Summary Report[1]
of the Workshop on
Enhancing Integrated Science

November 4-5, 1998
Reston, Virginia

Integration among sciences is critical in order to address some of our most pressing and complex scientific and environmental problems, now and in the future. The complex nature of natural ecosystems, and the increasingly complex nature of human stresses and demands on ecosystems, means that simple and narrowly focused approaches are not sufficient to penetrate modern environmental problems. This increasing need for interdisciplinary science also poses new and important demands on the scientific enterprise, and on mission-oriented research institutions. The central question for institutions is how to promote and enhance interdisciplinary science efforts.

Purpose

The purpose of this workshop[2] was threefold: (1) identify the social, scientific, and administrative environments that lead to successful collaboration and integration; (2) develop a set of guiding principles for the conduct of integrated scientific endeavors; and (3) make recommendations to the U.S. Geological Survey and the scientific community at large on strategies to promote interaction and integration of disciplines (biological, physical, and social) for a more adequate understanding of complex natural systems.

There were 24 invited workshop participants with representation from government agencies, academia, and private industry. A list of participants is provided in Appendix 1. The first day of the workshop centered on:

- the need for the scientific community to more explicitly consider the integrated nature of both natural systems and modern environmental problems;
- scientists' perspectives on the challenges, obstacles, and opportunities for integrating the sciences;
- end-users' perspectives on the value of and need for synthesized, integrated information from the scientific community;
- lessons learned (see Appendix 2) from interdisciplinary projects presented through 6 case studies; and
- a look at the collaborative culture from a social scientist's perspective.

Day two focused on developing a set of guiding principles for integrated scientific efforts that emerged from the discussion on day one, and recommendations for USGS and the scientific community at large.

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[1] *This report was written by workshop staff, and is not intended to be a consensus document or a comprehensive workshop proceedings.*

[2] *Two previous workshops with the participation of the Ecological Society of America, the Geological Society of America, the Keystone Center, and the USGS identified new interdisciplinary research opportunities relevant to the mission of the USGS. Summary Reports of these two workshops are available through ESA by calling 202-833-8773.*

The Interdisciplinary Model

Operational definitions employed in this report are based on Gilbert, 1998[3] and a synthesis of discussions in the first day of the workshop by Gilbert, May and Marzolf. In this model, scientific endeavors are viewed on a continuum, moving from disciplinary to interdisciplinary, from depth to breadth, and from analytic to synthetic goals. Specifically:

- **Disciplinary science** may be characterized by *singular* efforts within a well-defined specialization. The goal of disciplinary science is a deep understanding of a single problem or a single aspect of a problem. Though a disciplinary effort may involve many scientists, and the scope of the analysis may be broad, it will still employ the methods and theories of a single discipline.

- **Multidisciplinary science** is *an additive* approach that combines the efforts of more than one discipline. Multidisciplinary efforts seek to combine the results of specialized, disciplinary approaches for a broader understanding of a problem or question. Cooperation among contributors is necessary.

- **Interdisciplinary science** is a *cumulative* approach that synthesizes the perspectives of the individual disciplines and integrates during all phases of the approach to a question or problem. It differs from multidisciplinary science in that integration is required. This may allow new questions to emerge as the problem is further defined. Consequently, the results of interdisciplinary efforts may be emergent as well. True collaboration, beyond mere cooperation, is essential to successful interdisciplinary science.

The potential similarities between interdisciplinary investigations and the systems they are trying to understand makes such approaches particularly attractive with respect to highly integrated, complex and dynamic natural and artificial systems.[4] Such systems often display behaviors that are difficult to predict due to interconnections across several spatial and temporal scales and between sub-systems that can span several disciplinary frameworks. Multidisciplinary efforts can begin to articulate the scales and disciplinary distribution of the problem at hand; interdisciplinary approaches are required to understand the relationships among the range of problem elements from the outset.

The best interdisciplinary science is still limited in its ability to yield fully predictive explanations. The necessary ambiguity of interdisciplinary explanations does not have to mean the absence of rigor. The depth and rigor of the participating disciplines is an integral feature of interdisciplinary science that helps offset the limitations in complex explanations. As the disciplinary breadth of our interdisciplinary efforts increases so too will our understanding of the inherent limits in predictability.   Including the social sciences and their methodologies dealing explicitly with ambiguity is an important feature of interdisciplinary science.

The nature of interdisciplinary science offers opportunities that may be exploited and capitalized upon to a

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[3] *Gilbert, L.E., 1998 "Disciplinary Breadth and Interdisciplinary Knowledge Production," Knowledge and Policy, Vol. 11 (in press).*

[4] *Simon, Herbert, 1996 "The Sciences of the Artificial,"* 3rd ed. Cambridge: The MIT Press, 231 pp.

greater degree than in either the disciplinary or multidisciplinary approaches. The results of workshop discussions suggest that interdisciplinary science offers the opportunity to:

1. **Exploit the attributes of the spatial and temporal continua.**

   Complex systems that occur at small scales and over short-time intervals are likely to yield more data, and therefore more statistically significant results and deeper understandings. At larger scales, over longer-time intervals, data are more inclusive and therefore results and explanations are likely to be broader and more complete.

2. **Exploit ambiguity**.

   Ambiguity can point to areas where additional research efforts will be most effective. Exploit institutional ambiguity--it may be an indication of a relaxation of constraints and it may suggest that innovative work can be done in the absence of a decree that it can't be done.

3. **Capitalize on social sciences in dealing with ambiguity.**

   The social sciences have a long history of working with uncertainty. Their models include "messy variables" associated with human behavior.

4. **Exploit disciplinary science.**

   Science has moved through an era of increasing specialization, yielding deep understandings and highly specialized methodologies. The goal of interdisciplinary science is not to undo history, but to build on the foundation that specialization provides. By doing so, and by honing our skills at synthesis, we can derive new, synthetic explanations and understandings that are critical to addressing complex questions and problems.

5. **Span the boundaries through collaboration.**

   Interaction among and across the disciplines can occur in any number of ways. There are a number of models that are practiced and shown in Appendix 3.

   The principals in a true collaboration represent complementary domains of expertise. As collaborators, they not only plan, decide, and act jointly, they also *think together*, combining independent conceptual schemes to create original frameworks. Also, in a true collaboration, there is a commitment to shared resources, power, and talent: no individual's point of view dominates, authority for decisions and actions resides in the group, and work products reflect a blending of all participants' contributions.[5]

In summary, we are looking for a willful redirection of our evolutionary trajectory as the greater community called SCIENCE. The following set of principles for the conduct of interdisciplinary science endeavors are offered to the science community for further discourse, debate, and refinement.

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[5] Minnis, M., John-Steiner, V.P., & Weber, R.J. 1994. Collaborations: Values, Roles, and Working Methods. Research proposal submitted in August, 1994 to the National Science Foundation.

PRINCIPLES

Interdisciplinary science seeks to:

recognize the interdependence of science and societal concerns,

value all disciplines (social and natural) and honor the validity of each other's work,

use approaches to understanding natural systems that are as integrative as natural systems are themselves,

illuminate the complexity and interdependency of the natural world,

develop rigor and breadth from the strengths of the participating disciplines,

provide an adaptable approach in which teams are organized explicitly to address scientific questions and/or societal concerns,

share common vision, authority, responsibility, accountability, trust, and ownership of the endeavor, and

provide a framework that can communicate knowledge and understanding in a relevant, timely, and accessible manner to society.

RECOMMENDATIONS

With the principles for interdisciplinary science as the foundation, the following recommendations are offered to the USGS and the broader scientific community as a means of "enhancing integrated science".

U.S. Geological Survey

- Alter the way scientific research is administered and supported. Initiate the process of integrating the organization and changing the budget structure to focus on issues rather than division or discipline lines. Establish an agency-wide multiyear budget. Uniform divisional overhead and cost accounting systems are essential for successful integration.

- Accelerate the establishment of issue oriented teams by setting aside a portion of the budget as venture capital for competition among interdisciplinary teams. Establish a fair and creative process to encourage teams to develop proposals for consideration. Reward teams, not individuals for the products these teams produce.

- Establish a panel of external advisors (drawn from the social, economic, political and scientific communities) to provide guidance to the Director for allocating resources to implement interdisciplinary scientific endeavors and fostering interdivisional research and collaboration. See diagram in Appendix 4.

- Continue to support the disciplines and other enabling sciences (including monitoring) that are the foundation for interdisciplinary/integrated efforts.

- Redesign the incentives and rewards system, including the Research Grade Evaluation Guide to: value collaborative, interdisciplinary scientific endeavors and reward teams; reward behaviors conducive to successful collaboration; reinvigorate the workforce in approaches to science through rotational assignments, sabbaticals, education and retraining; allow scientists to achieve potential in interdisciplinary science; and reward interdisciplinary scientific leadership.

- Fully utilize new means of communication (e.g., world wide web), to better link scientists within the USGS, to distribute agency products, and to enhance the relationship with local, regional, and national customers and obtain their feedback.

- Allocate time and resources to include the end user during the problem definition, planning and/or research design, and assessment phases of an interdisciplinary scientific endeavor.

Scientific Community at Large

- Identify new ways to communicate information — explicitly explore use of the World Wide Web. Increasingly there will be data sets produced through teams of people at various time/spatial scales that should be accessible and usable, locally, regionally, nationally, and globally.

- Develop Knowledge Maps. This recommendation is intended to result in a "Yellow Pages" of who is working on what where.

- Identify "Story Tellers" with credibility and charisma in the scientific community. These individuals should convey a sense of excitement and generate enthusiasm among scientists and the public for successful integrated scientific efforts. This recommendation is intended to begin to provide a history of experiences with the issues/questions investigated, who was chosen inside and outside science to participate, and what works and does not work in the interdisciplinary, collaborative environment.

- Promote and support sabbaticals/details/ exchanges within, between and among the academic, government and industry science institutions to encourage the exchange of thinkers, thinking and ideas. Constant cross-fertilization is viewed as opportunity to be productive scientifically in another environment. This kind of opportunity should be open to managers, technicians, etc. for as short a time as a week to a year or more.

- Stress the importance of cooperative integrated learning.

- Create a Presidential award to recognize a group doing integrated science that has had the greatest impact.

- Through community/town hall meetings learn about problems or what are perceived problems that need to be addressed.

Conclusion

The U.S. Geological Survey has the advantage of a broad range of programmatic scientific opportunities that require an interdisciplinary, integrated approach. The outcomes from this workshop, provide a number of suggested approaches that tackle the institutional and cultural adjustments needed to enhance the conduct of interdisciplinary science. The enthusiasm and interest of participants for future discussion will result in the establishment of a self-directed cohort group. Additionally, to sustain momentum, ideas for an action plan are offered in Appendix 5 to move forward in the community with continued debate, discussion, and finally implementation of workshop results and recommendations.

APPENDIX 1

Workshop Participants

Buckler, Denny R., U.S. Geological Survey
Casadevall, Thomas J., U.S. Geological Survey
Crow, Michael, Columbia University
De Cola, F. Lee, U.S. Geological Survey
Foley, Mary, National Park Service
Fontaine, Thomas D., South Florida Water Management District
Gerould, Sarah, U.S. Geological Survey
Hamilton, Pixie, U.S. Geological Survey
Howell, David G., U.S. Geological Survey
Jensen, Deborah, The Nature Conservancy
John-Steiner, Vera P., University of New Mexico
Kaplan, Joel, Appropriations Committee Staff, U.S. House of Representatives
Kennedy, Julie, Stanford University
Lane, H. Richard, National Science Foundation
Loveland, Thomas R., U.S. Geological Survey
Magnuson, John J., University of Wisconsin
McGregor, Bonnie A, U.S. Geological Survey
Okita, Patrick Masao, BHP Minerals
Poff, N. Leroy, Colorado State University
Prestegaard, Karen, University of Maryland
Rogers, Caroline S., U.S. Geological Survey
Shasby, Mark B., U.S. Geological Survey
Thomas, James P., National Oceanic and Atmospheric Administration
Wilson, Bruce, Minnesota Pollution Control Agency

Planning Group

Barber, Mary C., Ecological Society of America
Barnes, Peter B., U.S. Geological Survey
Crane, Michael, U.S. Geological Survey
Gilbert, Lewis, Columbia University
Hedin, Lars O., Cornell University
Hren, Janet, U.S. Geological Survey
Lauer, Donald T., U.S. Geological Survey
Marzolf, G. Richard, U.S. Geological Survey
May, Cathleen L., Geological Society of America
Muir, Thomas, U.S. Geological Survey
Sarewitz, Daniel, Columbia University
Stanley, Linda D., Ecological Society of America

APPENDIX 2

Summary of Lessons Learned and Participant Observations

Summary of Lessons Learned

From the presentations and discussions a number of lessons learned emerged. These focused on future demands on the scientific community, ingredients for successful collaborative efforts, hurdles to overcome, and the need to measure success.

C **Future Demands of the Scientific Community**

Science is increasingly required to take a more comprehensive approach in our understanding of natural systems, thereby seeking to link and integrate disciplines that have been traditionally separated. But interdisciplinary science is not easy to do, nor is it easy to manage. It is an evolution in the conduct of science. Opportunities must be made available where interdisciplinary science may be taught and is practiced. Strong disciplinary science will remain critical, and is necessary to rigorous integrated approaches.

C **Support Systems for Successful of Interdisciplinary Scientific Endeavors**

Working across, and integrating among, disciplines requires a support system that will promote and facilitate this type of scientific endeavor, including:

Leadership and management support -- a marriage of skills focused on "doing the right things" and "doing things right";

Building a "community" for collaborative science that includes new cohorts, networks, and mentorship;

An infrastructure that provides funding and funding pathways and other non-monetary resources;

Integration at all stages, especially early in the planning and/or research design phase; and

Adequate recognition and reward for individuals and groups.

Attributes of successful collaborators, whether they be individuals, groups, or institutions include:

Risk tolerant	Creative
Tenacious	Optimistic
Adaptive	Sharing
Trusting	

- **Hurdles or Impediments to Overcome or to Circumvent**

  Turfism
  Selfish (i.e., non sharing) behaviors
  Myopia (i.e., resistance to new ways of conceiving of problems/questions)
  Lack of common vocabulary
  Exclusivity (i.e., not including all relevant collaborators)
  Disincentives
  Inadequate recognition and reward systems out of alignment with institutional responsibilities
  Elitism

- **Evaluating Success in Integrating the Sciences**

  Integrated scientific endeavors result in generation of novel, inclusive interpretive frameworks that:

  - are adaptive, modifiable, and responsive
  - are explicit about their assumptions, completeness and reliability;
  - can incorporate new knowledge;
  - can be accessed and manipulated by others;
  - can generate a variety of predictive models and alternatives that can be evaluated in larger contexts (e.g., for use by decision makers**).**

<u>Participant Observations</u>

- "It is not science integration per se that we are after, rather it is field integration. Field is a pseudo name for a generalized area of work that draws from a range of disciplines to understand and solve a problem, e. g., ecosystem restoration."

- "Committed leadership is needed along with a willingness to experiment and fail."

- "Refocusing intellectually is a challenge to many scientists after investing their career in a narrow specialty."

- "The system's rules constrain the "willing". Younger scientists who are "willing" to take risks are often casualties along the way in fighting the system."

- "Leaders of an enterprise must be totally ecumenical. If one iota of preference for a field or approach is demonstrated, you are done as a leader."

- "Terms of reference for team leaders do not exist. It is very difficult to communicate across disciplines and terms of reference are needed to facilitate communication and the collaborative process. "

- "Put resources into team building. We need to find ways to work together."

- "We need to move away from the zero sum mentality. Change does not mean extinction."

- “Scientists must be taught to boundary span. We don’t know how to cross fields.”

- “We must be willing to let distinguished scientists of the past go if they are standing in the way of the enterprise and can block collective progress for 10-15 years. “

- “We need new methods for performance evaluation. You can’t expect a scientist to invest 5 years in a scientific endeavor and then at year 2 ask what contribution has been made to advance our basic knowledge.”

- “Administrative support is necessary for integrated teams.”.

- “Question everything--motivation, intention and agendas of team members.”

- “To undertake an integrated scientific endeavor you need reasons, resources, a leader, recognition, participants, opportunity, and power.”

- “Characteristics of successful team members: brightness, common sense, good training, creativity, trustworthiness, willingness to share, ability to give team time, respect for each other.”

- “There is a false dichotomy between applied and curiosity-driven research. Basic research questions are addressed in applied research endeavors. The differences between the two are in the approach, sampling and research design, and timing of various aspects of the study. The approach should be iterative in both cases. In the end, it is the results of research that are applied, not the approach, research and design.”

- “There is increasing demand for scientific information that is synthesized and integrated from across the relevant disciplines and available in an understandable form to address scientific, as well as public policy and private industry, decision making.”

- “Research, internships, and group problem-solving work in the university setting for teaching/learning about interdisciplinary approaches.”

- “The physical setting of the work environment is important to bringing people together.”

- “As the scope of any venture gets more complex, partnerships are an essential.”

- “Holistic data frameworks are better than reductionist ones and are more suitable to serving the needs of the various modeling regimes in different disciplines.”

- “Strong leadership is needed to unite science around issues rather than disciplines.”

- “Recognize differences in communication across disciplines, expand one’s view of the value of other disciplines to the scientific endeavor, and build on personal relationships.”

- “Reward systems are out of alignment with institutional goals--rewards are for doing it the same old way.”

APPENDIX 3

Hierarchy of Collaborative Patterns[6]

[6] Figure modified by Cathleen L. May, Ph.D. from John-Steiner, V.P. and Mahn, H. 1996. Sociocultural Approaches to Learning and Development: A Vygotskian Framework. *Educational Psychologist* 31(4), 191-206.

APPENDIX 4

Allocating Resources to Implement Interdisciplinary Scientific Endeavors

APPENDIX 5

Suggested Action Plan

Briefings:

- C Deliver Summary Report of Workshop Results to Director, USGS. Brief Director and others at USGS.
- C Develop a "Roadshow" using taped presentations from the Workshop on Enhancing Integrated Science, the Summary Report and give briefings at major USGS installations and universities. Make additional investment in "telling the story" by having presentations accompanied by one or more "cohorts" (workshop participant or planning group member).
- C Provide briefings, one on one for Federal Science Agency senior officials to talk about the results of the workshop and ways in which institutional collaborations can be enhanced.

Publications:

- C Publish Workshop Results via Ecological Society of America and Geological Society of America publications.
- C USGS Director submits Guest Editorial derived from the workshop results for publication in *Science.*

Electronic Communication

- C Establish USGS Website with a focus on the topic of Interdisciplinary Science using the results of the three workshops and linking the site to other related material and/or websites.
- C Fund a "history of integrated science" stories as a means of providing an educational tool containing lessons learned and post on USGS Integrated Science Website.
- C Post Summary Report of Workshop to INTEGRAT (electronic listserv). Appendix 6 contains a summary report of the listserv dialogue for September/October 1998.

Other

- C Capitalize on science society annual meetings, e.g., GSA, ESA, AGU, AASG, and schedule discussions, presentations, etc.of the principles.
- C USGS Director works with the Council of Science Society Presidents to promote discourse on the Principles for Integrated Science and ways that may foster greater acceptance and practice of integrated science.
- C Invite workshop participants to become members of a "group of cohorts" that continues to promote the dialogue and story telling about integrated science.

APPENDIX 6

Summary of INTEGRAT Discussion

The two day workshop on "Enhancing Integrated Science" was supplemented by an electronic dialogue to gather perspectives about integrated science from a wider range of interested parties than could be accommodated by the workshop. There are about 300 subscribers to the electronic dialogue. Topics covered in the dialogue included: Definition of Integrated Science, Education and Training, Ingredients for Success, Barriers to Success, and Integrated Science in Academia, Government, and Industry.

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The INTEGRAT Listserv was established in early September to encourage a dialog on integrated science. Subscribers to the listserv were asked to provide their perspective on the social, scientific, and administrative environments that lead to successful collaborative scientific efforts. Specifically, they were asked to address the kind of environment that must exist to encourage, facilitate, and validate the utility and advantages of interactions across the disciplines, including opportunities seized, challenges met and resolved, and barriers encountered with recommendations for their removal as they relate to the working environment:

- ADMINISTRATIVE (funding, facilities, staffing a project/program);
- CULTURAL (incentives, job security/advancement, management/supervisory support, senior leadership participation); and
- SCIENTIFIC (planning/problem definition, interaction with the policy maker/decision maker, interaction of disciplines, and publication/report of results).

INTEGRAT was advertised through the USGS homepage, the ESA homepage, and mailings to GSA membership and the ECOLOG-L listserv at the University of Maryland. INTEGRAT has attracted 300 subscribers, about 25% from the government science community.

Below is a summary of the discussion points raised on the INTEGRAT listserv and presented in five topical areas: definition, education and training, ingredients for success, barriers to success, and integrated science in academia, government, and industry.

DEFINITION: WHAT IS INTEGRATED SCIENCE?

There was discussion that "interdisciplinary" research is not just research conducted by coordinated groups of people with different disciplinary interests, but should be based on METHODS that integrate data from many different "disciplines" to make inferences about phenomena that are too broad to be explained by the usual scientific disciplines. Interdisciplinary research can be done by individuals or by groups, the difference is in the approach to research design and analysis. The point was raised that "interdisciplinary" should not refer to the expertise of the various people involved, but rather to the questions asked and the approach to answering them. One issue raised is that we often make "interdisciplinary" synonymous with "collaborative" or "multi-institutional" without necessarily realizing it.

The importance of synthesis was stressed. Teams may work in a coordinated fashion on disciplinary research or work together on interdisciplinary questions without ever developing interdisciplinary results because synthesis is never achieved.

A distinction was made between interdisciplinary research and integrated multidisciplinary research. Integrated multidisciplinary research is very synergistic--multiple disparate fields influenced by the multidisciplinary nature of the research, which is different from multidisciplinary problem-solving sessions where markedly different points of view of participants from diverse disciplines can result in important advances.

Another distinction was drawn between integrating the sciences and “solving a problem with an integrated approach involving many sciences.”

A comment was made that the true strength of interdisciplinary research is in the study of phenomena that occur at “real-world” scales and that relate to “real-world” issues.

The best integration involves constant interaction between long-term research and short-term problem solving, so they can motivate and help each other.

As the group began to define what “integrated science” was, they also identified the need to agree on a term to represent what they were defining. Some suggested terms included integrated science, and various combinations of integrated, interdisciplinary, multidisciplinary, and transdisciplinary science. A comment was made that “integrated science” seems to be the only term broad enough to include all of the ways of doing “integrated science.” Any other term is too restrictive, as well as cumbersome.

It was noted that integrated science should not be limited to “integrating the sciences,” but should include collaborations that create new ideas, research, problem-solving that isn’t trapped inside a disciplinary paradigm. It can involve conceptual breakthroughs that occur because disciplinary paradigms are broken down.

The term “integrated science” may be too limiting by restricting our attention to science. Projects addressing environmental problems involve a large science component, but also must include interaction with and integration of economic, social, psychological, political, demographic, etc. components as well. While it seems important to include these other disciplines, it of course makes “integrated science” even more difficult.

There are huge numbers of opportunities to work together and integrate the science we already have. What about all the things we could do with the tools already here if we only talked to the people who have them? Isn't this also integrated science?

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EDUCATION AND TRAINING

In terms of education, the point was made that we need to prepare scientists in a more integral way, i.e., each one must have a better knowledge of mathematics, physics, and some other area so a project can join people who will be prepared to better understand each other to develop an integral work. It is also important to develop new general theories to provide a common language and conceptualization that will link and relate different areas of knowledge. There is a need to develop a common vocabulary – putting aside the jargon and evolving a common dictionary. This (to some “metasciences”) will be transdisciplinary which is different from multi- or inter-disciplinary and being so they will touch several areas permitting new ways of study, very probably, nearer to nature than other approximations.

There was discussion as to how universities should train scientists to be able to tackle interdisciplinary problems. An example was given of the University of Virginia’s Environmental Sciences Department and its use of team teaching to train scientists and non-scientists alike to be able to work in integrated teams. Interdisciplinary training is helpful when it is focused on new scientific/technical skills and applications. “Problem-based” learning approaches fit well with training integrated scientists.

The question was raised about whether cross training of individuals is a necessary factor for success in integrated science. There was discussion of the need to broaden degree programs. A number of universities are offering courses that teach science across disciplines, and this should be encouraged in the high schools and middle schools. At the graduate level, more credence and encouragement should be given to theses/dissertations that cross disciplines and include advisors from different departments. It was suggested that all students should have broader scientific training, in addition to their discipline-specific training, as well as courses in history and philosophy of science. Adding a couple of well designed courses to open students up to the advantages of collaboration could help them make their own projects more approachable.

There was discussion as to whether people with interdisciplinary degrees will have difficulty finding jobs either within academia or outside it. A comment was made that at least in the beginning, students with broad interdisciplinary degrees will fare poorly in the job market, especially in academia where departments tend to look for people to fill definite niches in departmental structure. A response noted that a number of graduates with interdisciplinary degrees were getting the "best" jobs, at least in the area of global change ecology.

The comment was made that those with interdisciplinary degrees will fare poorly with the government until the folks who classify jobs and assign scores based on application forms have revised criteria.

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INGREDIENTS FOR SUCCESS

There seemed to be agreement that successful interdisciplinary research often has the key ingredient of focus on a scientific question of interest to scientists from different disciplines. Furthermore, the scientists interested in the question recognize that an answer or answers to the question requires examination by a variety of disciplines. The incentive to work together is the challenge of finding answers to an interesting scientific question. The reward is actually finding some answers to the question. Synergy between people having different specialized skills produces breakthroughs when needed to achieve the common goal.

If a team is already interdisciplinary, or, for that matter, if an investigator is, then the tendency to look outside a single discipline is built in. If the team is all from the same discipline, then it is a bold thinker indeed who introduces ideas from the outside world.

One key element to doing multidisciplinary integrated research is to form a team of scientists of markedly different disciplines (e.g., soil scientist, physiologist, vertebrate ecologist, mycologist, etc.) that are not in intellectual or disciplinary competition but rather in collaboration that benefits from disparate viewpoints. In such endeavors, a number of elements are necessary for success:

1. Each scientist must be committed fully enough so that his or her career goals depend on success.

2. The research problem must be a pressing, multidisciplinary one--one whose solution can bring substantial recognition to the individual scientists and the team.

3. The team must have a common view of the problem and set goals (and obtain funding) that all agree will lend themselves to timely solution of the problem.

4. There must be congruence in time and space, experimental design and sampling plan, and scale of effort for synergy to emerge.

5. There must as part of the team be a statistician and statistical staff that participate fully and that have the capacity to serve all the data processing, archiving, and analytical needs in a timely

manner.

The importance of a project leader to prioritize the goals of the group and the project was stressed. Few scientists volunteer for this role because it involves more administration and one can get distanced from the practical aspects of scientific study (fieldwork, labwork, etc- which often were the initial attraction to get involved in science). Furthermore, few scientists today have the breadth of knowledge and training, and imagination, to understand all aspects of a multidisciplinary study, and so can conceptualize and lead a multidisciplinary team. And this is precisely why graduate (or other) training needs to incorporate across-the-discipline training and integration, and explicit team participation. Even if leadership can't be taught (?), this at least gives talented people with potential the right experience and increases the likelihood that they'll play a leadership role later.

Team "leadership" consists of 1 - having good ideas, interesting questions in mind, and vision 2 - realizing that multiple kinds of expertise are needed, 3 - knowing who to call, 4 - having the interpersonal skills (personality?) to get others involved VOLUNTARILY, 5 - having the humility to work with really good people who do different things, 6 - having enough familiarity with other disciplines to be able to communicate with them, and 7 - having willingness to make the non-research effort to keep everyone on the bus. You can see that some of these things can be taught (e.g., in grad school), some can be encouraged, and some are just, well, inherent.

The personalities of the individuals involved seems to be a play a key role in the success or failure of interdisciplinary projects. Some people like and thrive in these kinds of projects and others do not. When we assign teams we may be trying to put a square peg in a round hole, but when teams form naturally, through mutual interest and mutual respect, the outcome is often good. Working on integrated projects means mastering tough problems while being sensitive and skillful in questions of turf. A key ingredient for an integrated team is strong and diverse CORE skills and experience.

There was discussion regarding how the natural formation of teams can be encouraged and supported and ways to increase the likelihood of success of teams, which for a number of reasons, are assigned.

The suggestion was made that if you create the right kind of environment, the right people will be drawn to it. However, the point was made that as new people come into the environment, it will change. Teams formed to address multi-disciplinary problems should be temporary. Such agglomerations are better between institutes rather than creating an institute for the purpose, which might outlive its purpose. Teams must be able to change as the problem changes or new problems are addressed.

Another comment on the process of integrating science on the team level, suggested that it is important for each member of an inter-disciplinary team to expose issues to his/her peers in that discipline in a timely manner. This could provide a peer review in a dynamic manner to minimize or eliminate the potential problem of the rest of the team basing research on improper assumptions, methods, and theories.

There seem to be some differences as to how teams are formed—formal assignment of teams to address a problem vs. the serendipitous coming together of interested colleagues. In this world with demands to solve complex problems in short time frames, it may not always be possible to wait for the establishment of self-generated collaborations. Knowledge maps, showing what people are actually doing, may help us understand the formation of ad hoc teams.

In forming a team, the best success would come from choosing the team leader, and letting him/her find the team. Assigned teams do not work. Assigned teams do NOT attract top talent, they do NOT motivate people to do their best, and they do not have the problem-solving productivity of teams that come together because people WANT to be on board. The best teams come together when one or two people want to answer a question, find others who agree, and they agree to work together - voluntarily. However, it was noted that it would work fine to have a team that has been thrown together if the members become curious about what they are supposed to investigate. If they simply resent the demands on their time, it will not be successful.

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BARRIERS TO SUCCESS

Barriers to success identified during the discussion included funding, the emphasis on single author publications, and management's lack of understanding of the need to take a broad interdisciplinary approach to problem solving.

Funding barriers result from no one entity being responsible for interdisciplinary funding and the reluctance of disciplinary bodies to fund "on-the-edge" work.

Many institutions place an emphasis on single author publications as their reward structure. This discourages scientists from tackling projects that would require an interdisciplinary team. Also, there are not as many outlets to publish interdisciplinary work.

In the Columbia River example a major barrier that had to be overcome was management not really understanding the breadth of the problem. Scientists from different disciplines had to find ways to breach this barrier before moving forward with the project.

In addition to barriers caused by funding, institutional walls, and management (poor and micro), a problem faced in assembling a successful team is egos. The right people can work to overcome the other barriers, so it is important to get the right people together.

Reluctance to join a team may be tied to the inertia that comes with more people—the "too many cooks" theory. When research involves management regulations or policies there is an additional source of inertia

Some suggested ways of overcoming some of the barriers to success can include:

1) providing funding to address environmental problems in an integrated fashion
2 ignoring barriers or working around them
3) creating an encouraging managerial structure with the will and funding to support integrated projects

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INTEGRATED SCIENCE IN ACADEMIA, GOVERNMENT, AND INDUSTRY

There was discussion as to whether integrated science means something different in academia, government, and other scientific communities that makes it difficult for conversations on integrated science. The reason behind this is likely to be that the goals, objectives, and time frames are often quite different. These communities can help each other by sharing what works and seeing what translates.

Government, as an end user, needs to consider more variables including social, political, life, and physical sciences. Government is an appropriate forum for integrated science because, while burdened with bureaucratic divisions, it's less constrained by the antiquated divisions of the academy. People are being encouraged to collaborate with others outside of their organizations, and at the USGS at least this seems to help.

Academia is organized along disciplinary lines; the handling of grant funds, the supervision of graduate students, the hiring of new faculty are all organized within the disciplines. Any project involving more than one discipline must inevitably run into problems in these, and many other areas. Usually such projects are handled by the creation of a super-entity which exists just to run this project. It is also usually in conflict with the regular departments wherever the needs of the project come into conflict with the normal functioning of the department (which is almost everywhere). It is hardly likely that any academic structure would include the social and political sciences along with the life and physical sciences. Even on campus, the social and political types and the life and physical science types have little to say to each other. Try telling a physical scientist that the obviously right thing to do cannot be done for political reasons.

In government, as well as in some research institutes, reorganization is often a way of life, with new entities coming into being and fading away almost as regularly as the fashions. Under these conditions, the formation of interdisciplinary groups is not notably more difficult than the formation of any others. Of course, what the scientists in these groups do often doesn't change very much, no matter what the group may be called this year, but under these conditions the scientists are not overly sympathetic to the rigidity of the academic structures.

There was discussion as whether experiences of teams are different between those in which collaborators identify an idea/problem and go about finding funding (via grants, etc.) and those in which a funding agency simultaneously gives a group an idea/problem and the money to solve it, as often happens in government, consulting, and industry. In the first they want to know the answers badly enough to put in quite a lot of work etc. and so are more likely to participate and carry through. The second can be difficult if the group does not see the problem the same way as the funding agency, or has different assumptions or different endpoints in mind. Framing the questions is one of the most important parts!

The USGS seems to have had some success focusing on regions (Yellowstone, SF Bay, South FL). Given government's role as steward of large pieces of land, this model works.

When a funding agency gives a group a problem to solve, the solution is pre-ordained; it is the route to the solution which is sought. The route may provide surprises along the way, but if you want a cure for AIDS, a vaccine against the common cold will not be a satisfactory solution. This is even more the case with consultants and industry. Successful consultants do not very often come up with solutions which are unsatisfactory to their clients, not if they want to stay in business. This may mean applying a heavy sugar coating to an otherwise distasteful (to the client) dose of facts.

The research group finding its own problem is typically looking at a much more open-ended system. While cures for cancer and Nobel prizes would be nice, most are more realistic than that and would be satisfied with interesting problems, ingenious solutions, and enough publications to guarantee continued funding at a decent level. In the beginning, the group may have had a particular end in mind, but if the research leads off in another direction, they will not necessarily consider it to have failed.

A comment was made that we need to look at some important parallels in problem resolution and product development in industry. Many major corporations that have science and technologically related goals must pursue them across disciplines. Examples include oil companies and pharmaceutical companies. Many federal governmental agencies are feeling pressure to adopt parts of the private model. They have to provide tangible benefits to public and private users with a cross-cutting grasp of the economic and social realities. Private market models and short-term competitiveness shouldn't completely control thinking - or we'd have no permanence and stability in government agency services to society. But private industry experience and case examples should occupy a place in discussions regarding integrated science. However, industry (and other forms of applied research or research application) has short-term goals which may not be an appropriate model for many other endeavors.

A business is task directed and typically bureaucratic. It encourages specialization, because if you cross lines, you're making a political mistake. There's plenty of incentive to cross lines in academia. One is that it's harder to work on a team without learning what other scientists are actually doing, and they won't be nearly as offended if one does take an interest.

There are factors encouraging the growth of interdisciplinary research institutions and projects, such as several at Columbia University (CERC, the Earth Institute, Biosphere 2, etc.). For one thing, as funding and jobs diminish, scientists have to share resources, which leads to labs and observatories outside a university on which people work together and share time. For another, grants often favor institutions rather than studies. But also scientists have inherently interdisciplinary problems and are paid to be creative about work.

Academics have to teach, which means becoming quasi-experts in things outside one's research. I edited an astronomy textbook in which the chapters on the planets got way out of hand, because the author, a cosmologist, had never thought about them before and was intrigued. And since students are ordinary citizens who may not take another science course, no wonder that helps teachers already interested in policy implications of geology and earth-systems themes.