analysis of Current Uses and User Needs for Water Management in the Interior West American Meteorological Society Annual Meeting, January, 2001, Albuquerque, NM.

Rayner, S., D. Lach, H. Ingram and M. Houck, 2002, Weather Forecasts are for Wimps: Why Water Resource Managers Don't Use Climate Forecasts. Final Report to the NOAA Office of Global Programs.

Scheraga, J. D., and J. Furlow, 2001, From Assessment to Policy: Lessons Learned from the U.S. National Assessment. Human and Ecological Risk Assessment, Vol. 7, No. 5, pp 1227-1246.

U.S. Global Change Research Program, 2001, National Assessment Synthesis Team. Climate Change Impacts on the United States: ThePotential Consequences of Climate Variability and Change. Cambridge University Press..

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, 1999. Vision 2005: National Weather Service Strategic Plan for Weather, Water and Climate Services.

U.S. Department of the Interior, April 4, 2002, Geological Survey, Science Impact – Enhancing the Use of USGS Science.

Thanks to the dozens of people interviewed for this project, and multiple anonymous reviewers—you will recognize your contributions throughout this document. Thanks also to Claudia Nierenberg, Jim Buizer, Roger Pulwarty, and Nancy Beller-Simms for your advice and encouragement. I am especially indebted to Jonathan Pundsack for his assistance in finalization of this handbook.

A publication (or report) of the University Corporation for Atmospheric Research pursuant to National Oceanic and Atmospheric Administration Award No. NA17GP1376

How to Lose Your Political Virginity while Keeping Your Scientific Credibility

DAVID E. BLOCKSTEIN

Many biologists and other scientists shy away from the political process. The reasons for this lack of involvement include unfamiliarity with the legislative and other political processes, concerns that their science will somehow be compromised, and the dissatisfaction that many Americans feel with the political system. Yet there are many reasons—self-interest and the interests of the biota we study—for biologists to become educated about the political system and involved politically. Involvement can take a wide variety of forms, such as writing a letter that provides information about a topic of public debate, giving testimony at a public hearing, signing a letter that requests a particular action, or becoming involved in helping someone get elected to public office.

As Congressman Maurice Hinchey (D-NY) told the League of Conservation Voters—the group created by leaders of the environmental movement to evaluate legislators and to help elect pro-environment candidates—at their Earth Day gathering in 1999, "Without politics, there is no conservation; without politics, there is no wilderness." Wilderness has existed since the earliest days of the planet, when all was wilderness. But until wilderness in the United States was protected by an act of Congress, and until individual wilderness areas were set aside, wilderness was not safe. It is also safe to say that, although legislation alone will not conserve biodiversity, without politics there will be no biodiversity.

For scientists to begin to interact with the political system, it is necessary to understand something about the job of making political decisions in our democracy. Elected officials are a special class of decisionmakers whose profession is to make decisions based on their perceptions of the views of the people who elect them. Their job description includes making decisions, choosing among alternatives, allocating resources that are usually insufficient for the tasks required, balancing or choosing among competing values and interests, and ultimately reaching compromise with individuals who profess and represent differing values. As one member of Congress said to me, "I vote for a living." Not only do legislators vote for a living, but their ability to earn a living as an elected voting representative depends on their ability to convince the voting public to select them for this job. Their accountability comes up for ratification every two or six years, when they request that their employers—the voting public—grant them a job extension.

Even though the culture and values of the political system are very different from the culture of science, where the uncompromising search for truth is paramount, scientists have much to offer to the political process, including

- specialized expert knowledge
- critical thinking
- objectivity
- data and informed interpretations
- credibility
- independence
- wisdom

Each of these is a valuable commodity that can help the decisionmaking process.

In addition to our responsibilities as citizens in a democracy, we have additional responsibilities as scientists claiming the attributes listed above to contribute them to the political

Editor's note: This article was adapted from a paper presented at the annual meeting of the Society for Conservation Biology in June 1999.

David E. Blockstein (e-mail: David@NCSEonline.org) is a senior scientist with the National Council for Science and the Environment, Washington, DC 20006. As the 1987–1988 Congressional Science Fellow of the American Institute of Biological Sciences and American Society of Zoologists, Dr. Blockstein worked with the environment subcommittee of the House science committee to prepare the National Biological Diversity Conservation and Environmental Research Act. He is the chair of the Ornithological Council and a Fellow of the American Ornithologists' Union. His research focuses on ecology and conservation of pigeons and doves.

process. Most scientists are recipients of public funds for our research. As part of the social contract by which society supports science, we are obligated to provide some payback by sharing the fruits of our knowledge with society.

As biologists, our professional responsibility is even deeper. In concluding his term as president of the Society for Conservation Biology, Tom Lovejoy wrote an essay entitled "Obligations of a Biologist" (Lovejoy 1989). He points out that we biologists have a responsibility to use our science, and to speak out as advocates for biodiversity. I keep this essay above my desk.

Our professional responsibility is a public responsibility. It is also a moral responsibility. The ethics of human civilization compel that if we see a person who is injured, we have an obligation to help. Those who have first aid or medical training have a particular obligation to use their specialized knowledge to help the injured. Physicians have codified this ethical professional responsibility as the Hippocratic oath.

Perhaps we biologists should have a similar oath. It is more complicated, because we have research subjects, not patients. Yet if we see a planet or an ecosystem or a biota that is being injured, we have an obligation to help. If our special training allows us to see something and understand something better than the average person, our obligation to use that knowledge is even greater. Those of us who by virtue of our education can see that we live in the proverbial "world of wounds" (Leopold 1953) have both professional and personal obligations to try to heal those wounds. I don't think that any biologist would argue that we should be doing nothing; indeed, anyone within the biological science community who self-identifies as a conservation biologist has made a professional commitment to help heal our embattled planet.

Nobel laureate chemists Mario Molina and Sherwood Rowland presented the first Senator John H. Chafee Memorial Lecture on Science and the Environment at the first National Conference on Science, Policy and the Environment in December 2000 (Rowland and Molina 2001). Molina asked rhetorically, "Is it enough for a scientist simply to publish a paper? Isn't it a responsibility of scientists, if you believe that you have found something that can affect the environment, isn't it your responsibility to actually do something about it, enough so that action actually takes place?" Rowland concluded the lecture by answering a question about his move from the lab into advocacy: "If not us, who? If not now, when?"

Yet our scientific skills and understanding may not be sufficient for us to apply our knowledge in a decisionmaking context. Our scientific training often does not include interaction with political and social institutions and those who populate them. Moreover, many scientists become quite wary and inappropriately characterize any interaction with the legislative decisionmaking process as "advocacy." And many scientists regard advocacy as anathema.

Yet the skills necessary to present scientific information to decisionmakers, who are lay people, are really only extensions of the skills we use to present scientific information to our colleagues and to our students. The concern about advocacy is often no more than a red herring pulled out of the basket by those who have little experience with the decisionmaking environment.

I argue that there is a continuum from data to advocacy (Figure 1). All scientific reporting, whether among scientists or to a nonscientific audience, involves interpretation and contextualization. Collecting and interpreting data in a scientific setting are, of course, what all scientists do. Interpreting data for lay people is what all educators do.

Data → Interpretation → Advice → Counsel → Advocacy

Figure 1. The data-to-advocacy continuum.

Yet many of us are uncomfortable extending this approach to questions of policy and management. Admittedly, it is much messier. Science is never straightforward and applications of science to policy are even less so. The answer to the policy question is never "found in Table 1."

There is always a need for interpretation, as well as data. The application of science to any problem, whether it is a scientific problem, a resource-management problem, or a policy decision, involves judgment. Yet who is better qualified to provide this judgment than scientists? Many scientists believe that at some point on this data-to-advocacy continuum, there is a line that we should not cross. If it exists, the line is certainly gray, and scientists disagree on where to place that line. Many will say that it is a slippery slope. Each scientist should find a place where he or she personally feels comfortable and should not be critical of other scientists whose personal values may put them at different points along the continuum.

Advocacy has a bad reputation among some scientists. The dictionary definition of an advocate is "one that pleads the cause of another." What is wrong with pleading the cause of another, particularly if the other—biodiversity, in this case—can't plead its own case? If biologists are not advocates for biodiversity, who will be? Are we not to be blamed if we walk away from the scene of an accident or crime and do not help in any way?

A legitimate concern among scientists is that if we become advocates, we somehow tarnish our credibility. *Credible* is defined as "capable of being believed." Like virginity, credibility can be lost only once.

There is a perception among scientists that, if we "go beyond our data" and interpret, recommend, counsel, or advocate that a particular action be taken, somehow our credibility is tarnished. We need to examine this perception and to ask who is judging our credibility. The peer review process does not discriminate as to whether the author has been an advocate or has visited his congressional representative or has been on the board of an environmental group. However, a tenure and promotion committee might.

Politicians, on the other hand, expect scientists to have an agenda or a purpose. They are suspicious of those who say they don't have one. However, they generally have high expectations that science will provide answers that they can trust. De-

Table 1. Seventeen cardinal rules for working with Congress.

1.	Convey that you understand something about Congress.
2.	Demonstrate your grasp of the fundamentals of the congressional decisionmaking system.
3.	Don't seek support of science as an entitlement.
4.	Don't convey negative attitudes about politics and politicians.
5.	Perform good intelligence gathering in advance.
6.	Always use a systematic checklist.
7.	Do your homework on the issue or problem.
8.	Timing is vital.
9.	Understand congressional limitations.
10.	Make it easy for those in Congress to help you.
11.	Keep the "bottom line" in mind.
12.	Use time—yours and theirs—effectively.
13.	Remember that members and staff are mostly generalists.
14.	Don't patronize either members or staff.
15.	Don't underestimate the role of staff in Congress.
16.	Consider and offer appropriate follow-up.
17.	Remember that the great majority of members and staff are intelligent, hardworking, and dedicated to public service.

Source: From Wells 1993 (© 1993 by American Association for the Advancement of Science).

spite the pedestal that we scientists have placed ourselves upon, nobody expects scientists to be infallible.

Here are a few guidelines on how to maintain scientific credibility while going beyond presentation of data.

1. Follow the facts and tell the truth.
2. Obey the "rules" of science.
   —Base interpretation upon data and conclusions that are peer reviewed.
   —Explain how conclusions are reached.
   —Present margins of error.
3. Present caveats.
4. Identify uncertainty.
5. Help to distinguish between uncertainty and guesswork.
6. Avoid hyperbole.

As Lovejoy (1989) pointed out, "If we explain what we are doing, we in no way compromise our scientific credibility." Molina emphasized that "we need to make clear when we are speaking as scientists and when we are expressing our values" (Rowland and Molina 2001).

Now that I've answered the second part of the question on my title, let's go to the first part, losing your political virginity. Without being too graphic, there are three main methods:

1. Do it yourself.
2. Do it with a group.
3. Pay someone else to do it for you.

Doing it yourself

A recent editorial in *Science* (van der Vink 1997) framed the question as the scientifically illiterate politician versus the politically clueless scientist. That may be only a slight exaggeration. All Americans, other than those living in Washington, DC, have two elected senators and a member of the House of Representatives. These people work for the public. Their ability to keep their jobs depends on keeping the public happy (or at least the majority of the people who actually vote). There are also a host of local and state elected officials who also work for the public, who are generally even more accessible, whose areas of responsibility have an even greater effect on a day-to-day basis (such as local land use planning), and who hear from scientists even less frequently. Although I very much agree with the adage "think globally, act locally," my focus here is on conversations with congressional representatives and senators. However, the lessons I present apply broadly to communication with elected officials anywhere in the United States and probably in other countries too.

The first thing to know is that elected officials are very busy and have lots of demands on them. However, they also have staff who work for them whose job it is to supply the best possible information on issues to their bosses. Staff are generally young (just out of college) and don't have much scientific background—freshman biology class may have been their last formal education in science. Each congressional office has one (or, rarely, more) legislative assistant who handles environmental issues. Staff members like to talk to scientists because scientists give them information. Information is the currency of Washington (money is, too). Information is power. Scientists have it. However, Washington has an oral culture. Staff are not interested and don't have time to read your thesis or a pile of reprints. As painful as it may be to scientists, a one-page summary is the most that they will read.

Harold Hansen, former staff director of the House science committee, stated that the first two commandments are "Know thy congressmember (personally)" and "Know about thy congressmember." The best place to get to know your congressmember is in the home district where you both live. Invite the representative or senator to your university, your laboratory, or your field site. Show him or her what you are doing with taxpayer money and explain why it is important and beneficial to society. You will be more effective if you do not come with a political agenda. Instead, build up a relationship so that you can be relied upon as a trusted source on scientific and environmental issues.

There are many resources for scientists who want to speak with congressional people. William Wells (1993), who has made a career of helping scientists work with politicians, has come up with 17 cardinal rules for scientists working with Congress (Table 1). A whole industry has developed to provide information about Congress. The best publications are those by the National Journal company, including the annual *Almanac of American Politics* (Barone and Cohen 2001). The League of Conservation Voters provides environmental profiles of members of Congress and compiles an annual scorecard of their voting record at *www.lcv.org*. The Library of Congress Thomas system *(www.thomas.loc.gov)* provides access to all official congressional Web sites, including congressional directories, hearing schedules, legislation, and the *Congressional Record*. Exclusive access to over 1,000 Congressional Research Service reports on policy issues relating to the environment and natural resources, and a plethora of other online resources, are available at the National Library for the Environment *www.cnie.org/NLE*, maintained by the National Council for Science and the Environment.

How to Influence Federal Decisionmaking—Without Writing a Single Letter!

Is your in-box stuffed with pleas from AIBS and other professional organizations and interest groups asking you to write to Congress? Would you like a more direct opportunity to influence federal decisionmaking? Consider serving on a federal advisory committee (FAC). You won't be alone: Over 52,000 individuals served on 956 federal advisory committees last year.

The federal government recognizes the value of expert advice, ideas, and diverse opinions offered by various advisory groups to federal agencies. But to avert undue influence by special interest groups and closed-door decisionmaking, input from outside groups is regulated by the Federal Advisory Committee Act, which established a regulatory scheme for the establishment, membership, and operation of such entities. Requirements for appointments of members, public meetings, and public reporting of minutes and recommendations were intended to ensure that the decisions of advisory committees would be open and impartial. Federal advisory committees can be created by federal agencies, by Congress, or by the president.

Some critics say that FACA's procedural requirements, together with amendments intended to prevent FAC mission creep and senility, have a "chilling" effect on public participation in environmental decisionmaking (Long and Beierle 1999). The Clinton administration imposed policies that limit the number of advisory committees that agencies are allowed to establish. The number of advisory committees fell from 1,305 in fiscal year 1993 to 956 committees in fiscal year 2000.

Whatever their limitations, federal advisory committees offer scientists myriad opportunities to contribute directly to the federal decisionmaking process. Probably the most high-profile science FAC is the Presidents' Committee of Advisors on Science and Technology. The National Science Foundation's discipline-oriented advisory committees, advisory panels, and special emphasis panels are all federal advisory committees. They serve the directorates, addressing such issues as priority investment areas in research disciplines; ways in which the directorate's mission, programs, and goals can best serve the scientific community; institutional administration and policy; and promotion of high-quality graduate and undergraduate education in various disciplines.

Especially within the Department of the Interior, the US Department of Agriculture, and the Environmental Protection Agency, scientists are invited to join various science or resource management advisory committees. Some focus on specific issues. The US Department of Agriculture's 1999 forest management planning regulations were based in large part on the recommendations of the Committee of Scientists. These 13 experts represented such disciplines as forest management, forest ecology, landscape ecology, forest hydrology, range ecology and management, animal ecology, natural resource law, sociology and organizational theory, and public participation and dispute resolution. The Invasive Species Task Force Advisory Committee, an interdepartmental entity, has a number of nongovernment scientists helping to devise appropriate policies and programs to address this thorny issue. At the Environmental Protection Agency, the sole function of the Endocrine Disruptor Screening and Testing Advisory Committee was to recommend to EPA methods and procedures to detect and characterize endocrine activity of pesticides, commercial chemicals, and environmental contaminants. At the Department of the Interior, one FAC focuses on the Going-to-the-Sun Road.

Other FACs are more general. The EPA's Science Advisory Board (SAB) is a technical review panel that provides scientific advice on many subjects. SAB is unusual in that it was established by Congress, rather than by the agency itself, to provide independent scientific and engineering advice to the EPA administrator on the technical basis for EPA regulations. It is now formal practice that many major scientific points associated with environmental problems are reviewed by SAB. Generally, SAB deals with risk assessment issues associated with various control options under consideration by the EPA. Its 10 sub-

Doing it collectively

One of the best vehicles for scientists to provide information to policymakers is through scientific professional societies. These societies have differing philosophies regarding public policy. Most of the big societies recognize that it is necessary to be involved in policy issues. Most societies are engaged in advocacy on behalf of the direct interests of their members, particularly when it comes to funding and regulatory issues (such as research permits). More challenging is to what extent and how societies should be involved in social issues, such as the teaching of evolution, animal welfare, and conservation.

Biomedical societies and others hire lobbyists to represent them in the constant chase for the federal dollar and to help present the perspectives of their members on national issues of concern. The American Institute of Biological Sciences (AIBS) has a long tenure in Washington, DC, and has recently reactivated its public policy program after several years' hiatus (see sidebar). This office is staffed by Adrienne Froelich and Ellen Paul. The Ecological Society of America (ESA) has a very active public policy program that prepares white papers, provides briefings for politicians and staff, communicates with the press, and works closely with agencies. ESA, like many scientific societies, rarely takes positions on specific legislation. The Society for Conservation Biology (SCB) has recently opened an executive office in Washington, DC, and hired Alan Thornhill as its first executive director. One of the purposes of this office is to allow SCB to provide information relevant to the national decisionmaking process on natural resource issues. The 10 ornithological societies in North America and the Caribbean joined together in 1993 to form the Ornithological Council, which has a mission to provide scientific information about birds to decisionmakers and others needing this information.

The American Association for the Advancement of Science (AAAS) has a substantial public policy program. AAAS rarely takes stands on issues. Through its public policy program, AAAS provides valuable resources to educate scientists about the political process and to educate politicians about science. For more than 25 years, AAAS has coordinated a Congressional Science Fellow Program. This program provides scientists with an incomparable year-long experience working as a scientific expert on a congressional staff. The program is a career-changing and life-changing experience for most Fellows, including myself. Many former Fellows occupy important positions in national science policy, in the government and outside the government. Fellows are sponsored by indi-

Continued from previous page

committees provide expertise on diverse subjects, including radiation, air pollution, and environmental economics. Under the US Department of Agriculture's new forest management planning regulations, biennial, independent peer review of the monitoring program is mandated. Outside scientists will also form regional science advisory boards and a national board will provide guidance on issues of national significance. The Department of Defense seeks advice from its Science Board, Ocean Research Board, Strategic Environmental Research and Development Program Scientific Advisory Board, and American Heritage Rivers Initiative Advisory Committee. In 1998, the Bureau of Land Management created a Science Advisory Board.

Still other FACs focus on local issues. The Bureau of Land Management's 23 Resource Advisory Councils, all in the western states, provide advice on the management of public lands and resources. The councils are citizen-based groups that advise the Bureau on standards of rangeland health and guidelines for grazing management. Each council consists of 12 to 15 members from diverse interests in local communities, including ranchers, environmental groups, tribes, state and local government officials, academia, and other public land users. Other local councils cover various rivers, national parks, and recreation areas.

Opportunities for direct participation exist even in international affairs. The US Department of State's advisory committees counsel the US National Section of the Inter-American Tropical Tuna Commission and the US Section of the North Pacific Anadromous Fish Commission. Advisors sometimes accompany US delegations to meetings of the United Nations Food and Agriculture Organization and a host of other conferences focused on, for example, genetically modified organisms; and US representatives to the Subsidiary Body on Science, Technical, and Technological Advice of the Convention on Biodiversity, or to the Scientific Assessment Panel of the Montreal Protocol, regularly consult with outside experts.

All FACs, and contact information for them, are listed on the General Services Administration Web site, *www.policyworks.gov/org/main/mc/index-r.htm.*

When new agency FACs are created or vacancies occur on existing FACs, notices are published in the *Federal Register.* AIBS sends these notices to its member societies and organizations via the biweekly policy update. Agencies generally identify potential members of highly specialized committees, but they are required by law to consider for membership any interested parties with professional or personal qualifications or experience that might contribute the functions and tasks to be performed. Scientists can and should seek appointment. Endorsement from scientific societies is helpful and should be submitted for agencies' consideration. Committee members typically attend two to four meetings each year. Travel expenses, and occasionally compensation, are paid by the agency.

Reference cited

Long RJ, Beierle TC. 1999. The Federal Advisory Committee Act and Public Participation in Environmental Policy. Washington (DC): Resources for the Future. (28 November 2001; *www.rff.org/CFDOCS/disc_papers/PDF_files/9917.pdf)*

vidual societies. AIBS has cosponsored fellows from time to time (see below).

Doing it anonymously (Paying someone else to do it)

It is important to understand that many scientists simply do not feel comfortable speaking with congressional staff, writing letters, testifying, serving on public policy committees, or participating in the policy process by other personal means (I hope that they do, at least, vote). These people can still contribute to improving the connection between science and decisionmaking. They can follow the time-honored method of helping to fund those who are more skilled in speaking out for their interests. Financial contributions are generally anonymous and thus cannot be said to harm anyone's scientific credibility.

Some scientific societies, such as The Wildlife Society, have a surcharge to their society dues to operate their public policy programs. My congressional fellowship in 1987–1988 was cosponsored by AIBS and the American Society of Zoologists (now the Society for Integrative and Comparative Biology), which financed their part of my fellowship through voluntary contributions from individuals. The Ornithological Council is financed by membership fees from its member societies and by voluntary contributions from individual ornithologists.

Most conservation biologists belong to one or more environmental groups. Many of these groups have a strong scientific basis. Although they are generally very effective politically, there is also a broad range of the political spectrum that reacts negatively to many environmental groups.

Finally, scientists, like any other citizen, can add their drops to "the mother's milk of politics." Campaign contributions can be given individually to the candidate of one's choice, or they can be bundled with other contributions through political action committees, principally the League of Conservation Voters or the Sierra Club, both of which take an active part in election campaigns.

However one approaches it, biologists have a responsibility to take advantage of the opportunities offered in our democratic system and use them for the conservation of biodiversity.

References cited

Barone M, Cohen, R. 2001. Almanac of American Politics 2002. Washington (DC): National Journal Group.

Leopold LB. 1953. Round River: From the Journals of Aldo Leopold. New York: Oxford University Press.

Lovejoy TB. 1989. Obligations of a biologist. Conservation Biology 3: 329–330.

Rowland FS, Molina MJ. 2001. The CFC-Ozone Puzzle: Environmental Science in the Global Arena. The John H. Chafee Memorial Lecture on Science and the Environment, presented at the First National Conference on Science, Policy and the Environment. Washington (DC): National Council for Science and the Environment.

van der Vink GE. 1997. Scientifically Illiterate vs. Politically Clueless. Science 276: 1175.

Wells WG Jr. 1993. Working with Congress: A Practical Guide for Scientists and Engineers. Washington (DC): American Association for the Advancement of Science.

Discussing dialogue: perspectives on the value of science dialogue events that do not inform policy

Sarah Davies, Ellen McCallie, Elin Simonsson, Jane L. Lehr and Sally Duensing

Public Understanding of Science 2009; 18; 338 originally published online Oct 1, 2008;
DOI: 10.1177/0963662507079760

Public Understand. Sci. **18 (3)** (2009) 338–353

Discussing dialogue: perspectives on the value of science dialogue events that do not inform policy

Sarah Davies, Ellen McCallie, Elin Simonsson, Jane L. Lehr and Sally Duensing

While theoretical work and empirical research have examined science policy-informing "dialogue events," dialogue events that do not seek to inform public policy are under-theorized and under-researched, even though they are common and growing in popularity in the UK. We describe how, from a critical perspective, it may initially appear that such events cannot be justified without returning to the deficit model. But with this paper, we seek to open up a discussion about these non policy-informing events by arguing that there are in fact further ways to understand and frame them. We deliberately draw on different literatures and seek to make use of practitioner expertise within our discussion, in order to display several perspectives on the value of non-policy dialogue on science as sites of *symmetrical individual or small-scale learning*—rather than institutional learning—through *social processes*.

1. Introduction

Over the last decade within the UK,[1] government and philanthropic organizations have been actively promoting many forms of public engagement with science (British Association for the Advancement of Science, 1999; Council for Science and Technology, 2005; Parliamentary Office of Science and Technology, 2001, 2006; Royal Society, 1999). The Science and Society Third Report (House of Lords Select Committee, 2000) can be seen as having solidified this trend towards science–society communication being based on a "dialogue" rather than a "deficit model" (Wynne, 2005).

The familiar concept of a deficit model of the public was coined by Wynne in the late 1980s (Irwin and Wynne, 1996; Wynne, 1992a, 1993) to describe the implicit assumptions within science itself and much of the then burgeoning "public understanding of science" (PUS) movement. The model depicts the public above all as deficient: in knowledge, understanding, and agency. In the context of the early PUS movement, "the public" was viewed as an empty vessel, an audience waiting to be filled with a collection of authoritative scientific "facts" (Gregory and Miller, 1998).

Those who identified the deficit model also critiqued it. Research showed that publics' relations with science were much more complex than the deficit model suggested: individuals were active in handling scientific information, rather than passive; had their own forms of expertise which they applied to scientific knowledge; and—perhaps most importantly—interacted

 ISSN 0963-6625 DOI: 10.1177/0963662507079760

with science not in a vacuum but within social contexts and for social purposes (Layton et al., 1993; Michael, 1992, 1998; Wynne, 1992b). These studies demonstrated that, far from being simply an empty space defined only by a knowledge deficit, publics are sophisticated at handling science and at negotiating relations with it, constructing their own meanings from science communication (de Cheveigné and Véron, 1996; Wynne, 1993; Yearley, 1999).

Such findings led strongly to arguments that publics can be *trusted* in their dealings with science. Various authors have argued that laypeople have the competences necessary to be involved with scientific decision-making (Irwin, 2004; Kerr et al., 1998; Lévy -Leblond, 1992; Locke, 1999) and should be involved. Indeed, it can be argued that not only are the public competent to take scientific policy decisions, but that their involvement will actually help make more robust judgments (Grove-White et al., 2000; MacMillan, 2004).

These arguments provided part of the impetus for a change within the PUS movement, from a deficit model approach towards a more interactive model. Drawing on the Third Report's call for a "new mood for dialogue" (House of Lords Select Committee, 2000: 37), this new model stressed a "dialogue" approach in which the interactions between science and publics are mutually informing, or symmetrical. Numerous event formats have since been developed and used (for example: consultations on a national level, consultations at a local level, deliberative polling, standing consultative panels, focus groups, citizens' juries, consensus conferences, stakeholder dialogues, Internet dialogues—see Rowe and Frewer, 2005) with the aim of engaging the public with science and the specific intention of informing policy processes. Rowe and Frewer (2005) attempt to categorize these different methods based on situation and output. In practice, however, despite the diversity of formats, many of these formats are generically known as "dialogue" or "dialogue events" by practitioners.

Simultaneously, organizations—such as scientific associations and societies, science centers and museums—with *no* formal science and technology policy remit and no connections to scientific governance began using language such as "participation," "engagement" and "science and society."[2] They also started hosting "dialogue" or "dialogue events," but without any connection to policy. Thus, though initially developed in contexts of governance and policy processes, the language of engagement and dialogue was adopted by other institutions and implemented in a variety of ways. In this paper we therefore start with a basic typology: the premise that there are two main types of public engagement with science and technology events, those that seek to directly influence policy processes and those that do not (Lehr et al., in press). Within both types, there are events, often called dialogue events by practitioners, which claim to promote dialogue between science and publics. While this typology is simplistic, the distinction—we would argue—is an important one and a fruitful way of analyzing "dialogue."[3] More detailed typologies of science–society communication and dialogue are already in existence (see Bucchi and Neresini, in press; Callon, 1999; Lehr et al., in press; Rowe and Frewer, 2000, 2004, 2005).

An example of this latter type of "dialogue"—public engagement without formal connections to policy—is the events that take place at the Dana Centre, London. The Dana Centre is a venue, institutionally attached to London's Science Museum, which hosts a range of face-to-face evening programs targeted toward adults and dealing with topic-areas related to science, technology and medicine. Dana Centre events are often—although not solely—based on a dialogue focused format. The main aim for these events is to produce dialogue (Science Museum Visitor Research Group, 2004; Simonsson, 2006) and to achieve this, the Dana Centre employs a range of different formats that are made up of elements that have been found to promote dialogue (McCallie et al., in review). For example, some events use a small discussion group format. Other factors that encourage dialogue include making sure that the format, subject and aims of the event are clearly explained to participants, and providing a relaxed and friendly atmosphere. It is also important that sufficient time for dialogue to develop is given within the event structure and that the event facilitator is skilled in promoting and supporting dialogue during the event (Simonsson, 2006).

Another key example of this second type of "dialogue" is the Café Scientifique movement (see Café Scientifique, 2006; Lehr et al., in press). First formally established in the UK, but now present in various forms around the world, "science cafés" provide for the discussion of contemporary issues in science and technology in a relaxed and informal environment. Such cafés are held in non-academic contexts and are "committed to promoting public engagement with science and to making science accountable" (Café Scientifique, 2006).[4]

While there is therefore a coherence of language which seems to mark a distinct trend towards "dialogue" within current relations between science and society in the UK, there remains a multiplicity of meanings of this word in use in both policy-informing and non-policy related context. "Dialogue events" in a non-policy context can, from our experience, involve anything from small discussion groups to more traditional question and answer sessions. A universal definition of what constitutes a dialogue event is lacking both theoretically and within the communities that host such events.

2. Theorizing and analyzing "dialogue": from large to small scale

Most academic analyses of dialogue events have focused on participatory processes with direct links to policy. Such analyses have so far tended to be pessimistic (Grove-White, 2001; Irwin, 2001; Wynne, 2001, 2002, 2005). Wynne has argued that the imposition of a naïve sociology—which includes "arbitrary, deeply inadequate and damaging visions of the human" (Wynne, 2001: 475)—which occurs in normal interactions between science and its publics is simply heightened in participatory processes. Such processes continue to be framed by science and on scientific terms, failing to take into account broader questions and different kinds of knowledge. In practice this has led to a focus on "back-end" consequences such as risk, in effect protecting the broader trajectory of scientific and technological development from accountability. Similarly, Irwin has argued in his analysis of one participatory process (Irwin, 2001) that publics were framed and positioned in negative ways by the policymakers and scientists organizing the process. A lingering deficit model perspective meant that citizens were framed as ignorant and that informing them became a key aim of the process. On a more pragmatic level, processes such as the *GM Nation?* debate have been criticized for their lack of clear outcomes (Rowe et al., 2005). If such debates are unfocused as to what their output should be, or fail to act on public opinion, then they leave themselves open to the charge that they are simply a public relations campaign for science, seeking to convince the public of the justification for an already-decided policy (Beder, 1999).

While there has been a small amount of other discussion examining the importance and efficacy of policy-informing dialogue events (Durodié, 2003; Jackson et al., 2005; Llewellyn, 2005; Rowe et al., 2005), dialogue events that do not seek to inform public policy are under-theorized and under-researched in regard to their nature and effectiveness, even though they are common and growing in popularity in both the UK and US.

This lack of academic research is perhaps understandable, given that the key reason for the development of public dialogue on science revolved around using public expertise to inform policy and increase democratic participation. If the goal is to have publics impact on science, why study processes that don't directly address such change? A justifiable focus on policy and effective public involvement in science has thus led to an emphasis, in analysis, on the large-scale processes of science–society dialogue.

It also seems probable that the criticisms concerning the deficit model approach to engagement outlined above would be redoubled at dialogue formats that are not linked to policy processes. If policy-related dialogue has been accused of being a smokescreen for continued deficit model perspectives as well as a cynical bid to increase public trust without increasing public accountability, then what else can non-policy related dialogue events be? It appears as though dialogue events that do not directly inform policy processes simply cannot be justified, even in theory, without returning to the desire to "educate" publics or for public relations work to increase trust and acceptance. Dialogue without policy outcomes cannot, it seems, fit into an existing critical framework.

While sympathetic to this perspective, we do not simply want to abandon what is a growing phenomenon as a site of theoretical interest and empirical research. Within this paper we argue that there are other ways of understanding, valuing and framing dialogue events that do not seek to influence science policy processes. Specifically we argue three points with respect to the interest in and value of such events. First, we argue that a shift in perspective to analyzing dialogue on the level of *individuals* and small groups, rather than that of *institutions* (governments, publics, organizations), removes many of the problems of a lack of policy outcomes by focusing attention on outcomes on a much smaller scale. Dialogue events can thus be viewed as sites of individual learning through social processes.[5] Second, we claim that dialogue events that do not seek to inform policy do not have to be based on a deficit model of interaction between scientists and publics, and we support this by emphasizing the importance of *symmetry* in learning. Third, we discuss learning as more than an accumulation of facts: learning involves emotions, empathy, and social understandings. In doing this, we are careful to distance ourselves from the model of learning present in PUS, in which the end goal was dependent upon participants memorizing and mastering the material presented by the "experts" (referred to as a "transmission-and-acquisition" model, Sawyer, 2006). The model of learning we discuss views understandings and learning as created, directed, and determined by those participating.

We conclude that by focusing on these concepts, dialogue events that do not seek to influence policy could (1) provide opportunities for empowering individuals for further involvement, (2) be viewed as personally beneficial, or (3) be part of a gradual step by step change in science and society.

Thus this paper opens up a discussion about non-policy informing dialogue events. We are deliberately drawing on research from more than one literature base—in particular education and public participation literature—and have sought to make use of practitioner expertise within our discussion. We are therefore seeking to display several perspectives on the value of non-policy dialogue on science—which, indeed, no one theoretical perspective can claim as its own domain. While each approach can be critiqued (in ways that themselves depend on one's own theoretical standpoint), we largely leave this to the reader. Our aim is to provide a richness of outlook that mirrors the process of dialogue itself in its articulation of several worlds.

3. Dialogue as a symmetrical learning process: views from participatory and educational literature

The focus on individual benefit within dialogue processes is not a new concept within public participation literature. Laird (1993), for example, has argued that learning is a useful outcome of participatory processes. In his discussion of direct participation in democratic processes he describes how "educational and psychological effects" (Laird, 1993: 345) on participants are viewed as a useful outcome alongside actual effects on policy. As he writes, "democracy enables people to become fully developed citizens" (p. 345). Such learning is not merely of new "facts," but rather is an augmented understanding of the complexity of an issue, the wide range of views, and the various ways to negotiate and analyze these. The idea of "social learning" is perhaps useful to us here (Limoges, 1993; Rip, 1986). Developed in the context of scientific controversies in the public domain, the concept of social learning describes a process of articulation of different viewpoints and the interactions of these viewpoints. Limoges suggests that to maximize social learning, controversies should be managed in order to ensure the articulation of as many different viewpoints or "worlds of relevance" as possible. It is through this articulation, followed by the negotiation and bridging of these worlds, that learning can occur, perhaps changing the very nature of the controversy in the process. Importantly, this learning "is not a question of transferring existing knowledge, understanding or skills to people who do not yet master them. The learning is open ended … The controversy is about what the content of the learning should be" (Rip, 1986: 358). There is therefore no fixed agenda, no one set of facts to be transmitted from one group to another. Debate will focus around which issues are important as much as the content of those issues.

In the context of controversies, there is a clear endpoint to be aimed for: a socially robust outcome,[6] which Limoges and Rip argue can be best reached through this process of social learning. The scale again tends to be on the level of institutions and the learning on the level of whole societies. But the concept can also be applied on a smaller scale to those individuals within dialogue processes. As articulation occurs within these contexts, diverse—indeed, often incommensurable—worlds are described and understood and negotiated. The learning that takes place would not be only or even primarily expected to be about new "facts" or information; rather it would be a complex process of social, cultural and moral understanding and may result in changes of attitude as well as of knowledge and knowledge of knowledge.

Similar conceptualizations of learning appear within the educational literature. For example Cremin (1988: x) recognizes education as "the deliberate, systematic and sustained effort to transmit, evoke, or acquire knowledge, values, attitudes, skills and sensibilities, as well as any learning that results from that effort, direct or indirect, intended or unintended." This definition reformulates education from a one-way, transmission process solely concerned about the acquisition of facts (Sawyer, 2006; Silberman, 1970) to a powerful conceptualization that provides for learning to take place (or not) when one is specifically intending to "teach" or "learn" as well as when no one intends to be teaching or learning (Lave and Wenger, 1999; Rogoff et al., 2003). Likewise, included in this definition of education are the domains of morals, ethics, attitudes, dispositions, and abilities to successfully operate within society (cf. Kolstø 2001; Sadler and Zeidler, 2003). Education, in terms of teaching and learning, thus moves from filling an empty vessel to interacting with others in order to become more aware and capable people. In the case of dialogue events, the explicit mission of the event or venue may not be to "educate." However, by the nature of the social interactions promoted within the events and the intentional and unintentional learning and teaching which may be taking place, they can reasonably be considered an educational context. Thus in order to understand further the value of dialogue events from this perspective it is useful to survey some recent trends within education.

A major focus of recent science education in both the US and the UK has been "science literacy" (American Association for the Advancement of Science, 1993; Bingle and Gaskell, 1994; DeBoer, 2000), "science-for-all" (Jenkins, 2000), or "science for citizenship" (Osborne, 2000, 2002; Ratcliffe and Grace, 2003). Dialogue events fit within these science-for-citizenship aims of science education. Science-for-citizenship argues that the purpose of science education focuses on preparing citizens for life within societies in which science plays a significant role, including preparing citizens who are going to be scientists as well as those who are not. Engagement with science in the context of society allows scientists and publics to explore ideas, to examine current societal issues, to challenge the claims of others, and to develop their own understandings. Thus, whether or not dialogue events inform policy, they may provide an important and effective venue for adults to voluntarily engage with science in the context of society.[7]

To achieve science-for-citizenship goals, science education must move beyond "science-as-fact," in which science is presented as a static body of facts to be mastered. Instead science needs to be presented and explored as "ideas-about-science" (Millar and Osborne, 1998) in which the nature of science and the processes of science are studied in parallel with current scientific understandings (Osborne et al., 2003) and science-in-the-making (Latour, 1987). In dialogue events, the mix of those who generate scientific knowledge, those who affect its use in context, and those who experience it in daily life can bring to the fore the social, cultural, and moral aspects of science in society in order for them to be discussed transparently. In this way, dialogue events move beyond serving as a forum for transmission and acceptance of science to a place of problematizing and negotiating knowledge.[8]

The science education literature also advocates a toolkit of pedagogies, depending on the nature of what is to be learned and who is learning. While Cremin's definition of education implies that learning takes place in all settings, whether intentionally or unintentionally, socio-cultural and social constructivist theories of learning argue that some types of interactions promote greater learning than other types of interactions. The overarching, common premise between these approaches is that active participation in one's learning enhances meaning-making. The two theories focus on different aspects of the interactions, however. First, socio-cultural theories of learning place prime importance on the pedagogies of social interaction and the fact that learning is mediated by cultural tools such as language (Rowe, 2004). For example, it is theorized that people come to or achieve greater, more advanced, or more complex meaning-making through talking with others in a dialogue format, especially with others with different experiences or expertise. This does not suggest that *all* social interaction is more productive than an individual working alone—the key is to create social interactions that facilitate achievement beyond individual capacity (Mercer, 2000; Mortimer and Scott, 2003; Vygotsky, 1978; Wells, 1999).

Social constructivist theory, however, focuses on pedagogies that support people integrating past experiences and understandings with current experiences in order to construct new understandings (Driver, 1997; Hodson and Hodson, 1998). These pedagogies encourage active participation and see all learning as constructed meaning-making. Social constructivist pedagogies often encourage people to interact in order to facilitate personal understanding, but most importantly, they directly negate the transmission model of learning. In summary, these theoretical approaches to learning about science and socio-scientific issues lead to pedagogies that encourage direct and sustained interaction amongst people.

Science education, in its broadest sense, is thus inherent in dialogue events because they are social events that involve interaction and meaning-making and therefore are sites of learning. Such events can therefore be a subject of study for educationalists as well as for those interested in public participation in science, and their perspectives are both valid and valuable for understanding better the processes that occur in these events. Educationalists will—as we have described above—view "dialogue" as valuable in a variety of ways.

Learning—social or otherwise—can be viewed as empowering participants for further debate. But positioning learning as the key outcome for participants in non-policy dialogue, as we do, could still appear a deeply deficit model perspective. It is therefore vital that any such learning, to be truly part of a dialogue process, should be *symmetrical*. Social learning and enhanced understandings must occur within *all* those involved, whether they are present in their roles as scientists or as citizens. Rogoff, Matusov and White (1996) specifically describe this type of learning and teaching as based on a socio-cultural model in which no one participant has a fixed role, each has an active role in learning among the community, and the roles one takes will change over time, such that participants will experience various roles at different times and in reference to different issues.

Thus the dialogue forum should not imply the superiority of one form of knowledge over others or the expertise of one group as more valuable than that of others: conditions of strict equality must be imposed. The dialogue would then be occurring on a micro scale; rather than public(s) interacting with science(s) en masse to influence policy and knowledge production, individuals would interact with other individuals to come to shared understandings in the processes of learning described above. Impacts and outcomes will be on the level of individuals and could be anything from changed knowledges, understandings or attitudes to changed behavior. As Laird notes for direct participation theory, participation "changes the outlooks and attitudes of participants. It makes people more aware of the linkages between public and private interests, helps them develop a sense of justice, and is a critical part of the process of developing a sense of community" (Laird, 1993: 345). In other words, social learning in a dialogue forum could equip all involved to be more effective citizens.

Indeed, it could be argued that non-policy dialogue may in some ways be a better forum for this learning process than dialogue with policy outputs, where formalized, consensual outcomes are often demanded. Without the reductionist pressure of having to create an often impossible consensus or sum up diverse viewpoints into one statement or recommendation, participants can be free to explore all positions and to avoid polarizing the debate into opposing camps. As Rip (1986) discusses, such processes, in all their complexity, tend to lead to a more socially robust outcome to a controversy. Non-policy dialogue could therefore be viewed as a part of, and in fact linked to, wider and more formal interactions between science and society: dialogical processes, in their development of citizens, could empower and equip individuals and small groups. Media attention may bring the diverse articulations of the issues at stake further into the public sphere. If managed correctly (see Limoges, 1993), dialogue events around controversial issues could initiate a "ripple" effect of activity, protest, and participation which leads to policy impacts.[9]

4. Dialogue in practice: the value of dialogue events that do not inform policy from a museum's perspective

We now turn to look at the value of dialogue events that do not aim to influence policymaking from a practitioner's perspective—specifically, from the experience of one of the authors in working with the Science Museum's Dana Centre in London. We have already discussed some of the details of the format and process of Dana Centre events. As museums and other informal institutions have no remit to influence science policy directly, the dialogue processes they are involved in rarely have formal policy outputs. However, such institutions see dialogic processes as valuable and useful to them: it is this perspective, and the reasoning behind it, that we explore here.

We have already pointed out that there are currently many varying meanings of what dialogue is and what it involves. One such meaning is the Dana Centre's definition: dialogue is

> a process of communication in which two or more participants engage in an open exploration of issues and relationships on an equitable basis. Dialogue is the exchange of ideas, opinions, beliefs, and feelings between participants—both speakers and audience. It is listening with respect to others and being able to express one's own views with confidence. Dialogue is not silence, chaos, or one person or faction monopolizing the session. (Gammon and Burch, 2003: 1)

This meaning is used when such events are developed, delivered and evaluated by museum staff. This definition also outlines what should happen during dialogue-focused events and highlights the importance of the interactions within these events being social and symmetrical. Thus, according to the Dana Centre, for dialogue-focused event formats to be considered successful it is important that dialogue occurs during the event and that participants take part in a two-way communication: a question and answer session could not be considered a successful dialogue event.

More specifically, the Science Museum's Dana Centre finds dialogue events valuable for a number of reasons. Firstly, events that are based on a dialogue format help the Dana Centre to achieve its aim of *actively* engaging people in discussions on science. This aim is also in line with a section of the vision statement of the NMSI (the National Museum of Science and Industry, the overall body of which the Dana Centre is part):

> We engage people in a dialogue to create meanings from the past, present and future of human ingenuity. (NMSI, 2002: 3)

Thus, when dialogue between participants occurs during a Dana Centre event, it contributes towards NMSI achieving its overall mission.

Secondly, compared to the more traditional lecture format which is primarily one-way communication, an event format based on dialogue is more interactive and gives more participants extended opportunities to actively take part and contribute. As a result, the dialogue format has the potential to offer all participants a more entertaining and enjoyable experience. Audience research conducted at Dana Centre dialogue events supports this: both invited speakers and visiting participants indicate they enjoy and prefer the dialogue-based format to the more traditional lecture set-up. In fact, even though many participants indicate they had expected the event to be a lecture-style format, they were positively surprised. The event was much more interactive and informal than they had anticipated.

> I thought a lecture is a lecture, but this is actually better, it's much more interactive. (Interview with visiting participants)

> A refreshing change from a stagnant lecture theatre. (Interview with visiting participant)

Thirdly, the dialogue event format has the potential to promote many different types of learning. The way in which dialogue events are set up allows extended opportunities for those taking part to engage in discussions with other participants (both invited speakers and visiting participants). This is particularly true in comparison with event formats that are structured as a formal one-way communication with few opportunities to contribute and interact with others participating in the same event. Therefore, an event format that is focused on dialogue is more likely to facilitate social learning and has the potential to challenge and change participants' attitudes and opinions as ideas are discussed and negotiated. Moreover, although focused on a dialogue format, these Dana Centre events also facilitate cognitive learning and knowledge building in relation to the topic-area the event covers. Dana Centre audience research supports the need for providing participants with information relating to the topic-area under discussion. Participants want to learn. Therefore they want and expect information to be presented during the event, and when this is not given to them they are frequently disappointed. Such information does not just involve presenting factual information but also includes a variety of opinions, beliefs and ideas related to a specific topic. Dialogue events must also provide information *in order* for opinions to be formed or challenged and for dialogue to take place. It appears to be difficult for those attending a dialogue-focused event to discuss the issues that the event covers if they are not given any form of introduction to the relevant subject and issues—unsurprising given that it is hard to have a discussion when the topic, major issues, and boundaries of the discussion are vague or ill-formed among a group.

> I felt like it left me wanting a discussion, but with no information I couldn't get very far with my own thoughts and would have liked people with real inside knowledge or experience to be somehow involved. (Interview with visiting participant)

Interestingly, this seems to suggest that we cannot completely discard the concept of the presentation of information or "fact" transfer being key during these events. Publics that attend are often actively seeking specific information and are frustrated if this is not accessible. Thus, participants conceptualized these events as resources that can be used to equip and empower themselves for further engagement.

Finally, as discussed earlier, events that use a dialogue-based format are likely to have an impact on the individual level rather than an institutional one. As such, events that use a dialogue-based format may act as a stepping stone in motivating participants (both invited speakers and visiting participants) to further involvement. This is particularly true given that these events are more interactive and offer more opportunities for contribution and active participation. Such processes can provide a neutral ground where participants from different backgrounds can meet, exchange ideas and views, and openly explore different issues. Therefore attending a Dana Centre event may inspire and motivate participants to investigate the issues covered by an event further after taking part in an event. Attending an event that uses a dialogue format may also give all attending—both those who are invited as subject specialists and those who visit the event—increased confidence to attend other, science-focused dialogue events or debates as they become familiar with the format. Such a raised level of confidence could motivate and enable individuals to take part in processes that do inform policy.

It is also important to point out that practitioners are aware that dialogue does not naturally occur just because an event is labeled as a dialogue event. Unpublished research on Dana Centre dialogue events has shown, for example, that during some events invited speakers have monopolized discussions or that the interaction between invited speakers and visiting participants has never moved beyond a question and answer session. However, such research not only has detected problems and barriers but has helped to ensure that dialogue-focused events are constantly altered and improved to achieve their intended outcomes.

There are many barriers to dialogue taking place during an event, and anything from the overall structure of the event, the skills, personality and experience of the facilitator and of the invited speakers to the participants who attend may affect these. It is therefore important that dialogue events such as those held at the Dana Centre are subject to research and evaluation in order for barriers to be identified and changes to be implemented. As noted above, practitioners are often aware that the "dialogue" their institutions carry out can be problematic. In addition, it seems likely that practitioner rationales, motivations and evaluations of dialogue processes would benefit from further critical analysis. In the discussions above, for example, we find ideas of dialogue as empowerment or citizen-building; of enjoyment as key to participation; and of public desire for relevant "facts" or information. Research might productively examine and interrogate some of these concepts, both in theoretical analysis (for example, asking what *kind* of "citizenship" is constructed by these arguments?), and in empiricalstudies of dialogue processes (including investigating longer term impacts of these events on participants). It would be productive, for instance, to examine exactly how participants view and construct the dialogue process in order to understand more fully what it means to "enjoy" this kind of event. Do they see it primarily as entertainment, and if so, how will this affect future impacts on participants' lives? Studies such as Goven's (2006) will also push us to examine not just stated motivations and reasoning but also how the wider political-economic context frames and shapes dialogue.

5. Conclusion

We have argued that non-policy dialogue events should be viewed as having learning outcomes at the level of individuals rather than influencing policy at the level of institutions. We also argue that it is valuable to frame and evaluate dialogue events in terms of symmetrical social learning. Thus dialogue events that do not seek to influence policy are spaces enabling individuals from potentially diverse cultures to come together, articulate positions and views, and interact in a context of genuine equality. It could even be argued that this could—theoretically—be a far more effective way of affecting the culture of science to become more personally relevant and democratically accountable than through public participation in policy. Within dialogue events genuine learning should be taking place on all sides; there should be no holding back or reliance on entrenched positions of authority. And if enough individuals within science learn about the diversity of opinions about science, the manifold framings of scientific questions, and the pragmatic capabilities of publics, then science as a body will slowly be changed.

However, to argue that this is how non-policy dialogue *could* be justified is not to say that this is what actually occurs at such dialogue events—as, indeed, we have already noted within our discussion of the practitioner's point of view. Analysis of these processes is much needed in order to identify just how much of the old PUS movement's turn to dialogue is genuine and how much is rhetoric that glazes entrenched deficit model positions. Certainly anecdotal evidence (and much of our own early stage research) suggests that many dialogue events are emphatically not the spaces of equality and symmetrical social learning that is the ideal described above. Observational data indicate that dialogue events can in fact quickly revert to traditional question and answer sessions, that events may continue to operate under assumptions of the primacy of scientific knowledge, and that the roles participants assume or have imposed upon them can damage equity. Such problems may—we suggest—be due to cultural habit, a lack of clarity among organizers, speakers and other participants with respect to the intended nature of the event, or be based on how the event is policed. Those who "facilitate," for example, may not be trained or confident in producing this style of interaction. Publics also, it appears, often continue to come to dialogue events with the expectation of learning from experts and deferring to perceived authority. At the same time, emerging research indicates that some dialogue events do achieve their intended aims (McCallie, forthcoming).

Further research on these issues needs to be conducted from all of the perspectives discussed above—by those in education, science studies and by practitioners. In particular we believe that critical perspectives, when integrated into research from all these domains, can be especially valuable. Such perspectives help us challenge the taken-for-granted assumptions and boundaries found both in practice and in academic disciplines. They would push us to ask, for example, what *kind* of "citizenship" are educationalists referring to when they speak of "science education for citizenship"? What are the political meanings of constructing citizenship in this way? Or they might challenge the definitions of dialogue that practitioners use. Where do these definitions come from? What assumptions underpin them? Empirically, these are also rich sites for analysis. Issues of control within dialogue seem important: how are discussions "kept on track" and who decides what that track is? How are science and non-science distinguished and bounded? How are concepts of risk and expertise constructed and used by participants?

Several of the authors are currently analyzing and characterizing the talk that occurs during dialogue events, providing some insight into learning on a social—though small-scale—level. However, other methods are needed to evaluate how far individual learning also takes place. For example, interviewing participants after events and following up with them over time would allow researchers to determine what participants—whether scientific or lay—take away from these events, and how their lives are affected. Future research could also address the wider context of non-policy dialogue, including its links to and impacts on policy processes and cultural change, and how particular cultural assumptions—such as what "citizenship" is—are embedded in the processes.

Finally, dialogue, as we have envisioned it, requires scientists and publics to be entering the forum with open minds and desiring to learn as much as to teach. These events require *all* participants to come expecting both to engage with and to treat with respect other viewpoints and ways of knowing. This does not imply that people should accept all contributions equally; on the contrary each contribution should be considered critically. But such a requirement may itself need a sea change within science and society: we have suggested that currently non-policy dialogue is often a difficult and problematic process. Research is needed to test this suggestion and to evaluate our model of dialogue against what happens in informal dialogue contexts. Such research will do much to clarify what actually takes place within dialogue events, and will help ultimately to ensure that barriers that limit symmetrical learning and engagement are reduced.

Acknowledgements

This material is based partially upon work supported by the National Science Foundation under Grant No. 0119787 to the Center for Informal Learning and Schools. Any opinions, findings, conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

One of the authors has been supported by a doctoral grant from the Arts and Humanities Research Council.

Notes

1 The situation in the US and Europe is similar but not identical. In the US "dialogue events" are not new, but the involvement of informal institutions in "dialogue events" is a more recent development (Lehr et al., in press). The differences between the countries are further compounded by the histories of the "public understanding of science" and "science literacy" movements and the differing assumptions that underpin these (Jasanoff, 2005; Lehr, 2006). In this paper, therefore, we will be focusing on the situation in the UK whilst acknowledging that there are many similarities with that in the US and, indeed, in Europe.

2 For examples see the websites of the British Association for the Advancement of Science (http://www.the-ba.net/the-ba/, accessed 4 July 2006: "Your support will allow the BA to continue its mission, from our schemes

for young people of every ability, encouraging participation and excellence in science, to facilitating open debate where the social and ethical issues of science can be discussed. And everything in-between!") or the Royal Institution (http://www.rigb.org/rimain/abouttheri/index.jsp, accessed 4 July 2006: the RI "prides itself on its reputation for engaging the public in scientific debate").

3 This typology, while helpful, can be problematic in that the distinction between the two types is not always as clear-cut as it may suggest. Both types are—as described above—ultimately part of the same cultural trend towards "engagement" and there can be overlap.

4 The Café Scientifique movement grew out of the similar Café Philosophique, which started in Paris but has spread around Europe (Spire, 1998; see also PEALS, 2007). That this type of "dialogue" format is not limited to science suggests that it is part of a broader social trend that includes other areas of knowledge and expertise.

5 There is, of course, an interesting tension between our emphasis on the individual and small groups as sites of analytical interest, and our insistence that learning is a social process. We can clarify by expanding on our use of the term "individual": we use it not in a cognitive or psychological sense but rather as a way of expressing the small scale—compared to policy or other institutional effects—of the impacts we are interested in. Thus we are not suggesting that learning itself is an "individual" thing—rather, as should be clear from later sections, we believe that learning is always a social—even dialogical—process (see Lefstein, 2006). Neither do we wish to ignore wider social processes beyond the dialogue forum itself; the media and other features of the public and private spheres will impact the interactions and effects of dialogue, and be impacted in their turn. Thus any dialogue forum is situated in a much wider web of social relations than those that we consider in this paper. Further discussion of these is beyond the scope of this article and, indeed, demands empirical work alongside theoretical consideration. Thus by talking of the individual we refer to the power of small-scale interpersonal relations and the impacts that these can have in, for example, developing citizens (cf. Laird, 1993).

6 Rip uses the term "robust" to describe the successful closing down of a controversy, where "arguments, evidence, social alignments, interests, and cultural values" (Rip, 1986: 353) interrelate and lend support to a dominant view. Examples of such successful closing downs are perhaps the public controversies over the safety of smoking or of rDNA research, where the dominant view, supported by social and scientific networks, has become received wisdom (e.g. "everyone knows that smoking is bad for you").

7 Again, there are differences between the UK and US. In particular an emphasis on science "process" and science for citizenship has been longstanding in US education (Lehr, 2006), dating from the 1980s, while this type of curriculum—while a factor in discussion for some time, e.g. Layton (1973)—has only been developed in practice over the last decade in the UK.

8 "Science-for-citizenship" is, of course, itself not unproblematic. Zembylas (2005) has distinguished between "science-for-citizenship" and "science-for-social-justice," and Lehr (2006) has discussed the *type* of citizenship constructed by these curricula.

9 Envisioning non-policy dialogue in this way does, of course, relate to a previous point about the limitations of our typology: interlinkages between "policy" and "non-policy" dialogue are complex and they may not always be readily distinguishable. In particular, informal and non-policy dialogue may—in our model—have wider effects that go on to influence science policy through other channels. Conversely, policy dialogue processes may also have impacts on a small scale (as Laird, 1993, argues; see also Involve, 2005).

References

American Association for the Advancement of Science (1993) *Benchmarks for Science Literacy (Project 2061)*. New York: Oxford University Press.

Beder, S. (1999) "Public Participation or Public Relations?," in B. Martin (ed.) *Technology and Public Participation*, pp. 169–92. Wollongong: Science and Technology Studies, University of Wollongong, Australia.

Bingle, W.H. and Gaskell, P.J. (1994) "Scientific Literacy for Decision Making and the Social Construction of Scientific Knowledge," *Science Education* 72: 185–201.

British Association for the Advancement of Science (1999) *Evidence to the House of Lords Select Committee on Science and Technology Inquiry into Society's Relationship with Science*. URL: http://www.the-ba.net/the-ba/CurrentIssues/ReportsandPublications/Reports/ (accessed July 2006).

Bucchi, M. and Neresini, F. (in press) "Science and Public Participation," in E. Hackett, O. Amsterdamska, M. Lynch and J. Wajcman (eds) *New Handbook of Science, Technology, and Society*. Cambridge, MA: MIT Press.

Café Scientifique (2006) http://www.cafescientifique.org/ (accessed January 2007).

Callon, M. (1999) "The Role of Lay People in the Production and Dissemination of Scientific Knowledge," *Science, Technology and Society* 4(1): 81–94.

Council for Science and Technology (2005) *Policy through Dialogue: Informing Policies Based on Science and Technology*. March. URL: http://www2.cst.gov.uk/cst/reports/ (accessed June 2005).

Cremin, L.A. (1988) *American Education, the Metropolitan Experience, 1876–1980*. New York: Harper and Row.

DeBoer, G.E. (2000) "Scientific Literacy: Another Look at its Historical and Contemporary Meanings and its Relationship to Science Education Reform," *Journal of Research in Science Teaching* 37(6): 585–601.

de Cheveigné, S. and Véron, E. (1996) "Science on TV: Forms and Reception of Science Programmes on French Television," *Public Understanding of Science* 5: 231–53.

Driver, R. (1997) "The Application of Science Education Theories: A Reply to Stephen P. Norris and Tone Kvernbekk," *Journal of Research in Science Teaching* 34(10): 1007–18.

Durodié, B. (2003) "Limitations of Public Dialogue in Science and the Rise of New 'Experts,'" *Critical Review of International Social and Political Philosophy* 6(4): 82–92.

Gammon, B. and Burch, A. (2003) "Indicators of Dialogue," unpublished Science Museum paper.

Goven, J. (2006) "Processes of Inclusion, Cultures of Calculation, Structures of Power: Scientific Citizenship and the Royal Commission on Genetic Modification," *Science, Technology and Human Values* 31(5): 565–98.

Gregory, J. and Miller, S. (1998) *Science in Public: Communication, Culture and Credibility*. New York: Plenum Press.

Grove-White, R. (2001) "New Wine, Old Bottles? Personal Reflections on the New Biotechnology Commissions," *Political Quarterly* 72(4): 466–72.

Grove-White, R., Macnaghten, P. and Wynne, B. (2000) *Wising Up: The Public and New Technologies*. Lancaster: Centre for the Study of Environmental Change, Lancaster University.

Hodson, D. and Hodson, J. (1998) "From Constructivism to Social Constructivism: a Vygotskian Perspective on Teaching and Learning Science," *School Science Review* 29(289): 33–41.

House of Lords Select Committee on Science and Technology (2000) *Third Report: Science and Society*. 23 February. URL: www.parliament.the-stationery-office.co.uk (accessed October 2004).

Involve (2005) *People and Participation: How to Put Citizens at the Heart of Decision-making*. London: Involve.

Irwin, A. (2001) "Constructing the Scientific Citizen: Science and Democracy in the Biosciences," *Public Understanding of Science* 10: 1–18.

Irwin, A. (2004) "Rather than Representing Citizens as Risk-Averse, We Should be Engaging More with What People Want from Technical Change," Spiked online debate. URL: http://www.spiked-online.com/articles/0000000CA375.htm (accessed November 2004).

Irwin, A. and Wynne, B., eds (1996) *Misunderstanding Science? The Public Reconstruction of Science and Technology*. Cambridge: Cambridge University Press.

Jackson, R., Barbagallo, F. and Haste, H. (2005) "Strengths of Public Dialogue on Science-Related Issues," *Critical Review of International Social and Political Philosophy* 8(3): 349–58.

Jasanoff, S. (2005) *Designs on Nature: Science and Democracy in Europe and the United States*. Princeton, NJ: Princeton University Press.

Jenkins, E. (2000) "'Science for All': Time for a Paradigm Shift?," in R. Millar, J. Leach and J. Osborne (eds) *Improving Science Education*, pp. 207–26. Buckingham: Open University Press.

Kerr, A., Cunningham-Burley, S. and Amos, A. (1998) "The New Genetics and Health: Mobilising Lay Expertise," *Public Understanding of Science* 7: 41–60.

Kolstø, S.D. (2001) "To Trust or Not to Trust … Pupils' Ways of Judging Information Encountered in a Socio-Scientific Issue," *International Journal of Science Education* 23: 877–901.

Laird, F.N. (1993) "Participatory Analysis, Democracy and Technological Decision Making," *Science, Technology and Human Values* 18(3): 341–61.

Latour, B. (1987) *Science in Action: How to Follow Scientists and Engineers through Society*. Milton Keynes: Open University Press.

Lave, J. and Wenger, E. (1999) "Legitimate Peripheral Participation in Communities of Practice," in R. McCormick and C. Paechter (eds) *Learning and Knowledge*. Milton Keynes: Open University Press.

Layton, D. (1973) *Science for the People: The Origins of the School Science Curriculum in England*. London: Allen and Unwin.

Layton, D., Jenkins, E., Macgill, S. and Davey, A. (1993) *Inarticulate Science? Perspectives on the Public Understanding of Science and Some Implications for Science Education*. Nafferton: Studies in Education Ltd.

Lefstein, A. (2006) *Dialogue in Schools: Towards a Pragmatic Approach*. Working Paper 33. London: King's College London.

Lehr, J.L. (2006) "Social Justice Pedagogies and Scientific Knowledge: Remaking Citizenship in the Non-Science Classroom," unpublished doctoral dissertation, Virginia Tech.

Lehr, J.L., McCallie, E., Davies, S.R. Caron, B.R., Gammon, B. and Duensing, S. (2007) "The Role and Value of Dialogue Events as Sites of Informal Science Learning," *International Journal of Science Education,* 29(12): 1–21.

Lévy-Leblond, J. (1992) "About Misunderstandings about Misunderstandings," *Public Understanding of Science* 1: 17–21.

Limoges, C. (1993) "Expert Knowledge and Decision-Making in Controversy Contexts," *Public Understanding of Science* 2: 417–26.

Llewellyn, N. (2005) "Audience Participation in Political Discourse: a Study of Public Meetings," *Sociology* 9(4): 697–716.

Locke, S. (1999) "Golem Science and the Public Understanding of Science: From Deficit to Dilemma," *Public Understanding of Science* 8: 75–92.

McCallie, E. (forthcoming) Ph.D. thesis, Department of Education and Professional Studies, King's College London.

McCallie, E., Simonsson, E., Gammon, B., Nilsson, K., Lehr, J. and Davies, S.R. (2007) "Learning to Generate Dialogue: Theory, Practice, and Evaluation." *Museums and Social Issues* 2(2): 165–184.

MacMillan, T. (2004) *Engaging in Innovation: Towards an Integrated Science Policy*. London: IPPR (Institute for Public Policy Research). URL: http://www.ippr.org.uk/research/teams/project.asp?id=995 (accessed October 2004).

Mercer, N. (2000) *Words and Minds: How We Use Language to Think Together*. London: Routledge.

Michael, M. (1992) "Lay Discourses of Science: Science-in-General, Science-in-Particular, and Self," *Science, Technology and Human Values* 17(3): 313–33.

Michael, M. (1998) "Between Citizen and Consumer: Multiplying the Meanings of the 'Public Understanding of Science,'" *Public Understanding of Science* 7: 313–27.

Millar, R. and Osborne, J., eds (1998) *Beyond 2000: Science Education for the Future*. London: King's College London.

Mortimer, E.F. and Scott, P.H. (2003) *Meaning Making in Secondary Science Classrooms*. Buckingham: Open University Press.

NMSI (2002) *In the 21st Century What Role Should a Museum Play*. NMSI brochure.

Osborne, J. (2000) "Science for Citizenship," in M. Monk and J.F. Osborne (eds) *Good Practice in Science Teaching: What Research Has to Say*, pp. 225–40. Buckingham: Open University Press.

Osborne, J. (2002) "Science without Literacy—A Ship without a Sail?," *Cambridge Journal of Education* 32(2): 203–18.

Osborne, J., Collins, S., Ratcliffe, M., Millar, R. and Duschl, R. (2003) "What 'Ideas-about-Science' Should be Taught in School Science? A Delphi Study of the Expert Community," *Journal of Research in Science Teaching* 40(7): 692–720.

Parliamentary Office of Science and Technology (2001) *Open Channels: Public Dialogue in Science and Technology*. Report number 153, March. URL: http://www.parliament.uk/parliamentary_offices/post/pubs2001.cfm (accessed October 2004).

Parliamentary Office of Science and Technology (2006) *Debating Science*. Report number 260, March. URL: http://www.parliament.uk/documents/upload/postpn260.pdf (accessed June 2006).

PEALS (2007) "Dialogue at PEALS." URL: http://www.ncl.ac.uk/peals/dialogues/index.htm (accessed January 2007).

Ratcliffe, M. and Grace, M. (2003) *Science Education for Citizenship: Teaching Socio-Scientific Issues*. Maidenhead: Open University Press.

Rip, A. (1986) "Controversies as Informal Technology Assessment," *Knowledge: Creation, Diffusion, Utilization* 8(2): 349–71.

Rogoff, B., Matusov, E. and White, C. (1996) "Models of Teaching and Learning: Participation in a Community of Learners," in D.R. Olson and N. Torrance (eds) *The Handbook of Education and Human Development*, pp. 388–414. Oxford: Blackwell.

Rogoff, B., Paradise, R., Arauz, R.M., Correa-Chavez, M. and Angelillo, C. (2003) "Firsthand Learning through Intent Participation," *Annual Review of Psychology* 54: 175–203.

Royal Society (1999) *Science and Society: A Response from the Royal Society to the House of Lords Science and Technology Select Committee Inquiry*. URL: http://www.royalsoc.ac.uk/document.asp?tip=0&year=1999&id=1170 (accessed July 2006).

Rowe, G. and Frewer, L.J. (2000) "Public Participation Methods: A Framework for Evaluation," *Science, Technology and Human Values* 25(1): 3–29.

Rowe, G. and Frewer, L.J. (2004) "Evaluating Public-Participation Exercises: A Research Agenda," *Science, Technology and Human Values* 29(4): 512–56.

Rowe, G. and Frewer, L.J. (2005) "A Typology of Public Engagement Mechanisms," *Science, Technology and Human Values* 30(2): 251–90.

Rowe, G., Horlick-Jones, T., Walls, J. and Pidgeon, N. (2005) "Difficulties in Evaluating Public Engagement Initiatives: Reflections on an Evaluation of the UK *GM Nation?* Public Debate about Transgenic Crops," *Public Understanding of Science* 14: 331–52.

Rowe, S.M. (2004) "Discourse in Activity and Activity as Discourse," in R. Rogers (ed.) *An Introduction to Critical Discourse Analysis in Education*, pp. 79–96. Mahwah, NJ: Lawrence Erlbaum Associates.

Sadler, T.D. and Zeidler, D.L. (2003) "The Morality of Socioscientific Issues: Construal and Resolution of Genetic Engineering Dilemmas," *Science Education* 88: 4–27.

Sawyer, R.K. (2006) "Analyzing Collaborative Discourse," in R.K. Sawyer (ed.) *Cambridge Handbook of the Learning Sciences*, pp. 187–204. New York: Cambridge University Press.

Science Museum Visitor Research Group (2004) *Naked Science: Evaluation of 18 Months of Contemporary Science Dialogue Events*. London: Science Museum.

Silberman, C.E. (1970) *Crisis in the Classroom: The Remaking of American Education*. New York: Random House.

Simonsson, E. (2006) *Dana Centre Audience Research Report 2005–2006*. London: Science Museum.

Spire, A. (1998) "Marc Sautet, promoteur des 'cafés philo', est mort," *Journal l'Humanité* 4 March.

Vygotsky, L.S. (1978) *Mind in Society: The Development of Higher Psychological Process*. Cambridge, MA: Harvard University Press.

Wells, G. (1999) *Dialogic Inquiry: Towards a Sociocultural Practice and Theory of Education*. Cambridge: Cambridge University Press.

Wynne, B. (1992a) "Public Understanding of Science Research: New Horizons or Hall of Mirrors?," *Public Understanding of Science* 1: 37–43.

Wynne, B. (1992b) "Misunderstood Misunderstanding: Social Identities and Public Uptake of Science," *Public Understanding of Science* 1: 281–304.

Wynne, B. (1993) "Public Uptake of Science: A Case for Institutional Reflexivity," *Public Understanding of Science* 2: 321–37.

Wynne, B. (2001) "Creating Public Alienation: Expert Cultures of Risk and Ethics on GMOs," *Science as Culture* 10(4): 445–81.

Wynne, B. (2002) "Risk and Environment as Legitimatory Discourses of Technology: Reflexivity Inside Out?," *Current Sociology* 50(3): 459–77.

Wynne, B. (2005) "Risk as Globalising 'Democratic' Discourse? Framing Subjects and Citizens," in M. Leach, I. Scoones and B. Wynne (eds) *Science and Citizens: Globalisation and the Challenge of Engagement*, pp. 66–82. London: Zed Books.

Yearley, S. (1999) "Computer Models and the Public's Understanding of Science: A Case-Study Analysis," *Social Studies of Science* 29(6): 845–66.

Zembylas, M. (2005) "Science Education: For Citizenship and/or for Social Justice?," *Journal of Curriculum Studies* 37(6): 709–22.

Authors

Sarah Davies is a Research Associate in Durham University's Institute of Hazard and Risk Research, working on a project looking at lay ethics of nanotechnology. Her PhD involved an ethnography of communication of Dana Centre events. Her research interests focus on different forms of public engagement with science. Correspondence: Department of Geography, Durham University, Science Site, South Road, Durham, DH1 3LE; email sarah.davies@durham.ac.uk.

Ellen McCallie is director of the Center for Advancement of Informal Science Education (CAISE). Her research, conducted as part of the Center for Informal Learning and Schools (CILS) at King's College London, examines how people interact and construct meaning during public engagement with science (PES) activities such as dialogue events.

Elin Simonsson is a Visitor Researcher at the Science Museum in London. Her work includes evaluation of Museum exhibitions, online resources, and programming, as well as audience advocacy. She is currently the audience advocate for the Dana Centre and is also involved in the redevelopment of a hands-on interactive gallery for children.

Jane L. Lehr is assistant professor in the Department of Ethnic Studies and Department of Women's & Gender Studies at California Polytechnic State University. She received her Ph.D. (2006) and M.S. (2002) in Science & Technology Studies from Virginia Polytechnic Institute and State University. Her current research explores how formal and informal education serves as a site of training for future participation by scientific and technical experts and public(s) in personal and public scientific and technical decision-making practices, with particular attention to issues of social justice and equity.

Sally Duensing is currently a visiting professor at King's College London in the Department of Education and Professional Studies. In 2000 she held the Collier Chair, a one year invited professorship in the Public Understanding of Science at the University of Bristol, UK. Prior to this, for over 20 years, she was at the Exploratorium in San Francisco.

Annu. Rev. Environ. Resour. 2006. 31:12.1–12.33
doi: 10.1146/annurev.energy.31.102405.170850

First published online as a Review in Advance on July 25, 2006

LINKING KNOWLEDGE AND ACTION FOR SUSTAINABLE DEVELOPMENT

Lorrae van Kerkhoff[1] and Louis Lebel[2]
[1]*National Centre for Epidemiology and Population Health, The Australian National University, Canberra, Australian Capital Territory 0200, Australia; email: lorrae.vankerkhoff@anu.edu.au*
[2]*Unit for Social and Environmental Research, Chiang Mai University, Muang, Chiang Mai 50202, Thailand; email: louis@sea-user.org*

Key Words engagement, integration, participation, power, research, science

■ **Abstract** It is now commonplace to assert that actions toward sustainable development require a mix of scientific, economic, social and political knowledge, and judgments. The role of research-based knowledge in this complex setting is ambiguous and diverse, and it is undergoing rapid change both in theory and in practice. We review conventional views of the linkages between research-based knowledge and action, and the early response to concerns that these links could and should be improved, through efforts at translation and transfer. We then examine the range of critiques that challenge those conventional views by highlighting different aspects of the relationships between science and society, focusing on the implications for action toward sustainable development. We then review the theories and strategies that have emerged in the attempt to improve the linkages between research-based knowledge and action in the context of sustainability across four broad categories: participation, integration, learning, and negotiation. These form a hierarchy with respect to how deeply they engage with the various critiques. We propose that the relationships between research-based knowledge and action can be better understood as arenas of shared responsibility, embedded within larger systems of power and knowledge that evolve and change over time. The unique contribution of research-based knowledge needs to be understood in relation to actual or potential contributions from other forms of knowledge. We conclude with questions that may offer useful orientation to assessing or designing research-action arenas for sustainable development.

CONTENTS

1. INTRODUCTION 12.2
1.1. Definitions 12.3
1.2. The Focus of This Review 12.4
2. CONVENTIONAL VIEWS OF LINKS BETWEEN KNOWLEDGE AND ACTION 12.5
2.1. Trickle Down 12.5
2.2. Transfer and Translate 12.6

18 Jul 2006 6:2 AR ANRV289-EG31-12.tex XMLPublishSM(2004/02/24) P1: OKZ
AR REVIEWS IN ADVANCE10.1146/annurev.energy.31.102405.170850

3. CRITIQUES OF THE CONVENTIONAL MODEL 12.8
3.1. Science is Socially and Institutionally Embedded 12.8
3.2. Scientific Knowledge is Socially Constructed 12.9
3.3. Boundaries Between Science and Society 12.10
3.4. Science and Power 12.11
3.5. Science Reflects Cultural Biases and Inequalities 12.13
3.6. What Lies Beyond the Trickle-Down and Transfer Model? 12.14
4. MAJOR RESPONSES TO CRITIQUES 12.15
4.1. Participation 12.15
4.2. Integration 12.17
4.3. Learning 12.18
4.4. Negotiation 12.19
5. KNOWLEDGE, ACTION, ENGAGEMENT, AND POWER 12.21
5.1. Implications for Linking Knowledge and Action for Sustainability 12.22
5.2. Tensions Between Knowledge, Action, Engagement, and Power 12.25
6. CONCLUSIONS 12.27

1. INTRODUCTION

Scientists are readily recognizable at the forefront of environmental issues, such ozone depletion, climate change, biodiversity loss, urban air pollution, and agricultural nutrient depletion. Perhaps less readily recognizable, but nonetheless significant, researchers have also been central to understanding and promoting human needs, such as access to clean water, safe living environments, health, and sufficiently productive livelihoods. In short, researchers have played, and continue to play, an important role in shaping our understanding of the need for sustainable development and generating public awareness of the challenges this poses to society. Yet generating awareness is not enough. Generating *actions* to counteract these problems, the essential next step, has proven to be a far more difficult task and one in which the role of science is not nearly as straightforward.

Over the past few decades, several different approaches to linking scientific, research-based knowledge with action have emerged. These vary in scope, influence, and their underlying assumptions, forming a complex, fragmented and often contradictory set of ideas and processes. As a result, there are few unambiguous lessons or tool options for either researchers or practitioners who attempt to foster change for sustainable development. As more and more researchers, governments, international agencies, research funding bodies, and nongovernmental organizations are confronting the real-world complexities of attempting to achieve sustainability, increasing attention is being paid to the question of how research can be harnessed more effectively to the task.

This review aims to provide some orientation in this complex area by presenting the conventional models of the linkages between research-based knowledge and action, critiques of these approaches, and four main classes of response to these

18 Jul 2006 6:2 AR ANRV289-EG31-12.tex XMLPublishSM(2004/02/24) P1: OKZ
AR REVIEWS IN ADVANCE10.1146/annurev.energy.31.102405.170850

critiques that represent different approaches to the key issues raised in the critical literature. Our coverage of these diverse and complex topics is necessarily incomplete. In particular, we do not cover the large literature concerned with commercial technological development and private sector innovation in development because this topic has been recently covered elsewhere (1). We have focused our review on the "public good" areas of sustainability, that is, those with no clear or immediate financial incentives for action but with characteristics essential for sustainable development. There is, of course, no clear line of demarcation between public and private benefit, and we do venture into the gray zone between them, for example, when addressing issues such as sustainable livelihoods and actions that have both public and private benefits. We try point this out where relevant.

We have approached this review as an effort to capture the main challenges and controversies while retaining a focus on the practical implications for researchers and practitioners as well as those at the interface between them. Following the review sections, we analyze the literature and draw out the main themes that cut across this diversity. We conclude by suggesting key questions that may be usefully considered by those concerned with improving linkages between research-based knowledge and action to achieve—or at least, move toward—sustainable development. We hope that this will serve as a platform for selecting, assessing, and designing tools and methods for linking research-based knowledge and action and also for challenging those involved in this work to think more deeply (or broadly) about those choices.

1.1. Definitions

In an effort to deal with such broad, open concepts as knowledge, action, and sustainable development, definitions are needed. Knowledge is defined here as justifiable belief (2). Different forms of knowledge emerge as different sets of criteria for what may constitute justification. Scientific knowledge, for example, must be justifiable according to the standards set by adherence to accepted scientific practice and peer review. Local knowledge must be justifiable according to claims of connection with a particular place. Practical knowledge is justifiable on the basis of experience in practice, and political knowledge must be justifiable according to experience within the political process.

In this review, we focus on what we have called research-based knowledge. Research-based knowledge is a wider category than scientific knowledge because it includes all areas of systematic inquiry that are justified by their adherence to a research process as defined by peers. As such, it includes knowledge generated from within both the natural and social sciences as well as areas that need not be regarded as scientific, e.g., history or philosophy. It also accommodates research oriented toward practice rather than theory. In this review, we do not make judgments regarding whether research-based knowledge is better as a result of adopting alternatives to the conventional model.

18 Jul 2006 6:2 AR ANRV289-EG31-12.tex XMLPublishSM(2004/02/24) P1: OKZ
AR REVIEWS IN ADVANCE10.1146/annurev.energy.31.102405.170850

Although research-based knowledge is our main focus, this is not to the exclusion of other sources or types of knowledge. Indeed, as we will show, it is the interaction between research and other sources of knowledge that is often crucial for understanding the role of research-based knowledge in action.

By action, we mean doing something that has physical or behavioral repercussions. Actions include purposefully changing practices and environments as well as implementing or changing regulations, policies, and institutions. Key challenges in this review are the different ways we can think about and represent the separation and independence (or not) of research-based knowledge from action. We return to this issue at the conclusion.

The classic definition of sustainable development was made by the World Commission on Environment and Development who described it as development "that meets the needs of the present without compromising the ability of future generations to meet their own needs" (3). However, as many have commented, sustainable development is ambiguous because it can be invoked to meet wide variety of goals (4). Some have even argued it is an oxymoron, a convenient political device that has stifled robust political debate over differing ethical and political stances with respect to global inequalities (5). Our approach is that sustainable development is the process of ensuring all people can achieve their aspirations while maintaining the critical ecological and biophysical conditions that are essential to our collective survival. We have tried to ensure that our analysis is global in scale (addressing low-income country issues as well as high-income country issues and the interactions between them when appropriate), and we regard sustainable development as including issues of well-being (health, aesthetics, livelihoods) and environmental management.

1.2. The Focus of This Review

This review focuses on approaches to linking research-based knowledge with actions that have been developed since 1990 in the context of sustainable development. In order to contextualize these, we briefly review conventional understandings of the links between research-based knowledge and action in Section 2. Although these understandings may seem mundane or obsolete to some readers, these views are still commonplace within research institutions, as well as holding a fairly broad common sense appeal in the practitioner community, and those that sit at the interface between researchers and practitioners. Such understandings also form the backdrop to much of the formal institutional structure that governs research, including the incentives and rewards for academic output. Nevertheless, these conventional models have been the subject of widespread, multifaceted critique, which we outline in Section 3. These two sections form the backdrop to the methods, techniques, and approaches we examine in Section 4. These are synthesized in Section 5, where we present key themes and a conceptual framework to distill some of the features of the diversity presented in Section 4. We conclude in Section 6 with observations regarding the how we can more usefully approach

18 Jul 2006 6:2 AR ANRV289-EG31-12.tex XMLPublishSM(2004/02/24) P1: OKZ
AR REVIEWS IN ADVANCE10.1146/annurev.energy.31.102405.170850

the challenge of linking research-based knowledge and action in the context of sustainable development.

2. CONVENTIONAL VIEWS OF LINKS BETWEEN KNOWLEDGE AND ACTION

We regard conventional views as those wherein the linkages between research-based knowledge and action are held to be either unproblematic or resolvable by relatively straightforward add-on measures. The science community is seen as an arena separate from those that might use the products of research, that is, a "two-community" concept of the problem of linking knowledge with action (6). With respect to connections across these two communities, we recognize two variants: the "trickle-down" and the "transfer and translate" models.

2.1. Trickle Down

The trickle-down view of the linkages between research-based knowledge and action, adapted from Latour (7), holds that good research will be taken up by practitioners without additional effort required by the research community. Bringing research into the public domain by publishing in peer-reviewed journals is implicitly regarded as the end of the researcher's responsibility. This perspective is deeply embedded in the scientific enterprise, manifested not only in attitudes but also in incentive structures that reward peer-reviewed publications and other academic output.

Although the trickle-down approach is often regarded as the natural or default relationship between researchers and those who might use research, it is important to note that this approach is not accidental or inevitable. The science policy that emerged in the United States following World War II, and emulated by many other countries, effectively created this distanced relationship between academia and the communities research was perceived to ultimately serve (8). Some science policy analysts have argued the freedom and independence granted to researchers over the ensuing 50 years is historically anomalous, rather than inevitable or natural (9).

The trickle-down model may be a good characterization of basic research however in the context of research that aims to inform or influence sustainable development decision making; it is now widely recognized that reality is somewhat different. In some instances, there is a seemingly straightforward link, as when there is widespread agreement that a current practice is unsustainable and solutions are in hand or potentially forthcoming. The Montreal Protocol to phase out the use of ozone-depleting substances is a case where action in response to scientific discoveries was relatively swift and effective. This well-known example gives the impression that science is an effective agent in bringing about change. But such cases tend to be the exception rather than the rule and tend to apply

18 Jul 2006 6:2 AR ANRV289-EG31-12.tex XMLPublishSM(2004/02/24) P1: OKZ
AR REVIEWS IN ADVANCE10.1146/annurev.energy.31.102405.170850

more to narrow, straightforward, technically defined issues than the more diffuse, ambiguous, public good–oriented issues that pervade sustainable development.

2.2. Transfer and Translate

The failure of trickle-down approaches to influence social policy led to the development of a new field of study in the 1970s, concerned with "research utilization" (6). The defining characteristic of these approaches is that they are founded on the one-way transfer of science to users. Research is characterized as a product that needs to be taken up by the relevant user communities. Activities to facilitate this transfer often include efforts to translate technical, jargon-laden science into terms that can be understood by the layperson. Solutions to the challenge of linking knowledge with action are commonly framed in the language of products, bridges, translation, and transfer (10).

The transfer of technology approach to linking research-based knowledge and action is perhaps the best known and appears in several different sectors, especially manufacturing and agriculture. It is based on the idea that, rather than passively relying on uptake of research, problem-oriented research generates knowledge that needs to be actively transferred to users.

The transfer of technology model is essentially a linear research and application process, as outlined in Figure 1.

The transfer of technology model embodies a particular way of thinking about the role of science, the relationship between research-based knowledge and other sources of knowledge, and the relationship of both with action. In agriculture, this has been widely manifested in the idea of extension officers, the use of specialized intermediary agents to transfer field station research findings into farmer practices. As Scoones & Thompson (11, p. 18) write: "The superiority of 'rational science' is assumed and the pursuit of change (development) is derived almost exclusively from the findings of the research station and transmitted to the farmer through hierarchical, technically oriented extension services. Farmers are seen as either 'adopters' or 'rejectors' of technologies, but not as originators of either technical knowledge or improved practice."

As such, the traditional transfer of technology model assumes an objective truth that the scientists pass on to the farmers via extension officers, and farmers

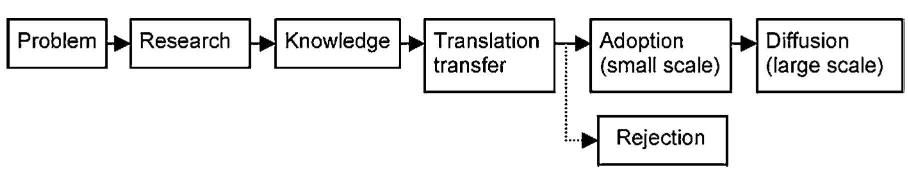


Figure 1 The linear model of the transfer of technology. Scientists set the research agenda, do the research, and then transfer the results to the users. The results then diffuse through the practice community.

18 Jul 2006 6:2 AR ANRV289-EG31-12.tex XMLPublishSM(2004/02/24) P1: OKZ
AR REVIEWS IN ADVANCE10.1146/annurev.energy.31.102405.170850

are assumed to make decisions independently on a technical basis. It is perhaps unsurprising then that although agricultural extension is effective in disseminating new technologies for increased production or profitability, it is far less successful in convincing farmers to prevent or ameliorate land degradation (12) or for farmers facing complex, diverse, and risk-prone contexts (13).

In the health sector, the transfer and translation model is manifested in the concept of evidence-based health care. Proposed in the late 1990s by a group of epidemiologists (14), the aim of evidence-based approaches is to integrate current best evidence from research with clinical policy and practice, public health programs, and health policy. It is based on the view that the findings from health and medical research are often slow in filtering through to professional practice communities and that as a consequence there is a gap between the technically rational policies and those actually in place. The centerpiece of the evidence-based movement are evaluations and syntheses of existing scientific literature. These syntheses aim to meet the challenge of translating research into useable clinical or public health polices, facilitating the uptake of those policies in practice (15).

From within the health care sector, evidence-based approaches have been criticized for attempting to mechanize and standardize health care provision, downplaying consideration of important contextual factors and the experience and skill of practitioners (16). Its practical usefulness has also been questioned. An empirical study in Australia, for example, found that the syntheses that form the centerpiece of the evidence-based health care solution have been accessed or used by only 4% of general practitioners (17). Regarding sustainable development, the evidence-based medicine movement has not been highly effective in addressing the challenges of health care in developing countries. Plant (18) has argued that this is not due to the lack of evidence or to practitioner confusion surrounding what form of clinical care is needed but results from the lack of knowledge of how to provide it.

The similarities between evidence-based health care and transfer of technology in agriculture are strong. There is a perception that practice can and should be based more systematically on recognized research evidence, with associated (often assumed) gains in efficiency and production or patient outcomes. The main barrier to improved outcomes is characterized as ignorance of practitioners, fuelled by poor access to high-quality research results. Consequently, improvement is best achieved by making efforts to translate scientific findings, and improve research products. Practitioners are assumed to make rational choices in light of new information and change their practices accordingly.

It is somewhat ironic that despite widespread evidence of the failure of transfer and translation models to achieve sustainability-oriented outcomes in agriculture, health, and other sectors, they still hold appeal in the imaginations of researchers and policy makers alike (19). The Report of the World Summit for Sustainable Development held in Johannesburg in 2002 described "knowledge transfer to developing countries" as a key component of poverty eradication and frequently cites the importance of technology transfer for sustainable development (20). Although

18 Jul 2006 6:2 AR ANRV289-EG31-12.tex XMLPublishSM(2004/02/24) P1: OKZ
AR REVIEWS IN ADVANCE10.1146/annurev.energy.31.102405.170850

widespread uptake of technologies that enhance the prospects of sustainable development is obviously important, the role of research goes well beyond developing commercially viable products. In essence, the success of the idea of transfer in the commercial arena (through product promotion, for example) is presumed to extend to the entire range of actions needed to move toward sustainable development. The appeal of this model is that it does not require a great deal of change on the part of the research community, does not conflict with academic goals or incentives, or challenge the view that technical solutions will provide the answers to sustainable development.

3. CRITIQUES OF THE CONVENTIONAL MODEL

The linear views of the relationship between research-based knowledge and action described in Section 2 have come under close scrutiny in recent years. This scrutiny has, in part, been concerned specifically with science and research but has been featured also in broader social critiques. These critiques have generated a decades-long debate about the nature of science, knowledge, and their relationships with society that has generated much controversy and acrimony (21) but relatively little productive guidance for people who want to improve those relationships (22). In this section, we do not review those debates as such [see, for example, Sardar (23)] but draw from them those insights that help inform our understanding of the relationships between research-based knowledge and action toward sustainable development.

3.1. Science is Socially and Institutionally Embedded

The first critique is that scientists' work is shaped by the social and institutional structures and processes in which it is embedded (24). From the research perspective, decisions regarding what is a suitable problem to work on is decided both with consideration of the state of the world that is of interest or concern to the researchers, but also with consideration of who will fund it (how should it be pitched?), how much they will pay (which parts of the ideal project can be trimmed?), where the work will be conducted (which field sites are feasible?), whether the work will advance one's standing with peers (where can it be published?), and so forth (25). Essentially, this critique highlights that research-based knowledge is not derived (solely) through a neutral, objective process of unfolding scientific discovery—it is the result of constructing a feasible balance between a range of personal, scientific, institutional, and practical considerations.

Classic anthropological studies of research laboratories have highlighted these personal and practical dimensions of research work (26, 27). This picture is further complicated by the present-day need for government- or university-employed researchers to find external funding to support their research, as researchers' financial interests are now often ambiguous, rather than simply public or private.

18 Jul 2006 6:2 AR ANRV289-EG31-12.tex XMLPublishSM(2004/02/24) P1: OKZ
AR REVIEWS IN ADVANCE10.1146/annurev.energy.31.102405.170850

The challenges to scientific authority that often characterize environmental politics often point to researchers' ties to political and economic interests (28).

Larger social and political processes can also stimulate new research agendas, where not enough is known about issues that people want to act on quickly. Taylor et al. (29) for example show how SO_2 regulations acted as spurs to innovation, even before they were implemented, by encouraging firms to invest in research and development. International agreements for biodiversity and attempts to go beyond national regulation of forests illustrate similar patterns of how institutional changes can precede and stimulate research, encouraging practitioners to seek alternative strategies and thereby increasing demand for innovative, action-driven research (30). In this way, social and political forces shape both problem setting and the conduct of research, as much as the other way around.

In terms of the relationship between research-based knowledge and action toward sustainable development, this critique has two main implications. The first is that these considerations can serve as mechanisms through which power and influence interact with research, a point that will be taken up later. The second is that it particularly focuses attention on the potential for mismatch between the knowledge researchers generate and the knowledge needs of practitioners. Sustainable development is characterized by complex interrelationships between the natural and social spheres, whereas science is dominated by fragmented, specialized areas of investigation (31). Under such circumstances, it is likely that mismatches are the norm, rather than the exception.

The argument that research is shaped by considerations that are external to the unfolding of scientific discovery is hardly news to practicing researchers; however, the trickle-down, transfer and translation models do not acknowledge these influences. Focused on the research product, the social, political, and economic forces that led to its development are regarded as irrelevant. Although these forces can be largely ignored when that product is a new, fully developed technology seeking a market, they cannot be ignored in the context of action toward sustainable development. The political and social history and context of the research is central to the question of who will regard it as a valid basis for action (32).

3.2. Scientific Knowledge is Socially Constructed

Second, there is the more controversial argument that science and research cannot uncover truth—the actual knowledge researchers produce is not an accurate reflection of the world, but rather is a lens that offers a particular picture of the world at a particular point in time. Supporters of this perspective adhere to the claim that "No body of knowledge, nor any part of one, can capture, or at least, can be known to capture, *the* basic pattern or structure inherent in some aspect of the natural world" (33). In simpler terms, knowledge is always uncertain because observations are subject to interpretation. The same issues, events, and things observed by people with a different lens will generate different knowledge, and arguments that one is more valid than another are simply that—arguments.

18 Jul 2006 6:2 AR ANRV289-EG31-12.tex XMLPublish^{SM}(2004/02/24) P1: OKZ
AR REVIEWS IN ADVANCE10.1146/annurev.energy.31.102405.170850

This stance has been the main wellspring for the acrimonious debates mentioned earlier, and many researchers (who take great care to expose and challenge their assumptions) reject this extreme point of view. Viewed from a science perspective, the key controversy regarding the social construction of scientific knowledge is about the nature of reality and our capacity to know and understand it. Viewed from the perspective of the role of research in action toward sustainable development, the key controversy is about the authority to make claims that should be acted upon, and the interactions between research-based knowledge and other knowledges. Imagine, for example, the different knowledges held by a soils scientist and a farmer, confronting, say, an eroded landscape. Although the researcher may know the physical and chemical soil processes that led to the view before them, the farmer may know the history of stocking the land that led to that same view. Both forms of knowledge may prove to be relevant—perhaps even essential—to reversing the degradation process.

In the context of understanding the role of science with respect to actions toward sustainable development, the implications of the social construction of science are profound and not necessarily negative. In particular, it opens up the possibility that other people with other knowledges may have useful contributions to make toward actions for sustainable development—that research does not have to provide the answers but rather needs to hold a clear understanding of its own lens. We return to this issue in the conclusion.

3.3. Boundaries Between Science and Society

The third main argument that is particularly relevant to the role of research-based knowledge in action for sustainable development is that the boundary that distinguishes science from the rest of society is not a natural boundary but is created by social and political processes that are permeable, changeable, and contestable (34). These boundaries emerge through controversies over where legitimate authority lies and, important to this review, which claims of knowledge should be acted upon and which should not. As Gieryn writes, "When credibility is publicly contested, putatively factual explanations or predictions about nature do not move naked from lab or scientific journal into courtrooms, boardrooms newsrooms or living rooms. Rather, they are clothed in elaborate *representations* of science—compelling arguments for why science is uniquely best as a provider of trustworthy knowledge, and compelling narrations of why my science (but not theirs) is bona fide" (35).

These boundaries are not, by definition, one sided and are subject to strategic maneuvering by researchers, by those on the other side of the boundary, and by those who operate across or in between. This maneuvering is central to sustainable development, as it is one of the processes through which questions of what counts as good or adequate science (including what can be considered science at all; which problems are political and which are technical; and who has authority in decision making) are decided. Bocking (28), for example, notes that politicians are adept

18 Jul 2006 6:2 AR ANRV289-EG31-12.tex XMLPublishSM(2004/02/24) P1: OKZ
AR REVIEWS IN ADVANCE10.1146/annurev.energy.31.102405.170850

at characterizing environmental controversies as technical puzzles, allowing them to draw on the authority of science and research in decisions that go against popular demand. This "depoliticization" strategy has also been noted in development work, wherein aid agencies, political leaders, and experts have often collectively emphasized the technical aspects of crises, rather than the social and political ones. Mitchell (36), for example, describes how in the early to mid-twentieth century the characterization of Egypt's development problems as "natural" (too many people crowded into a narrow river valley) rather than political (concentration of around one third of the arable land into a small number of large landowners) pushed questions of inequality into the background and brought technical solutions to expand the amount of arable land available to the fore, culminating in the construction of the Aswan Dam.

In terms of the relationships between research-based knowledge and action, the idea of boundaries and their construction and maintenance highlights that the authority of research-based knowledge in any given decision-making scenario is negotiated through the interaction of researchers and decision makers. At the global scale, for example, analysts have shown that society has sometimes reached agreement on collective action to address pressing environmental issues before major uncertainties in underlying causes and details of impacts were well understood, whereas in other cases, well-established science has failed to generate action (37–40). Authority is not, as the trickle-down, transfer and translation models assume, inherent in the research itself. Where the social construction of science and its social embeddedness discussed in the previous two subsections focused on the characteristics of problem setting and research, boundary work draws attention to the importance of the decision-making contexts in the ways research-based knowledge is used for sustainable development.

3.4. Science and Power

The previous three sections have described research as less autonomous, less certain, and more controversial than the conventional model portrays, and these attributes are all the more acute in the context of action for sustainable development. Implicit in these more fluid characterizations of research, and in need of expansion, is the role of interests and power in shaping the linkages between research-based knowledge and action toward sustainable development. This is important because interventions and actions for the public good often run counter to established private good regimes (41) and thus involve reconstructing power relations.

Issues of power with respect to research-based knowledge and action for sustainable development are ambiguous, complex and—not surprisingly—fraught with ideological conflict. In perhaps overly simple terms, this can be regarded as a "glass half-empty, glass half-full" situation. Analysts with a critical orientation emphasize the role of scientific and technical knowledge in the exploitation of the poor and vulnerable, supporting those power relations that perpetuate such

18 Jul 2006 6:2 AR ANRV289-EG31-12.tex XMLPublishSM(2004/02/24) P1: OKZ
AR REVIEWS IN ADVANCE10.1146/annurev.energy.31.102405.170850

exploitation for private gain (36, 42). Others point to successes in health and environmental management, where research has been a powerful ally in looking beyond immediate interests of firms and states and in challenging the status quo (11, 39, 43). Both need to be taken seriously in attempting to understand and enhance the role of research-based knowledge for sustainability because they point to the value judgments that are embedded in both research and action toward sustainable development (44).

Technical-rational ways of approaching policy, management, and development—including particularly the natural sciences and economics—have long been a subject of criticism for concentrating power in those who can lay claim to scientific knowledge and its interpretation and implementation in practice (45). Scott (46) argues that the appeal of modernist (technical, rational, scientific, evidence-based) ideals in development has favored the centralization of state activity, a major shift in power from distributed, local political regimes. Science and research that focuses on creating universal, generalized knowledge complement the centralized state by providing the technical tools that allow this "management at a distance." The outcomes of such management can, of course, support or run counter to sustainable development. Scott gives numerous examples of failure, including the forced settlement of nomadic peoples in Tanzania, which effectively rendered their local knowledge, and the adaptive capacity embedded within it, useless to their new surroundings. In contrast, however, centralized schemes can work to the benefit of the entire population. Cuba, for example, has basic health statistics comparable to (some superior to) those of the United States, on less than 3% of their gross national income per capita, through an effective centralized health care system (47).

Alongside the questions of when research has a positive or negative influence on action, one also needs to examine when research has no notable influence at all—or has not effected the change that is intended. In climate change, for example, a worldwide effort by researchers to consolidate scientific and technical understanding, generate technical consensus, and actively lobby on the world stage has not convinced key nations such as the United States and Australia to endorse the Kyoto Protocol (48). However, as noted earlier, these failures have been countered by successes in other areas such as ozone-depleting substances and pollution control. The contingent nature of whether science can influence policy is in direct contradiction to the trickle-down model.

The use of science to enhance or challenge power structures points to an important question of responsibility for change: under the conventional trickle-down, transfer and translate models, researchers are not responsible for the uses to which their research is put. Both critical and supportive accounts of the role of research in reshaping power relations in sustainable development challenge this lack of responsibility. As the previous critiques have also shown, the line between research-based knowledge and its application in action is not so clearly drawn that responsibility for the effects of redistributions of power can lie solely outside the domain of research.

18 Jul 2006 6:2 AR ANRV289-EG31-12.tex XMLPublishSM(2004/02/24) P1: OKZ
AR REVIEWS IN ADVANCE10.1146/annurev.energy.31.102405.170850

3.5. Science Reflects Cultural Biases and Inequalities

Although it is relatively easy to point to instances where funding or other identifiable interests could have influenced the selection of research topics, appropriate evidence, or recommendations, the more subtle and arguably more pervasive influence is that of the broader culture within which research is embedded. We have already noted in the previous section the dominance and shortcomings of techno-rational ways of thinking and attempting to address complex development issues. Research agendas, approaches, and world views inevitably reflect the biases, attitudes, and inequalities characteristic of the society that supports them.

Feminist critiques have pointed to the gender biases that are evident in science. Kohlstedt & Longino (49) point to three main areas of feminist investigation: historical analyses of the (limited) participation of women in science, gendered language and imagery in scientific communication, and the effects of gender imbalances in the practice of science for the ways we conceptualize knowledge.

In the context of sustainable development, the need for gender equality was a prominent theme in the Report of the World Summit for Sustainable Development (20). Yet the effects of gender inequality in science (and other inequalities, such as low participation by minorities and the overwhelming dominance of wealthy Western countries in academia globally) on the linkages between research-based knowledge and action have received little attention. In the U.S. context, a study of gender in two agricultural land grant universities shows differences regarding links with the private sector, with male faculty more likely to have collaborations with industry and more accepting of close ties between universities and industry than female counterparts (50). This indicates that gender may be a significant factor in how research-based knowledge is linked with action.

Similarly, proponents of the value of indigenous or local ecological knowledge claim that efforts to manage ecological systems that did not take local knowledge into account were missing a vital and rich source of knowledge about complex interactions. As Olssen & Folke describe it, "Locally evolved resource management systems can be looked upon as natural experiments; they are experiential through learning-by-doing rather than experimental in the scientific sense" (51). Authors argue that these knowledges are often denigrated in comparison to scientific knowledge, when they should be regarded as complementary (52, 53). These critiques emphasize both the substantive knowledge of local actors via their experience as well as the ethical dimension of the need to include the knowledges of those people who are likely to be affected by the outcomes of decision making.

In a more reflexive vein, Nygren (54) has noted that many analyses of local and indigenous knowledges have been based upon a number of dichotomies of knowledge: tacit versus scientific, folk versus universal, indigenous versus Western, and traditional versus modern. She argues that the presumption that indigenous and local knowledges are distinct from other forms of knowledge, including science and research, is not well supported. In her studies of forest-edge communities in Nicaragua, she found that knowledge was often controversial and changing, with

18 Jul 2006 6:2 AR ANRV289-EG31-12.tex XMLPublishSM(2004/02/24) P1: OKZ
AR REVIEWS IN ADVANCE10.1146/annurev.energy.31.102405.170850

new ideas being integrated into their day-to-day actions (54). In other words, the presumption that indigenous knowledge is disconnected from scientific knowledge is not necessarily the case.

Gender and local knowledge by no means represent the full extent of actual or potential cultural bias. Indeed, underlying both is the major inequality in the production of research itself—heavily concentrated in wealthy Western countries. The implications of this inequality are yet to receive the attention they deserve in the context of sustainable development. The effects of deeply embedded cultural biases and inequalities in the relationships between research-based knowledge and sustainable development are significant because they include questions of who gets to define which problems are most important as well as what should be done about them.

3.6. What Lies Beyond the Trickle-Down and Transfer Model?

The critiques discussed in this section, although by no means a complete account of the ways in which people have challenged the trickle-down and transfer models of science, do point to several key issues. First, critiques have come from different practical and ideological backgrounds—from those who see science and research as a hegemonic cog in the machinery of global oppression through to practicing researchers who have been frustrated in attempts to get what they see as important findings acted upon and those who examine the hybrid spaces in between. Second, the linkages between research-based knowledge and action are institutionally enabled and constrained; that is, the use of research is shaped by the explicit and implicit rules that govern social decision making, such as democracy, and the delegation of decision-making power.

The core insight is that the conventional models for linking research-based knowledge, founded on the idea that there is a research product that is independent of the processes that have gone into creating it, are unraveled in every critique. If we locate each critique with respect to the original transfer and translate model presented in Figure 1, we can see that the different critiques individually target different parts of that process. Yet taken *as a group*, they offer a comprehensive suite of challenges that leave no part of that model unscathed, shown in Figure 2.

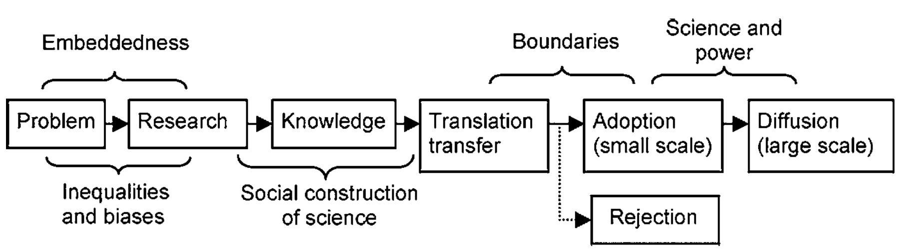


Figure 2 Critiques of the transfer and translate model.

18 Jul 2006 6:2 AR ANRV289-EG31-12.tex XMLPublishSM(2004/02/24) P1: OKZ
AR REVIEWS IN ADVANCE10.1146/annurev.energy.31.102405.170850

These critiques posit that in the context of sustainable development, the work that goes on prior to the actual research—in setting the problems to be investigated, as well as the actual research itself—matters to the eventual application (or not) in practice. Adoption or rejection of research does not flow automatically from understanding generated by well-translated findings but is a product of political context and how research findings align, conflict with, or transform existing power structures. The authority of research emerges from the *interaction* of the research process with the political processes of decision making and change.

Yet research itself has by no means remained static and passive in the face of these critiques and other shifting forces. Indeed, although some have expended their efforts on defending conventional ideas of scientific authority, others have begun to explore and exploit the opportunities that these alternative ideas have offered. New ways of thinking about research, action, and sustainable development, as well as new ways of doing research have emerged as a result. The next section examines a range of these new approaches to tackling the challenges of linking research-based knowledge with action for sustainable development.

4. MAJOR RESPONSES TO CRITIQUES

There have been many attempts to overcome some or all of these challenges in improving the linkages between research-based knowledge and action. The responses are many and varied, and any attempt to group them into a handful of categories necessarily rides roughshod over the subtleties and crossovers between them. Nevertheless, in this section, we examine the main responses to the critiques discussed in Section 3 under four headings: participation, integration, learning, and negotiation. In these four categories, we have tried to draw key distinctions that between them, but we must note that our use of these four titles does not always neatly correspond with the ways these terms are used in the literature.

4.1. Participation

Participation refers to the wide range of mechanisms and techniques by which nonresearchers become involved in research or governance. Enhancing public participation has been touted as crucial to informed decision making and taking action toward sustainability for several reasons. Randolph (55), for example, cites four reasons for taking a participatory approach to environmental management: to gain access to alternative, less easily available, sources of knowledge relevant to solving particular problems; to build support for decisions by addressing common problems and resolving disputes; to mobilize resources and share management responsibility for actions; and to develop agency, organization, or community capacity. Others focus on the rights of people to know and be involved in processes that may affect them (56). In practice exactly what constitutes participation and how it is to be achieved are often not clearly spelled out. Here we focus on weak

18 Jul 2006 6:2 AR ANRV289-EG31-12.tex XMLPublishSM(2004/02/24) P1: OKZ
AR REVIEWS IN ADVANCE10.1146/annurev.energy.31.102405.170850

levels or degrees of participation or consultation (57–59) because other models will be incorporated in sections below.

The failure of the transfer of technology model to address land degradation and the needs of poor farmers left a gap that was largely taken up by the concept of participation. As Richeleau describes it, participatory research proposes to "join together people and institutions with very distinct traditions of acquiring knowledge, in order to develop sustainable land use practices of interest to both" (60).

In some cases, participation evolved as extension services started to listen to farmers and as farmers began actively commissioning research and consultants. This led to the emergence of more collaborative models of research, validating experimental findings and making observations in practice that shifted the nature of the relationship between researchers and practitioner and emphasized process as well as output. For example, a study of the factors influencing adoption of integrated pest management of durian fruit growers in Thailand revealed that the collaborative approach between farmers and agricultural extension workers—wherein farmers learned from each other and extension agents learned things about durian farming—was more important to participants than the detailed content of instructional material (61).

These emergent participatory practices were supported and strengthened by a range of other forces. In a review of the catalysts driving the move toward participatory land management research, Keen (62) noted four distinct forces for change. These were (*a*) policy developments, embracing the ideas of sustainable development; (*b*) institutional catalysts, including changing conditions for government research funding; (*c*) academic developments, with new methodologies and changing theoretical paradigms; and (*d*) community catalysts, such as advocacy and changing community expectations of research.

Participation has also sought to address the exclusion of traditional knowledges noted in the critiques section. This is illustrated by the recent history of Karen land-use systems in northern Thailand, where participatory approaches recast and strategically connected traditional knowledges with technical alternatives to extraction forestry, such as community forests and rotating swidden agriculture in an effort to maintain access by the Karen to their land (63).

Another major route for participation has been in participatory governance and assessment processes that include both citizens and researchers as participants. Rayner has observed the way in which social scientists and policy entrepreneurs have created increasingly elaborate techniques which "re-establish a role for non-experts in scientific, environmental and technological decision making" (64) via focus groups, citizen juries, consensus conferences—all of which have a much greater emphasis on public participation alongside expert participation.

Participatory approaches have challenged the dominance of natural sciences and economics as foundations for decision making and have demonstrated that innovative relationships can generate innovative solutions to sustainability challenges (65). Others, however, argue that the actual outcomes of these approaches

18 Jul 2006 6:2 AR ANRV289-EG31-12.tex XMLPublishSM(2004/02/24) P1: OKZ
AR REVIEWS IN ADVANCE10.1146/annurev.energy.31.102405.170850

are uncertain and ambiguous. Petkova et al. (66), in a nine-country review of environmental governance found that participation opportunities "... tended to occur too late to meaningfully affect the scope and nature of the decision, and did not continue through the implementation phase of the decision making cycle." Some take this further to argue that participation has become a new democratic disguise for persistent power inequalities (67). These controversies suggest that participatory processes need to be carefully designed and executed to fulfill their promise in sustainable development.

4.2. Integration

A second response to the challenge of linking research-based knowledge and action took the form of calls for greater integration of interested parties, both within science and between researchers and decision makers. Although there are many variations on this theme of integration, this very variation is a response to the many ways in which relationships between researchers and their user communities are fragmented. A review by van Kerkhoff (68) has noted that calls for integrated research have often been initiated by people or groups who are not active researchers—particularly research funding agencies. Consequently, one feature of the integration literature is that it tends to focus on the structural, institutional, and governance issues surrounding the linkages between different parties in connecting research-based knowledge and action, rather than the microlevel interactions of researchers and practitioners that characterize the participatory approaches. Here, we cover three arenas for integration: scale, jurisdiction, and researcher-user chains.

Action for sustainable development is stretched over the entire range of geographic scales, from global regimes and conventions to regional, national or provincial policies, and local, on-the-ground decision making (41). Efforts to integrate across scales include linking global-scale science with local-scale actions and vice versa as well as enrolling science in struggles between global, national, and/or local politics and power. As noted in the Karen example above, in the field of forest management, growing interest in biodiversity conservation and community resistance to conventional extraction approaches focused on harvest and yield has forced policy makers and scientists to examine alternative models (30), wherein some form of comanagement among actors operating at different levels and interplay among institutions is now regarded as essential (69).

Another major context of integration has been the need to integrate research-based knowledge and action across jurisdictions (70). This has been particularly prominent in water management, where the effects of the actions of one jurisdiction (nation, province, town) can have important effects on others who rely on that water source. The engineering approach to water management, which has been dominant since the start of the twentieth century, was typically tied to a particular jurisdiction. This approach was criticized on the grounds that it failed to account for the negative effects of large-scale projects such as dams, including dispossession of people and loss of fertile cropland upstream. It also generated political

18 Jul 2006 6:2 AR ANRV289-EG31-12.tex XMLPublishSM(2004/02/24) P1: OKZ
AR REVIEWS IN ADVANCE10.1146/annurev.energy.31.102405.170850

problems because water management projects initiated by one jurisdiction often had important ramifications in others.

Since the late 1970s, this scientific-technocratic process has been countered by a variety of integrated watershed management approaches. The integration of water management includes linking different disciplines (hydrology, agronomy, social sciences) and creating governance structures whereby landholders, researchers, and government representatives participate in priority setting and decision making within a watershed. It also includes integration of different political units involved in or affected by water management efforts (71). This approach to linking knowledge and action sought to expand the concept of water management to address key failings in approaches dominated by technical sciences.

A third major axis for integration has been along the research production-to-use axis. Institutional innovations, such as cooperative research programs, integrated projects, and other mechanisms for connecting academic research with the users of research, have flourished over the past decade. These typically involve cofunding and oversight arrangements in which users (particularly industry, but also farmers, policy makers, and land managers) jointly set research agendas and participate in the development of research findings. For a review of current approaches to integrated research between research producers and users, see van Kerkhoff (68).

4.3. Learning

A third response to the critiques noted in Section 3 has been to develop models of research-practice interaction based on the concept of learning. These have a number of different origins, from participatory, power-sharing bases through to deliberation techniques and adaptations of private sector models. Here, we will draw on insights from studies in three different areas: knowledge sharing and management initiatives, agricultural knowledge systems and social learning, and adaptive management.

Knowledge sharing and management initiatives at the organizational level originated in the private sector. Early literature in the late 1970s (72–74) on knowledge management and organizational learning generated an avalanche of business programs over the following decades. The theoretical work by Nonaka and colleagues (75–77) is particularly noteworthy for bringing together practical, but hard to codify, knowledge that lies within employees and their relationships with conventional manuals and product or process-based knowledge that is easier to articulate and share. This literature aimed to help organizations gain better financial returns from the knowledge they already possess and a more strategic approach to their ongoing learning and development to build their knowledge base. There is typically a strong emphasis on technical systems to facilitate access to this knowledge base.

These ideas have also been taken up in the public sector and international agencies. In the mid-1990s, The World Bank initiated a new program of organizational reform around the idea of knowledge sharing, a concept based on knowledge

18 Jul 2006 6:2 AR ANRV289-EG31-12.tex XMLPublishSM(2004/02/24) P1: OKZ
AR REVIEWS IN ADVANCE10.1146/annurev.energy.31.102405.170850

management and organizational learning (78). This effort was soon emulated by other major development agencies (79).

Agricultural knowledge and information systems and social learning are approaches to learning based on engagement between researchers and farming practitioners to build ecologically sound farming practices (80). The agricultural knowledge and information system model examines farming change as a process of innovation in which knowledge and learning are central, but institutions, policies, and facilitation also play key roles. This model has been generalized to a broader concept of ecological knowledge systems, noting that other forms of knowledge system (notably, the transfer of technology and farm management development models) have been ineffective in the development of ecologically sound farming practices (81). A particularly distinctive feature of this approach to linking knowledge with action is the idea that participants need to learn to see themselves as a knowledge system; that is, innovation emerges through the interaction of social actors and can be enhanced as those actors begin to understand their role within a knowledge system. As this vision develops, either spontaneously or through facilitated processes, those involved in the system become more purposive, directed, and deliberate in their actions and interactions to support learning and innovation (82).

Adaptive Environmental Assessment and Monitoring (83) was proposed as a model for integration between researchers and policy makers. It has been an influential model that spawned several variations that can be more loosely grouped under the title "adaptive management." Adaptive management models and approaches also draw on systems theory to suggest that policy interventions, or environmental management more broadly, should be regarded as experiments with concomitant assessment and monitoring as a basis for ongoing learning. More recently, proponents emphasize building flexibility and resilience in the face of uncertainty rather than grand experiments (84). Other versions of adaptive management productively combined the more quantitative dimensions of adaptive management with social and organizational learning concepts, broadening the integrative scope of the models to include social factors (82, 85, 86). In all cases, however, research is an essential component. Dovers & Mobbs (87), for example, describe the important features of adaptive management approaches as "information is central, the focus is on integrating natural system and institutional/social dimensions, and it is absolutely and inevitably interdisciplinary." Adaptive management approaches are significant because they insist that researchers and managers can work together in productive, ongoing relationships in which research and management activities dovetail and strengthen each other.

4.4. Negotiation

Although the previous approaches to improving the linkages between research-based knowledge and action have focused on improving linkages at interpersonal, and institutional levels, our final category examines approaches that have focused

18 Jul 2006 6:2 AR ANRV289-EG31-12.tex XMLPublishSM(2004/02/24) P1: OKZ
AR REVIEWS IN ADVANCE10.1146/annurev.energy.31.102405.170850

on power sharing. Negotiation-based models acknowledge that researchers are political actors and provide a space for different political interests to be considered. In this section, we discuss three models based on negotiation and power sharing: advocacy coalitions, boundary work, and mode 2 research.

Work in the early 1990s, primarily by Sabatier & Jenkins-Smith (88), showed that research informed policy through researchers' participation in advocacy coalitions. These coalitions are formed by actors, including researchers, from government and private organizations who share a set of beliefs regarding policy and seek, over time, to influence government institutions accordingly. This work represents a major departure from previous concepts of research-policy linkages by differentiating groups according to their affiliation to a set of ideas or ideology rather than by their affiliation to a particular institution (the basis of the two communities idea) (10).

The idea of contested boundaries between science and society was introduced earlier. "Boundary work" is a concept that directs attention to the actual work that researchers and others engage in to demarcate research and establish its authority, both within science (boundaries between different disciplines or points of view, for example) as well as between science and society.

With regard to sustainable development, boundaries have been shown to be created as a result of public controversy and perceptions of risk. Bickerstaff & Simmons (89), for example, have examined the scientific contest between epidemiologists and academic veterinarian researchers over appropriate policies for controlling infectious animal-borne disease. They argue that the boundary work between these disciplines reflects different spatial practices, with different recommendations for disease control policy. When there are multiple authoritative sources of advice, policy makers can readily select those recommendations that are the most politically or practically feasible. Cash et al. (90) emphasize the importance of managing the boundaries between knowledge and action. Building on work with the Social Learning Group (38) on international assessments they proposed that "efforts to mobilize science and technology for sustainability are more likely to be effective when they manage boundaries between knowledge and action in ways that simultaneously enhance the saliency, credibility and legitimacy of the information they produce." They and others also suggest that institutional change and other mechanisms are often needed to facilitate negotiation across such boundaries (86). The danger, however, as Guston (91) points out, is that the very flexibility of these boundaries generates questions: How much blurring of these boundaries is enough, and how much might be too much? He suggests that organizations that are "tethered" to both scientific and political interests (i.e., are accountable to both) are best able to maintain a balance. The appeal and usefulness of the idea of boundary work is that it highlights the presence of multiple realities and thus reframes sustainable development as a negotiation among the groups involved at a particular boundary.

In the mid-1990s a new discourse began that started with the observation of Gibbons et al. (92) of newly (or recently) emerging research structures ("mode 2")

18 Jul 2006 6:2 AR ANRV289-EG31-12.tex XMLPublishSM(2004/02/24) P1: OKZ
AR REVIEWS IN ADVANCE10.1146/annurev.energy.31.102405.170850

that are different from conventional scientific structures of knowledge production and dissemination ("mode 1"). The aim of their analysis was to "clarify the similarities and differences between the attributes of each [mode], and help us understand and explain trends that can be observed in all modern societies." Mode 2, in contrast to the conventional mode 1, actively involves society (particularly research users and those affected by the outcomes of research) in the research process. In mode 2, negotiation between scientists and society becomes the norm, as governments, industry, and citizens demand a greater say in scientific processes, and science is deeply embedded in many—perhaps all—forms of day-to-day decision making. Nowotny et al. (93) have described this as the emergence of a new space, an "agora," where science and society, markets, and politics comingle.

The mode 1/mode 2 research distinction is an interesting contrast to the other models of negotiationbecause its proponents claim that the changes implied or carried out by implementing these models are the result of broader social, political, and scientific forces. They argue that the ability to cross boundaries, learn, and negotiate are increasing as education levels increase, civil society strengthens and organizes, and researchers are forced by ever-shrinking pools of public funding to seek new relationships outside academia.

5. KNOWLEDGE, ACTION, ENGAGEMENT, AND POWER

Our examination of the conventional model of how research-based knowledge is linked with action in Section 2, the various critiques of that model in Section 3, and the responses to those critiques discussed in Section 4 has covered very diverse territory, but two themes have persisted throughout. The first is the idea of engagement—whether, when, and how research and action are, or should be, connected and working together. The second has been the exercise of power, both in the service of and to the detriment of,sustainable development. The interactions between knowledge, action, and power have been approached differently in the five critiques we listed in Section 3 as well as in the major categories of response we discussed in Section 4. In this section, we look more closely at the different approaches to the relations between knowledge, action, engagement, and power in the four types of responses.

Engagement and direct interaction between researchers and practitioners has been a feature of each of the models we presented in Section 4, although taking a somewhat different form in each. The importance of engagement can be understood in relation to the critiques of the conventional, disengaged models of science discussed in Sections 2 and 3. In very simple terms, if the problem was lack of connection between research and practice, then the solution is surely to build up those connections. This is, however, where the simplicity ends. With the authority of research-based knowledge at least partly grounded in its independence from other interested groups, any efforts to engage with those groups must be approached carefully.

Issues of power are often regarded with some discomfort by researchers because they form an implicit challenge to the idea that science research should be based on neutral, disinterested application of scientific method. However, as soon as researchers become concerned with action, decision making, and change, power can no longer be ignored as it is intimately entwined with the ability to act. Power relations are fundamental to institutional enabling and constraining conditions that form the context of action both of individuals and groups. But how can it be applied usefully in this context? In sociological literature, power is often used as a synonym for domination and oppression. As we have noted in the critiques, science has been held by some to support such domination by legitimizing acts of violence and discrimination. Yet power is inherent in every organized society and is not always wielded to the detriment of citizens or against goals of sustainable development. Participatory and learning models have illustrated that research that shares power and authority between researchers and practitioners can lead to improved outcomes for livelihoods and sustainability. International regulatory regimes have illustrated that global power can be harnessed to the task of sustainable development.

The varied approaches to linking research and action that were discussed in Section 4 offer different interpretations of power and engagement and of the interactions between them. These are summarized in Table 1.

Table 1 shows that the structure of the engagement processes between research and action are deeply entwined with the ways decision-making power is formally allocated. Participation and integration, with their focus on particular, discrete activities (projects, events, decisions), tend to have clearly but narrowly defined avenues for sharing decision-making authority. They typically share efforts to define problems but not their resolution. In contrast, negotiation and learning are open-ended processes (at least in theory, but the practicalities of funding may lead them to project-oriented work) and have more diffuse, fluid arenas for decision making, both in defining problems and resolving them.

5.1. Implications for Linking Knowledge and Action for Sustainability

Power, engagement, knowledge, and action are general and abstract terms. What do the observations noted in the previous section mean in the context of efforts to achieve sustainable development? What is it that people do differently to shift power balances, challenge the status quo, or resolve specific sustainability problems?

In examining implications for practice, both for researchers and practitioners, it is important to note that either group may take responsibility for improving the linkages between research-based knowledge and action. Practitioners may seek out research-based knowledge to help their decision making; researchers may seek out practitioners to gain influence or bring new issues to their attention. The question of who takes the lead is significant because it is typically the initiator who has the greatest say in how the engagement is structured and, consequently, how power is

18 Jul 2006 6:2 AR ANRV289-EG31-12.tex XMLPublishSM(2004/02/24) P1: OKZ
AR REVIEWS IN ADVANCE10.1146/annurev.energy.31.102405.170850

TABLE 1 Engagement and power in participation, integration, negotiation, and learning

Approach	Engagement	Power
Participation	Individual- or small-group level engagement occurs around specific topics or issues. Terms of engagement are set by authorities (researchers, policy makers) for specific issues.	Personal empowerment (increased capacity to act) occurs through becoming a more informed participant, with some power to define problems. No higher-level decision-making authority is granted to participants.
Integration	Organizational level engagement occurs to set shared agendas and aims and to create supportive institutions for specific projects.	Problem definition is shared. Research becomes more powerful by formally engaging with influential decision makers but is less able to challenge their power.
Negotiation	Strong engagement occurs within coalitions and exists when there is political polarization (disengagement) on controversial issues, an ongoing process.	Researchers are powerful actors in their own right, adding the authority of science to particular political positions; autonomy from decision makers is often preferred.
Learning	Strong engagement occurs within groups that may emerge or be facilitated by researchers using specific methodologies, an ongoing process.	Researchers and practitioners both share learning experiences with equal power to implement them in their respective contexts.

shared. Specialist intermediaries such as knowledge brokers or new hybrid groups, who have experience and expertise in both research and action, can play important roles in facilitating these relationships. In Figure 3 we have tried to capture what the different approaches look like in practical terms, depending on who is driving the linkages, and note the intermediaries who may invoke these models using either or both of the strategies listed. We have included our original trickle-down and translation and transfer models for comparison.

Figure 3 shows that we can regard the two conventional models, plus the four response models, as forming a hierarchy with respect to engagement and power sharing. From the researcher's perspective, this hierarchy involves increasing interaction with practitioners, with ever-greater consideration of their perspective. From the trickle-down model, wherein no consideration is given, the translation and transfer models start to engage with the constraints faced by practitioners in accessing and understanding research-based knowledge. Science communication specialists may be employed to literally translate science into user-friendly formats. Participation steps up to actively involving practitioners in conceptualizing problem setting and problem solving, often using facilitators to manage the interactive process. Integration grants researchers and practitioners shared power

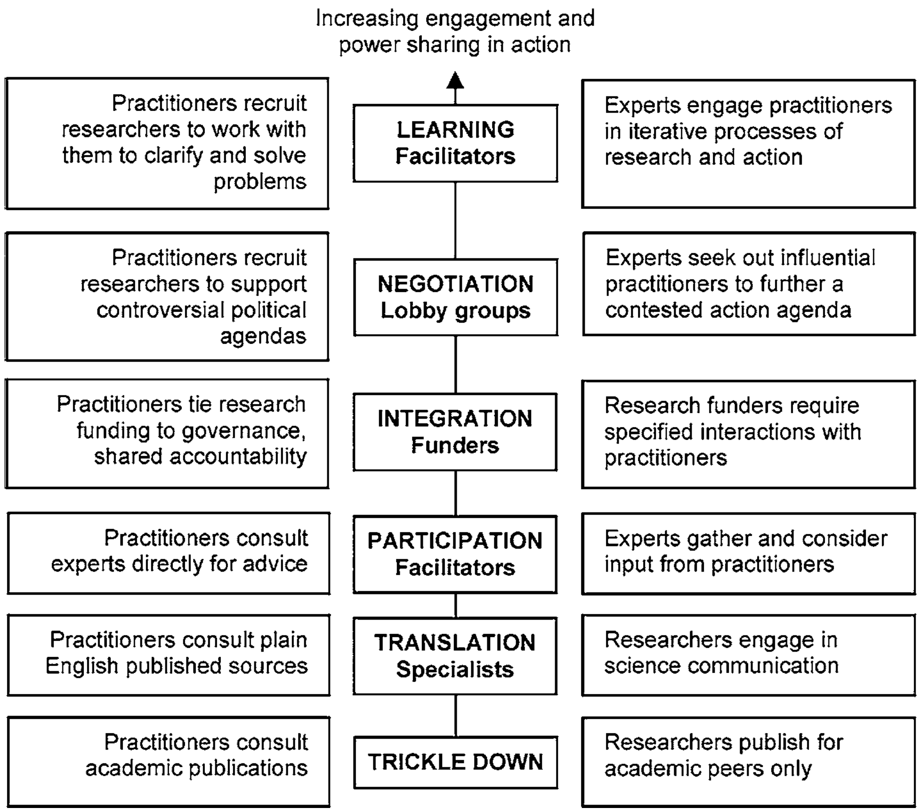


Figure 3 Knowledge, power, engagement, and action.

in setting research agendas, encouraged by research funding requirements. Under negotiation models, researchers seek out influential individuals or lobby groups to redefine or introduce new sustainability problems and work with them to further that agenda in political circles. Finally, in learning models, researchers invite practitioners to work with them throughout a research-action cycle, often managed by highly-trained facilitators, with responsibility for linking research-based knowledge and action formally shared.

From the practitioner's point of view, there is an equally increasing consideration given to research-based knowledge. Consulting academic sources is an option for those practitioners who have sufficient academic background to use them. Specific products created by the research community targeted at practitioners can reach a wider audience if practitioners seek them out (recall the 4% of medical practitioners who had consulted the evidence-based syntheses). Knowledge brokers can be useful intermediaries in helping practitioners identify and access research. Next, practitioners may consult or hire researchers to provide

18 Jul 2006 6:2 AR ANRV289-EG31-12.tex XMLPublishSM(2004/02/24) P1: OKZ
AR REVIEWS IN ADVANCE10.1146/annurev.energy.31.102405.170850

input to specific decisions or strategies. When issues are highly technical, or the ability to make decisions is affected by scientific uncertainty, integrated research projects or programs may be initiated, which allow practitioners working with researchers to set a research agenda that has immediate practical implications. The terms of the relationship may be formalized via funding agreements and oversight arrangements, such as shared representation on steering committees. When particular issues are not finding purchase in political arenas, practitioners may recruit researchers who are working on those issues to lend both technical support and authoritative support to lobbying efforts. Finally, if practitioners have a strong commitment to research-based knowledge, they may initiate longer-term learning relationships with researchers, managed by facilitators with experience in both research and action.

As noted earlier, although we have characterized these models as separate, in practice, they are clearly interrelated. The descriptions we have just given are perhaps more stereotypical than highly accurate reflections of how relationships between researchers and practitioners actually unfold. However, such stereotypes can be a useful point of comparison in the otherwise foggy domain of linking research-based knowledge and action. In the next section, we restore some of the complexity and examine a series of tensions that emerge in trying to understand and develop effective relationships between research-based knowledge and action.

5.2. Tensions Between Knowledge, Action, Engagement, and Power

Although engagement and power were consistent themes throughout the literature we have examined, it is equally clear that there is no straightforward relationship between them. The contrasts and contradictions between research-based knowledge, action, engagement, and power may be better understood as a series of tensions, which may become productive sources of creativity and innovation, destructive sources of marginalization and violence, or stagnant domains of blame casting and inaction. These tensions include

- Tension 1: Democratic processes of engagement and dialogue share power across participants but assume power sharing will lead to action; authoritative processes of expert knowledge concentrate power but can challenge existing power structures that are blocking change.
- Tension 2: Every research-action scenario needs to be understood as unique and context rich, dependent on one-on-one relationships; generalizations from research-action scenarios are needed to enable us to learn how to participate in these scenarios more effectively.
- Tension 3: Research-based knowledge is a special way of knowing that can make a unique contribution to societies' pursuits of sustainability, but actions toward sustainability are ultimately the result of social and political decisions.

- Tension 4: Efforts to link knowledge and action toward sustainable development are manifested in the changed behavior of individuals, but individual change may require altering powerful institutions or social relations first.
- Tension 5: Research-based knowledge can simplify causally complex situations to offer a clear course of action, but sustainable development is inherently complex, so simplification increases the risk that the course of action will be counterproductive.

There are, of course, no absolutely right or wrong approaches to deal with these tensions, nor is there much analytical work that takes us beyond the realm of best guesses and what seems opportune at the time. Despite the centrality of the dynamics between research-based knowledge, engagement, power, and action for sustainable development, we actually know very little about how these dynamics operate—especially in efforts that go beyond the trickle-down, translation and transfer models. How are these dynamics structured by institutional rules and conventions? How are these relationships mediated by the governance of research and action? And, most importantly, how might they be improved? Our review has shown that different methodological and institutional approaches to linking research and action can have a profound effect on the forms of engagement and the degrees of power sharing that can result.

One major implication of the review is that the way we conceptualize the connections between research-based knowledge and action can now be refined. As noted in the introduction, this was a key challenge for this review. The concept of linkages that we have used to this point implies a chain-like, disembodied, somewhat mechanistic relationship that is reminiscent of the transfer and translation models. The critiques and models we have reviewed have collectively destroyed any idea that such linkages are disembodied or chain-like, but as Gibson (10) has noted, the concept of two communities will persist while we continue to use the language that invokes it. We propose that the connections and relationships between research and action for sustainable development can be more usefully regarded as arenas. This allows us to point to specific instances where research-based knowledge and action are interacting but without necessarily implying that those interactions are simple or straightforward.

Finally, the different critiques and the responses to them also highlight the need for a system-wide perspective; that is, a perspective that examines the implications of the governance of research-action arenas that cover multiple scales and effects on groups beyond those immediately involved through direct engagement. This perspective would need to address three concerns: first, those microsolutions (for example strong participatory or learning processes that are built up between specific researcher and practitioner groups) need not scale up to macrolevel results owing to systematic biases or incentives at more aggregated scales. The orientation toward direct engagement between researchers and practitioners, particularly around specific projects or events, comes at a cost of generality and the ability to offer sweeping solutions to pervasive problems. However, the inability or

18 Jul 2006 6:2 AR ANRV289-EG31-12.tex XMLPublishSM(2004/02/24) P1: OKZ
AR REVIEWS IN ADVANCE10.1146/annurev.energy.31.102405.170850

unwillingness to see direct engagement within its broader context hampers efforts to learn across different activities. Second, just because processes encourage engagement, that does not mean they are necessarily immune from the cultural biases noted above. A systems perspective would need to consider (at least) issues of gender, minority interests, and representation of nontechnical knowledges. Third, a systems perspective would need to address concerns that any given effort to connect research with practice is embedded within a broader array of institutional structures and power relations that need not be immediately obvious. Robbins (94), for example, has written reflectively on his work with the middle-caste group in India. Although their relationship has been rewarding for both himself as a researcher and the group in maintaining their rights to access land, this has been at the expense of other lower-class groups, which are less powerful and therefore arguably in greater need of his support. There are, as he somewhat sadly notes, no easy solutions to this. Yet even this awareness of the broader system within which his work is situated and the connections between engagement, action, and power surely represents a positive standpoint from which to approach sustainable development.

6. CONCLUSIONS

In this review, we have outlined the shortcomings of conventional ideas of research utilization and provided some idea of the extent and breadth or present-day attempts to improve the linkages between research-based knowledge and action in the context of sustainable development. The two themes that most strongly emerged, engagement and power, both show that the responsibility and capacity to make useful links between these groups does not lie wholly within any particular group of actors, researchers, practitioners, or others. Rather it continually arises from engagement that brings critical tensions among those with different knowledges (and those with different capacities to act) to the fore.

Describing these tensions and the complexity of research-action arenas for sustainable development does not, unfortunately, make them easier to deal with. Indeed, as we noted in tension 5, there is often a trade-off between simple understandings that imply clear but inadequate courses of action and more complex understandings in which appropriate courses of action become far less clear. For those readers who have previously subscribed to the conventional model of the links between research-based knowledge and action, we acknowledge that the literature we have reviewed presents a far more complex picture. For those who have been involved in the critiques of that model or responses to them, we have most likely simplified the field, hopefully in a positive way.

As we noted above, research-based knowledge can and does make a unique contribution toward sustainable development, but this contribution needs to be understood in relation to actual or potential contributions from other forms of knowledge and to acknowledge that there are often no clear lines between "research" and "ther" in this regard. Understanding these relationships is not easy in situations

18 Jul 2006 6:2 AR ANRV289-EG31-12.tex XMLPublishSM(2004/02/24) P1: OKZ
AR REVIEWS IN ADVANCE10.1146/annurev.energy.31.102405.170850

that are socially, institutionally, and biophysically complex, with multiple layers of power and many contexts of action. Reconfiguring those relationships by adopting a notion of research-action arenas may be useful conceptually, but what might his mean in a real-world setting? Although it is not the purpose of this review to attempt to create a comprehensive guide, we do conclude with some suggestions of questions researchers may ask to gain some orientation to the issues of knowledge, action, power, and engagement from within a shared research-action arena.

1. Research-based knowledge

- How do participants in the research-action arena—both researchers and nonresearchers—understand the role of research-based knowledge for the particular decision-making scenario? (As authoritative solution provider? As a source of limited but useful knowledge? As a voice that can challenge power relations? As a guide to more detailed or disciplined learning?)
- Do various participants understand the role of research-based knowledge differently?
- Should any such differences be resolved, or can they become useful tensions for creativity and innovation?
- How might this be achieved?

2. Engagement

- Who is included in processes of engagement? Who is excluded? Why?
- What do these inclusions and exclusions say about the power relations that are in place? (Are efforts being made to share power? Could power relations be changed by changing who is in and who is out?)
- What do these inclusions and exclusions say about the actions that may result from engagement (Limited? Institutional change with uncertain application on the ground? Closely tied to a specific place?)

3. Power

- Who is funding participation in the research-action arena? (What are the formal channels of responsibility and accountability? What are the informal channels?)
- How is it governed? (Is there an oversight structure? Who is represented? Who is not?)
- How do these governance arrangements shape the research-action agenda?
- Are governance arrangements appropriate for sustainable development? If not, how might they be altered?

4. Action

- Who is responsible for action toward sustainability?
- Are all those holding responsibility involved in the research-action process?

- What knowledges are being brought to support decisions for action? (Are there any key participants missing?)
- What are the institutional constraints on what can be done (e.g., existing regulations? Lack of regulations?)
- Should institutional constraints be challenged? How?

We began this review with the goal of exploring ways of effectively linking research-based knowledge with action for sustainable development. By the end, we reached a contrary view of the world, one in which research, politics, researchers, and publics are intertwined in a constant struggle of justifications, explanations, and decisions in an uncertain and complex world. These questions encourage us to look at the relationships between research-based knowledge and action as arenas of shared responsibility, embedded within larger systems of power and knowledge that evolve and change over time. This conceptualization offers a more appropriate starting point for understanding the role of research in sustainable development than the conventional models of trickle-down, transfer and translation. It also serves as a point of comparison for the strengths and weaknesses of the many alternatives to that model. We hope it also offers richer possibilities for creating innovative, effective relationships between research and action in the pursuit of sustainable development.

ACKNOWLEDGMENTS

This article is based on research supported by a grant from the U.S. National Oceanic and Atmospheric Administration's Climate Program Office (formerly the Office of Global Programs) through the Environment, Science, and Development Program for Knowledge Systems for Sustainable Development Project. Additional support was provided by the Australian National Health and Medical Research Council's Capacity Building Grant in Environmental Health.

LITERATURE CITED

1. Juma C, Yee-Cheong L. 2005. *Innovation: applying knowledge in development*, Task Force Sci. Technol. Innov., UN Millenn. Proj., London
2. Rorty R. 1979. *Philosophy and the Mirror of Nature*. Princeton, NJ: Princeton Univ. Press
3. World Comm. Environ. Dev. 1987. *Our Common Future*. Melbourne: Oxford Univ. Press
4. Parris TM, Kates RW. 2003. Characterizing and measuring sustainable development. *Annu. Rev. Environ. Resour.* 28:559–86
5. Sachs W. 1999. *Planet Dialectics: Explorations in Environment and Development*. London: Zed Books
6. Booth T. 1988. *Developing Policy Research*. Aldershot, UK: Gower
7. Latour B. 1998. From the world of science

18 Jul 2006 6:2 AR ANRV289-EG31-12.tex XMLPublishSM(2004/02/24) P1: OKZ
AR REVIEWS IN ADVANCE10.1146/annurev.energy.31.102405.170850

to the world of research? *Science* 280:208–9
8. Guston D. 1997. Critical appraisal in science and technology policy analysis: the example of "science: the endless frontier." *Policy Sci.* 30:233–55
9. Weingart P. 1997. From "finalization" to "mode-2": old wine in new bottles? *Soc. Sci. Inf.* 36:615–40
10. Gibson B. 2003. Beyond two communities. In *Evidence Based Health Policy: Problems and Possibilities*, ed. V Lin, B Gibson, pp. 18–30. Melbourne: Oxford Univ. Press
11. Scoones I, Thompson J. 1994. Knowledge, power and agriculture: towards a theoretical understanding. See Ref. 56, pp. 16–32
12. Ison R, Russell D. 2000. *Agricultural Extension and Rural Development: Breaking Out of Traditions*. Cambridge: Cambridge Univ. Press
13. Chambers R. 1993. *Challenging the Professions: Frontiers for Rural Development*. London: Intermed. Technol.
14. Sackett DL, Richardson SR, Rosenberg W, Haynes RB. 1997. *Evidence-Based Medicine: How to Practice and Teach EBM*. Edinburgh/New York: Churchill Livingstone
15. Haines A. 1998. Making better use of research findings. *Br. Med. J.* 317:72–75
16. Maynard A. 1997. Evidence-based medicine: an incomplete method for informing treatment choices. *Lancet* 349:126–28
17. Young J, Ward J. 1999. General practitioners' use of evidence databases. *Med. J. Aust.* 170:56–58
18. Plant A. 2004. Evidence-based health care and international health: good, but not good enough. In *Evidence-Based Medicine: In Its Place*, ed. IS Kristiansen, G Mooney, pp. 141–50. London: Routledge
19. Lavis JN, Robertson D, Woodside JM, MacLeod CB. 2003. How can research organizations more effectively transfer research knowledge to decision-makers? *Milbank Q.* 81:221–48
20. UN. 2002. *Report of the World Summit on Sustainable Development*, Johannesburg
21. Brown J. 2001. *Who Rules in Science: An Opinionated Guide to the Wars*. Boston: Harvard Univ. Press
22. Jasanoff S. 1998. Coming of age in science and technology studies. *Sci. Commun.* 20:91–98
23. Sardar Z. 2000. *Thomas Kuhn and the Science Wars*. Cambridge: Icon
24. Merton RK. 1973. *The Sociology of Science: Theoretical and Empirical Investigations*. Chicago: Univ. Chicago Press
25. Houck O. 2003. Tales from a troubled marriage: science and law in environmental policy. *Science* 302:1926–29
26. Knorr-Cetina K, Krohn RG, Whitley R. 1981. *The Social Process of Scientific Investigation*. Dordrecht, Neth.: Reidel
27. Latour B, Woolgar S. 1979. *Laboratory Life: The Social Construction of Scientific Facts*. Beverly Hills: Sage
28. Bocking S. 2004. *Nature's Experts: Science, Politics and the Environment*. New Brunswick: Rutgers Univ. Press
29. Taylor MR, Rubin ES, Hounshell DA. 2003. Effect of government actions on technological innovation for SO_2 control. *Environ. Sci. Technol.* 37:4527–34
30. Lebel L, Contreras A, Pasong S, Garden P. 2004. Nobody knows best: alternative perspectives on forest management and governance in Southeast Asia: politics, law and economics. *Int. Environ. Agreem.* 4:111–27
31. Kinzig AP, Carpenter S, Dove M, Heal G, Levin S, et al. 2000. *Nature and Society: An Imperative for Integrated Environmental Research (Exec. Summ.)*, Natl. Sci. Found., Tempe, Ariz.
32. Landry R, Amara N, Lamari M. 2001. Utilization of social science research knowledge in Canada. *Res. Policy* 30:333–49
33. Barnes B, Edge D. 1982. General introduction. In *Science in Context: Readings in the Sociology of Science*, ed. B Barnes, D Edge, pp. 1–12. Milton Keynes, UK: Open Univ. Press

34. Gieryn T. 1983. Boundary-work and the demarcation of science from nonscience: strains and interests in professional ideologies of scientists. *Am. Sociol. Rev.* 48:781–95
35. Gieryn T. 1999. *Cultural Boundaries of Science: Credibility on the Line*. Chicago: Univ. Chicago Press
36. Mitchell T. 2002. *Rule of Experts: Egypt, Techno-Politics, Modernity*. Berkeley: Univ. Calif. Press
37. Dimitrov RS. 2003. Knowledge, power and interests in environmental regime formation. *Int. Stud. Q.* 47:123–50
38. Soc. Learn. Group. 2001. *Learning to Manage Global Environmental Risks: A Comparative History of Social Responses to Climate Change, Ozone Depletion and Acid Rain*. Cambridge, MA: MIT Press
39. Haas PM. 2004. When does power listen to truth? A constructivist approach to the policy process. *J. Eur. Public Policy* 11:569–92
40. Mitchell RB, Clark WC, Cash DW, Dickson NM, eds. 2006. *Global Environmental Assessments: Information and Influence*. Cambridge, MA: MIT Press
41. Jasanoff S, Martello ML. 2004. *Earthly Politics: Local and Global in Environmental Governance*. Cambridge, MA: MIT Press. 356 pp.
42. Ferguson J. 1994. *The Antipolitics Machine: "Development," Depoliticization, and Bureaucratic Power in Lesotho*. Minneapolis: Univ. Minn. Press
43. Mitchell RB. 2003. International environmental agreements: a survey of their features, formation, and effects. *Annu. Rev. Environ. Resour.* 28:429–61
44. Forsyth T. 2003. *Critical Political Ecology: The Politics of Environmental Science*. London: Routledge
45. Dore J, Lebel L, Manuta J. 2004. Gaining public acceptance. *Rep. UNEP Dams Dev. Project*, Chiang Mai Univ. Unit Soc. Environ. Res., Chiang Mai, Thail.
46. Scott JC. 1998. *Seeing Like a State: How Certain Schemes to Improve the Human Condition Have Failed*. New Haven: Yale Univ. Press
47. World Health Organ. 2000. *World Health Report 2000 Health Systems: Improving Performance*. Geneva: WHO
48. Miller CA, Edwards PN, eds. 2001. *Changing the Atmosphere: Expert Knowledge and Environmental Governance*. Cambridge, MA: MIT Press
49. Kohlstedt SG, Longino H. 1997. The women, gender, and science question. What do research on women in science and research on gender and science have to do with each other? *Osiris* 12:3–15
50. Buttel FH, Goldberger JR. 2002. Gender and agricultural science: evidence from two surveys of land-grant scientists. *Rural Sociol.* 67:24–45
51. Olsson P, Folke C. 2001. Local ecological knowledge and institutional dynamics for ecosystem management: a study of Lake Racken watershed, Sweden. *Ecosystems* 4:85–104
52. Berkes F. 1999. *Sacred Ecology: Traditional Ecological Knowledge and Management Systems*. London: Taylor & Francis
53. Jodha NS. 2001. *Life on the Edge: Sustaining Agriculture and Community Resources in Fragile Environments*. New Delhi: Oxford Univ. Press
54. Nygren A. 1999. Local knowledge in the environment-development: discourse from dichotomies to situated knowledges. *Crit. Anthropol.* 19:267–88
55. Randolph J. 2004. *Environmental Land Use Planning and Management*. Washington, DC: Island
56. Scoones I, Thompson J. 1994. *Beyond Farmer First: Rural People's Knowledge, Agricultural Research and Extension Practice*. London: Intermed. Technol.
57. Arnstein SR. 1969. A ladder of citizen participation. *J. Am. Inst. Plan.* 35:216–24
58. Clayton A, Oakley P, Pratt B. 1997. Empowering people—a guide to participation. *Prepared for* Civ. Soc. Organ. Particip. Programme, UN Dev. Programme, New York

18 Jul 2006 6:2 AR ANRV289-EG31-12.tex XMLPublishSM(2004/02/24) P1: OKZ
AR REVIEWS IN ADVANCE10.1146/annurev.energy.31.102405.170850

59. Int. Assoc. Public Particip. 2000. *Public participation spectrum*. (Accessed 11/20/05) http://www.iap2.org.au/spectrum.pdf
60. Richeleau D. 1994. Participatory research and the race to save the planet: questions, critique, and lessons from the field. *Agric. Hum. Values* 11:4–25
61. Elsey B, Sirichoti K. 2002. The learning facilitation role of agricultural extension workers in the adoption of integrated pest management by tropical fruit growers in Thailand. *Stud. Contin. Educ.* 24:167–80
62. Keen M. 1997. Catalysts for change: the emerging role of participatory research in land management. *Environmentalist* 17:87–96
63. Luangaramsri P. 2002. *Redefining Nature: Karen Ecological Knowledge and the Challenge to the Modern Conservation Paradigm*. Chennai, India: Earthworm
64. Rayner S. 2003. Democracy in the age of assessment: reflections on the roles of expertise and democracy in public-sector decision making. *Sci. Public Policy* 30:163–70
65. Kasemir B. 2003. *Public Participation in Sustainability Science: A Handbook*. Cambridge: Cambridge Univ. Press
66. Petkova E, Maurer C, Henninger N, Irwin F. 2002. Closing the gap: information, participation and justice in decision making for the environment. *Res. Rep.*, World Resour. Inst., Washington, DC
67. Cooke B, Kothari U, eds. 2001. *Participation: The New Tyranny?* London: Zed
68. van Kerkhoff L. 2005. Integrated research: concepts of connection in environmental science and policy. *Environ. Sci. Policy* 8:452–63
69. Lebel L. 2005. Institutional dynamics and interplay: critical processes for forest governance and sustainability in the mountain regions of northern Thailand. In *Global Change and Mountain Regions: An Overview of Current Knowledge*, ed. UM Huber, HKM Bugmann, MA Reasoner, pp. 531–40. Berlin: Springer-Verlag
70. Crabb P. 2003. Straddling boundaries: intergovernmental arrangements for managing natural resources. In *Managing Australia's Environment*, ed. S Dovers, S Wild River. Sydney: Federation
71. Lebel L, Garden P, Imamura M. 2005. Politics of scale, position and place in the governance of water resources in the Mekong region. *Ecol. Soc.* 10:18. http://www.ecologyandsociety.org/vol10/iss2/art18/
72. Argyris C, Schön DA. 1978. *Organizational Learning*. Reading, MA: Addison-Wesley
73. Argyris C, Schön DA. 1996. *Organizational Learning II: Theory, Method and Practice*. Reading, MA: Addison-Wesley
74. Liebowitz J, ed. 1999. *Knowledge Management Handbook*. Boca Raton, FL: CRC Press
75. Nonaka I. 1994. A dynamic theory of organizational knowledge creation. *Organ. Sci.* 5:14–37
76. Nonaka I, Toyama R. 2002. A firm as a dialectical being: towards a dynamic theory of a firm. *Ind. Corp. Chang.* 11:995–1009
77. Nonaka I, Toyama R, Konno N. 2000. SECI, Ba and leadership: a unified model of dynamic knowledge creation. *Long Range Plan.* 33:5–34
78. Gwin C. 2003. *Sharing Knowledge: Innovations and Remaining Challenges*. Washington, DC: World Bank
79. King K, McGrath S. 2002. *Knowledge Sharing in Development Agencies: Lessons from Four Cases*. Washington, DC: World Bank
80. Röling NG, Wagemakers MAE. 1998. *Facilitating Sustainable Agriculture: Participatory Learning and Adaptive Management in Times of Environmental Uncertainty*. Cambridge: Cambridge Univ. Press
81. Röling NG, Jiggins J. 1998. The ecological knowledge system. See Ref. 80, pp. 283–311
82. Leeuwis C, Pyburn R, eds. 2002. *Wheelbarrows Full of Frogs*. Assen, Neth.: Koninklijke Van Gorcum

18 Jul 2006 6:2 AR ANRV289-EG31-12.tex XMLPublishSM(2004/02/24) P1: OKZ
AR REVIEWS IN ADVANCE10.1146/annurev.energy.31.102405.170850

83. Holling CS, ed. 1978. *Adaptive Environmental Assessment and Management*. New York: Wiley
84. Gunderson LH. 1999. Resilience, flexibility and adaptive management—antidotes for spurious certitude? *Ecol. Soc.* 3:7. http://www.ecologyandsociety.org/vol3/iss1/art7/
85. Lee KN. 1992. *Compass and Gyroscope: Integrating Science and Politics for the Environment*. Washington, DC: Island
86. Folke C, Hahn T, Olsson P, Norberg J. 2005. Adaptive governance of social-ecological systems. *Annu. Rev. Environ. Resour.* 30:441–73
87. Dovers SR, Mobbs CD. 1997. An alluring prospect? Ecology, and the requirements of adaptive management. In *Frontiers in Ecology: Building the Links*, ed. N Klomp, I Lunt, pp. 39–52. Oxford, UK: Elsevier Sci.
88. Sabatier PA, Jenkins-Smith HC. 1993. *Policy Change and Learning: An Advocacy Coalition Approach*. Boulder, CO: Westview
89. Bickerstaff K, Simmons P. 2004. The right tool for the job? Modeling, spatial relationships, and styles of scientific practice in the UK foot and mouth crisis. *Environ. Plan. D* 22:393–412
90. Cash D, Clark W, Alcock F, Dickson N, Eckley N, et al. 2003. Knowledge systems for sustainable development. *Proc. Natl. Acad. Sci. USA* 100:8086–91
91. Guston DH. 2001. Boundary organizations in environmental policy and science: an introduction. *Sci. Technol. Hum. Values* 26:399–408
92. Gibbons M, Limoges C, Nowtony H, Schwartzman S, Scott P, Trow M. 1994. *The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Societies*. London: Sage
93. Nowotny H, Scott P, Gibbons M. 2001. *Re-thinking Science: Knowledge and the Public in an Age of Uncertainty*. Cambridge: Polity
94. Robbins P. 2004. *Political Ecology: A Critical Introduction*. Malden, MA: Blackwell