Kates, R.W. with National Academies Committee on Facilitating Interdisciplinary Research, 2005. Facilitating Interdisciplinary Research, National Academy Press.

# 10

# Findings and Recommendations

his chapter contains the committee's findings and recommendations, which have been gathered here from the foregoing chapters.

#### **FINDINGS**

#### Definition

1. Interdisciplinary research (IDR) is a mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of research practice.

#### **Current Situation**

- 2. IDR is pluralistic in method and focus. It may be conducted by individuals or groups and may be driven by scientific curiosity or practical needs.
- 3. Interdisciplinary thinking is rapidly becoming an integral feature of research as a result of four powerful "drivers": the inherent complexity of nature and society, the desire to explore problems and questions that are not confined to a single discipline, the need to solve societal problems, and the power of new technologies.

At a variety of academic institutions, the number of departments has increased steadily over the last century, from about 20 in 1900 to between 50 and 110 in 2000.¹ National professional societies have also increased in number from 82 in 1900 to 367 in 1985.² Although those changes may appear to indicate increasing specialization, the increase in new departments and societies primarily reflects a blending of previously distinct fields to produce new areas such as biophysics and biochemistry and, more recently, neuroscience and photonics.

4. Successful interdisciplinary researchers have found ways to integrate and synthesize disciplinary depth with breadth of interests, visions, and skills.

Studies of expertise have shown that perception and understanding of a given task or problem depends on the knowledge a person brings to a situation.<sup>3</sup> A challenge in interdisciplinary work is to develop expertise in more than one area. Among the respondents to the committee's survey, 94% of whom were at least partially involved in IDR, clear strategies to obtaining discipline-spanning expertise emerged. Over half indicated that after developing expertise in one field, they had sought training in additional fields through postdoctoral fellowships, additional advanced degrees, or day-to-day interactions with researchers in different fields to participate in interdisciplinary projects. These strategies were reflected in the top recommendations respondents made for institutions, principal investigators, postdocs and students: foster a collaborative environment (26 percent), build a network with other researchers (20 percent), find a postdoctoral appointment in a different field (13 percent), seek additional mentors (12 percent), cross boundaries between fields (25 percent) and at the same time develop a solid background in one discipline (12 percent).

5. Students, especially undergraduates, are strongly attracted to interdisciplinary courses, especially those of societal relevance.

For example, at Harvard University, the number of undergraduate joint concentrations in chemistry and physics has risen from 14 to 45 over the last 15 years. There has been large-scale growth at Columbia College since 1993 in majors and concentrations in interdisciplinary departments and interdepartmental programs. At Stanford University, a multiyear decline in the number of students majoring in earth science was reversed when the

<sup>&</sup>lt;sup>1</sup>See Figure 1-1.

<sup>&</sup>lt;sup>2</sup>See Figure 7-1.

<sup>&</sup>lt;sup>3</sup>National Research Council. How People Learn. Brain, Mind, Experience, and School. Washington, D.C.: National Academy Press. 2000.

major was changed from the single discipline of geology to the interdisciplinary "earth systems."

6. The success of IDR groups depends on institutional commitment and research leadership. Leaders with clear vision and effective communication and team-building skills can catalyze the integration of disciplines.

In the committee's survey, the top recommendation for principal investigators was to lead research teams in a way that is supportive of IDR (44 percent). Respondents also recommended that departments develop new organizational approaches permissive to IDR (32 percent).

## Challenges to Overcome

7. The characteristics of IDR pose special challenges for funding organizations that wish to support it. IDR is typically collaborative and involves people of disparate backgrounds. Thus, it may take extra time for building consensus and for learning of methods, languages, and cultures.

In the committee's survey, researchers' top three recommendations for institutions, project leaders, principal investigators, educators, postdoctoral scholars, and students focused on enhancing communication between researchers. Over 20 percent of the respondents stated specifically that principal investigators and postdocs need time to develop effective networks and research strategies.

8. Social-science research has not yet fully elucidated the complex social and intellectual processes that make for successful IDR. A deeper understanding of these processes will further enhance the prospects for creation and management of successful IDR programs.

## Changes Needed

9. In attempting to balance the strengthening of disciplines and the pursuit of interdisciplinary research, education, and training, many institutions are impeded by traditions and policies that govern hiring, promotion, tenure, and resource allocation.

In the committee's informal survey of those attending its workshop on IDR, 72 percent of respondents reported impediments to IDR at their institutions. Among researchers, the most common were promotion and tenure criteria (18 percent) and budget control (16 percent). Among provosts

responding to the survey, the most common impediments were tenure and promotion criteria (19 percent) and space allocation (19 percent).

10. The increasing specialization and cross-fertilization in science and engineering require new modes of organization and a modified reward structure to facilitate interdisciplinary interactions.

In the committee's survey, the top recommendation for academic departments was to create and emphasize new organizational approaches, such as (1) hiring strategies and practices and (2) physical and personnel networks conducive to interdisciplinary exchange.

- 11. Professional societies have the opportunity to facilitate IDR by producing state-of-the-art reports on recent research developments and on curriculum, assessment, and accreditation methods; enhancing personal interactions; building partnerships among societies; publishing interdisciplinary journals and special editions of disciplinary journals and promoting mutual understanding of disciplinary methods, languages, and cultures.
- 12. Reliable methods for prospective and retrospective evaluation of interdisciplinary research and education programs will require modification of the peer-review process to include researchers with interdisciplinary expertise in addition to researchers with expertise in the relevant disciplines.
- 13. Industrial and national laboratories have long experience in supporting IDR. Unlike universities, industry and national laboratories organize by the problems they wish their research enterprise to address. As problems come and go, so does the design of the organization.
- 14. Although research management in industrial and government settings tends to be more "top-down" than it is at universities, some of its lessons may be profitably incorporated into universities' IDR strategies.
- 15. Collaborative interdisciplinary research partnerships among universities, industry, and government have increased and diversified rapidly. Although such partnerships still face significant barriers, well-documented studies provide strong evidence of both their research benefits and their effectiveness in bringing together diverse cultures.

## RECOMMENDATIONS

The committee's recommendations are listed here primarily by category of stakeholders in interdisciplinary research and education. The recommendations are based on the committee's deliberations and suggestions

from convocation participants (students, researchers, academic and non-academic institutional leaders, funding organizations, and professional societies) the focus groups held at the Keck Futures Symposium, interviews with leading scholars, and responses to committee's surveys.

In each of the committee's category of pertinent stakeholders, general recommendations are presented in bold-face type. These are intended as guidelines or objectives derived from the findings of this study, and they are followed by suggestions of ways to implement them. The suggested actions, based on real examples and experiments summarized in the foregoing chapters, are intended not as prescriptions but as "templates" for people or organizations to adapt according to their particular situations and the availability of resources. The relatively large number of these actions is intended to indicate the diversity of possibilities.

The committee hopes that these templates will help people and organizations to design their own strategies, whether they are ready to act now or after months or even years of study and fund-raising. The committee also hopes that the results of this study provide convincing evidence both of the value of interdisciplinarity and of the urgent need to revise some traditions in academic, funding, and professional organizations in order to promote IDR.

## Students

S-1: *Undergraduate students* should seek out interdisciplinary experiences, such as courses at the interfaces of traditional disciplines that address basic research problems, interdisciplinary courses that address societal problems, and research experiences that span more than one traditional discipline.

For example, students can

- Begin preparation for IDR through an IDR project or summer IDR experience.
- Approach interdisciplinarity by first gaining a solid foundation in one discipline and then adding disciplines as needed. Additional courses provide opportunities to understand the culture of other disciplines, gain new skills and techniques, and network with other researchers.
  - S-2: *Graduate students* should explore ways to broaden their experience by gaining "requisite" knowledge in one or more fields in addition to their primary field.

For example, graduate students can

- Do this through master's theses or PhD dissertations that involve multiple advisers in different disciplines.
  - Share an office with students in other fields.
- Enhance their interdisciplinary expertise by participating in conferences outside their fields and in poster sessions that represent multiple disciplines. Those venues provide opportunities for junior researchers to present their work to colleagues outside their fields.

## Postdoctoral Scholars

P-1: Postdoctoral scholars can actively exploit formal and informal means of gaining interdisciplinary experiences during their postdoctoral appointments through such mechanisms as networking events and internships in industrial and nonacademic settings.

For example, postdoctoral scholars can

- Seek formal and informal opportunities to communicate with potential research collaborators in other disciplines and develop a network of interdisciplinary colleagues.
- Broaden their perspective through internships in industrial settings or other nonacademic settings.
  - P-2: Postdoctoral scholars interested in interdisciplinary work should seek to identify institutions and mentors favorable to IDR.

For example, postdoctoral scholars can seek positions at institutions that

- Have strong interdisciplinary programs or institutes.
- Have a history of encouraging mentoring relationships across departmental lines.
- Offer technologies, facilities, or instrumentation that further one's ability to do IDR.
- Have researchers and faculty members with whom the postdoctoral scholar interacts place a high priority on shared interdisciplinary activities.

## Researchers and Faculty Members

R-1: Researchers and faculty members desiring to work on interdisciplinary research, education, and training projects should immerse themselves in the languages, cultures, and knowledge of their collaborators in IDR.

For example, researchers and faculty members can

- Develop relationships with colleagues in other disciplines.
- Learn more about the knowledge and culture of other disciplines by participating in interdisciplinary projects.
- Actively seek opportunities to teach classes in other departments and give papers at conferences outside their own disciplines or departments. In their written and oral communications, researchers and faculty members can facilitate IDR by using language that those in other disciplines are able to understand.
- Mentor students and postdoctoral scholars who wish to work on interdisciplinary problems.
  - R-2: Researchers and faculty members who hire postdoctoral scholars from other fields should assume the responsibility for educating them in the new specialties and become acquainted with the postdoctoral scholars' knowledge and techniques.

For example, researchers and faculty members can

- Familiarize themselves with the research cultures and evaluation methods of the postdoctoral scholars' fields.
- Learn about the career expectations of the postdoctoral scholars, when possible, and the demands that they will encounter in their careers.
- Guide the postdoctoral scholars toward interdisciplinary learning opportunities, including workshops, research presentations, and social gatherings.

#### Educators

A-1: Educators should facilitate IDR by providing educational and training opportunities for undergraduates, graduate students, and post-doctoral scholars, such as relating foundation courses, data gathering and analysis, and research activities to other fields of study and to society at large.

For example, educators can

- Provide training opportunities that involve research, data-gathering, data analysis, and interactions among students in different fields.
- Demonstrate the power of interdisciplinarity by inviting IDR speakers, providing examples of major discoveries made through IDR, and highlighting exciting current research at the interfaces of fields.

- Encourage a multifaceted, broadly analytical approach to problem-solving.
- Include as part of foundation courses (such as general chemistry) materials that show how the subjects are related to other fields of study and to society at large.
- Show through explanatory examples the relevance of IDR to complex societal problems, which often require multiple disciplines and challenge current scientific and technical methods.
- Discourage the notion that some disciplines rank higher than others.
- Create more opportunities for students to learn how research disciplines complement one another by
- Developing policies and practices that support team teaching of interdisciplinary courses by faculty members in diverse departments or colleges.
- Modifying core course requirements so that students have more opportunities to add breadth to their study programs.
- Provide team-building and leadership-skills development as a formal part of the educational process.

#### **Academic Institutions' Policies**

I-1: Academic institutions should develop new and strengthen existing policies and practices that lower or remove barriers to interdisciplinary research and scholarship, including developing joint programs with industry and government and nongovernment organizations.

- Provide more flexibility in promotion and tenure procedures, recognizing that the contributions of a person in IDR may need to be evaluated differently from those of a person in a single-discipline project. Institutions could
- Establish interdisciplinary review committees to evaluate faculty who are conducting IDR.
- Extend the venue for tenure review of interdisciplinary scholars beyond the department.
- Increase recognition of co-principal investigators' research activities during promotion and tenure decisions.
- Develop mechanisms to evaluate the contribution of each member of an IDR team.
- Establish institutional advisory committees of researchers successful in IDR to evaluate new proposals prior to implementation.

- Require regular reviews of IDR centers and institutes and establish sunset provisions, where appropriate, when they are initiated.
- Give high priority to recruitment of appropriate faculty and other researchers whose focus is interdisciplinary; this can be accomplished in part by allocating substantial resources to centrally funded, multidepartmental hiring of faculty and postdoctoral scholars and admission of graduate students.
- Coordinate hiring across departments and centers to maximize collaborative research and teaching possibilities.
  - Develop joint IDR programs and internships with industry.
  - Allow for the longer startup time required by some IDR programs.
- Gather information about the extent, quality, and importance of IDR in the institution and make the information available to faculty.
- Provide mechanisms to build a community of interdisciplinary scholars across the institution similar to the community that is in a department.
  - I-2: Beyond the measures suggested in I-1, institutions should experiment with more innovative policies and structures to facilitate IDR, making appropriate use of lessons learned from the performance of IDR in industrial and national laboratories.

- Experiment with alternatives to departmental tenure through new modes of employment, retention, and promotion.
- Selectively apply pooled faculty lines and funds available for startup costs for new faculty toward recruitment of faculty with interdisciplinary interests and credentials.
- Experiment with administrative structures that lower administrative and funding walls between departments and other kinds of academic units.
- Create laboratory facilities with reassignable spaces and equipment for people performing IDR.
- Create specific IDR grants and training programs for distinct career stages to assist in learning new disciplines and participating in IDR programs.
- Create mechanisms to fund graduate students and postdoctoral scholars whose research draws on multiple fields and may not be considered central to any one department.
- Develop a process for dealing with intellectual-property allocation that is consistent with encouraging IDR.
  - Increase "porosity" across organizational boundaries by

- Encouraging joint recruitment and appointment of faculty through resources available centrally.
- Creating competitive internal leave for study in a new discipline, allowing faculty to take courses, training, and additional advanced degrees in their own universities.
- Encouraging departments and colleges to work with IDR centers and institutes in hiring faculty with interdisciplinary backgrounds.
  - Providing fellowships that are portable within the institution.
- Allowing courtesy appointments that recognize interactions and collaborations across departments but that do not have the formal split responsibility of a joint appointment.
- Placing departments near one another to take advantage of their potential for fruitful interdisciplinary collaborations.
  - I-3: Institutions should support interdisciplinary education and training for students, postdoctoral scholars, researchers, and faculty by providing such mechanisms as undergraduate research opportunities, faculty team-teaching credit, and IDR management training.

Such education and training could cover interdisciplinary research techniques, interdisciplinary team management skills, methods for teaching nonmajors, etc. For example, institutions can

- Provide more opportunities for undergraduate research experiences.
- Allow faculty to receive full credit for team teaching in interdisciplinary courses.
- Encourage multiple mentors for students and pairing of appropriate senior interdisciplinary faculty with junior faculty interested in IDR.
- Provide opportunities (such as sabbaticals) for students and faculty members to learn the content, languages, and cultures of disciplines other than their own, both within and outside their home institution.
- Support formal programs on the management of IDR programs, including leadership and team-forming activities.
  - I-4: Institutions should develop equitable and flexible budgetary and cost-sharing policies that support IDR.

- Streamline fair and equitable budgeting procedures across department or school lines to allocate resources to interdisciplinary units outside the departments or schools.
- Create a campuswide inventory of equipment to enhance sharing and underwrite centralized equipment and instrument facilities for use by IDR projects and by multiple disciplines.

- Credit a percentage of a project's indirect cost to support the infrastructure of research activities that cross departmental and school boundaries.
  - Allocate research space to projects, as well as departments.
- Deploy a substantial fraction of flexible resources—such as seed money, support staff, and space—in support of IDR.

## **Team Leaders**

T-1: To facilitate the work of an IDR team, its leaders should bring together potential research collaborators early in the process and work toward agreement on key issues.

For example, team leaders can

- Catalyze the skillful design of research plans and the integration of knowledge and skills in multiple disciplines, rather than "stapling together" similar or overlapping proposals.
- Establish early agreements on research methods, goals and timelines, and regular meetings.
  - T-2: IDR leaders should seek to ensure that each participant strikes an appropriate balance between leading and following and between contributing to and benefiting from the efforts of the team.

For example, leaders can

- Help the team to decide who will take responsibility for each portion of the research plan.
- Encourage participants to develop appropriate ways to share credit, including authorship credit, for the achievements of the team.
  - Acquaint students with literature on integration and collaboration.
  - Provide adequate time for mutual learning.

## **Funding Organizations**

F-1: Funding organizations should recognize and take into consideration in their programs and processes the unique challenges faced by IDR with respect to risk, organizational mode, and time.

For example, funding organizations can seek to

• Ensure that a request for proposals does not inadvertently favor funding a single-discipline project over an IDR project; for example, by including limitations on funding amounts, duration of funding (successful

IDR teams often take longer to build and to coalesce), scope, and allowable travel and other budget items, all of which would militate against IDR.

- Develop funding programs specifically designed for IDR, for example, by focusing research around problems rather than disciplines.
- Provide seed-funding opportunities for proof-of-concept work that allows researchers in different disciplines to develop joint research plans and to perform initial data collection or for new organizational models or project approaches that enable IDR.
- Have support for universities to provide shared research buildings, large equipment, or specialized personnel (machinists, glassblowers, and computer and electronic technicians).
- Provide funding mechanisms that allow researchers to obtain training in new fields.
- Fund programs of sufficient duration to allow for team-building and integration of research efforts.
- Provide funding mechanisms that facilitate universities working together (including those from different countries) to address societal problems each would be challenged to address alone.
- Develop mechanisms for budgetary flexibility in long-term, multiinstitutional grants.
- Acknowledge, for projects that require more than a single principal investigator (PI), the equal leadership status of multiple PIs when "co-PI" is ambiguous.
- Remove administrative barriers to, and explicitly encourage, partnerships between universities, industry, and federal laboratories to facilitate IDR.
  - F-2: Funding organizations, including interagency cooperative activities, should provide mechanisms that link interdisciplinary research and education and should provide opportunities for broadening training for researchers and faculty members.

They can

- Require institutions that receive IDR funding to demonstrate support for interdisciplinary educational activities, such as team teaching.
- Provide, to the extent allowed by the funding organization's mission and guidelines, special grants to support interdisciplinary teaching.
- Designate funds for IDR meetings that encourage interaction between researchers in different disciplines so they can learn about the research in other fields and network with other researchers with whom they might collaborate.
- Support sabbaticals and leaves of absence for studies that focus on interdisciplinary scholarship.

- Ensure that their staff is knowledgeable about interdisciplinarity.
- F-3: Funding organizations should regularly evaluate, and if necessary redesign, their proposal and review criteria to make them appropriate for interdisciplinary activities.

For example, funding organizations can

- Develop criteria to ensure that proposals are truly interdisciplinary and not merely adding disciplinary participants.
- Encourage IDR proposals that fall within the compass of the organizations' overall missions even if they cross internal organizational boundaries or do not fit specific (review) divisions.
- If they are organized along disciplinary lines, develop policies and practices for funding research that may have a major impact on research in other disciplines, for example, by awarding a mathematics section grant to a mathematician to work on a life-sciences project.
  - F-4: Congress should continue to encourage federal research agencies to be sensitive to maintaining a proper balance between the goal of stimulating interdisciplinary research and the need to maintain robust disciplinary research.

## **Professional Societies**

PS-1: Professional societies should seek opportunities to facilitate IDR at regular society meetings and through their publications and special initiatives.

For example, they can

- Include IDR presentations and sessions at regular society meetings by
- Choosing IDR topics for some of the seminars, workshops, and symposia.
- Promoting networking and other opportunities to identify potential partners for interdisciplinary collaboration.
  - Cohosting symposia with other societies.
- Holding workshops on communication skills, leadership, consensus-building, and other skills useful in leading and being part of IDR teams.
  - Establish special awards that recognize interdisciplinary researchers.
- Sponsor lectureships that bring recognition of the value of interdisciplinary experience.

- Prepare glossaries, primers, tutorials, and other materials to assist scientists in other fields who wish to learn new disciplines.
- Create sections, divisions, or boards that represent interdisciplinary aspects of their fields.

## **Journal Editors**

J-1: Journal editors should actively encourage the publication of IDR research results through various mechanisms, such as editorial-board membership and establishment of special IDR issues or sections.

In particular, journal editors can

- Increase the exposure of IDR by devoting special issues or sections to specific IDR directions in a field and accepting more research papers that introduce new IDR areas.
- Add researchers with interdisciplinary experience to editorial boards and review panels and develop specific techniques for evaluating interdisciplinary submissions.
- Consider whether their publications' guidelines for authorship and submission of manuscripts are appropriate for IDR.
- Take steps to improve the sharing of knowledge between disciplines by publishing
  - Comprehensive review articles on related disciplines.
- Overview articles on fields relevant to published interdisciplinary works.
  - A list of the fields covered in interdisciplinary research papers.
- Hyperlinked text in papers directing on-line readers to discipline-specific educational resources.
- Create subscription models based on article title and subject rather than journal title to enhance cross-discipline access.

## **Evaluation of IDR**

E-1: IDR programs and projects should be evaluated in such a way that there is an appropriate balance between criteria characteristic of IDR, such as contributions to creation of an emerging field and whether they lead to practical answers to societal questions, and traditional disciplinary criteria.

For example, organizations that review IDR can measure

• The degree to which IDR contributes to the creation of an emerg-

ing field or discipline; emerging fields have included nanoscience and nanotechnology and cognitive science.

- How well IDR enhances the training of students and the careers of researchers in ways that surpass the results expected from disciplinary research; these might include employment in a broader array of positions, more rapid progress in gaining tenure and other goals, and greater numbers of speaking invitations.
- Whether the research leads to practical answers to societal questions; for example, an IDR effort to reduce hunger should produce some measurable progress toward that goal. The same IDR program might produce additional outcomes of value, including basic research, that were not expected.
- Whether participants demonstrate an expanded research vocabulary and abilities to work in more than one discipline.
- The extent to which IDR activities, institutes, or centers enhance the reputation of the host institutions; reputation can be measured in research funding, external recognition of IDR leadership, awards, and recognition of participants in the research.
- The long-term productivity of a program; not all initiatives will have the same lifetime, and the use of "sunset" provisions should be considered in the planning of IDR centers and programs.
- Adopt multiple measures of research success, as appropriate to the fields being evaluated, such as conference presentations or patents in addition to publication in peer-reviewed journals.
  - E-2: Interdisciplinary education and training programs should be evaluated according to criteria specifically relevant to interdisciplinary activities, such as number and mix of general student population participation and knowledge acquisition, in addition to the usual requirements of excellence in content and presentation.

For example, organizations reviewing interdisciplinary education and training programs can begin with such criteria as the following, to be supplemented with others appropriate to the organizations' missions:

- Are interdisciplinary courses attracting more of the general student population to science and engineering courses?
- Are interdisciplinary courses and programs attracting a new or different mix of students to careers in science and engineering?
- Are interdisciplinary courses effective in instilling scientific and technological literacy and awareness of the roles of science and technology in modern life?

E-3: Funding organizations should enhance their proposal-review mechanisms so as to ensure appropriate breadth and depth of expertise in the review of proposals for interdisciplinary research, education, and training activities.

For example, organizations that fund IDR could

- Involve researchers who have experience with and are knowledgeable about interdisciplinarity and ensure representation of the most important disciplinary points of view on panels that review IDR proposals. Evaluate a proposal to its cell-biology research program by using researchers in cell biology and including a substantial number in chemistry, physics, computer science, the social sciences, and the humanities as appropriate; this practice would help to ensure disciplinary breadth and reduce bias.
- Review a proposed interdisciplinary program in climate change by using input not only from experts in climate change and related fields—such as oceanography, meteorology, atmospheric chemistry, and land use—but also experts in the constituent disciplines—such as physics, chemistry, and statistics—and nonresearchers for whom the research is relevant; the contributions of different disciplines might be submitted separately in written form, and these reports would be offered to a full review panel, including both disciplinary and interdisciplinary researchers, for final assessment.
  - E-4: Comparative evaluations of research institutions, such as the National Academies' assessment of doctoral programs and activities that rank university departments, should include the contributions of interdisciplinary activities that involve more than one department (even if it involves double-counting), as well as single-department contributions.

For example, organizations that evaluate such institutions can

- Survey emerging interdisciplinary fields to identify demographic information (e.g., numbers and characteristics of participants in various interdisciplinary fields, and/or the kinds of activities they engage in).
- Experiment with "matrix evaluation" to capture the activities and accomplishments of interdisciplinary researchers; a matrix approach is one that would consider IDR as an integral part of the disciplines in which the researchers are "embedded" and make visible the cross-departmental efforts of the researchers who make up the interdisciplinary teams.
- Include as evaluation criteria the comentoring of doctoral students, the contributions of individuals to multiple departments, and publication criteria. The publication criteria might include the nature of the journal audiences for whom the work is published; citation analysis that reveals a broad, interdisciplinary interest in the work being cited; "double counting"

of publications, by which credit for a given paper is awarded to all coauthors; multiple-authorship patterns that would reveal the disciplinary backgrounds of coauthors; and others that are still being developed.

• Include the facilitation of interdisciplinarity as part of the accreditation process.

## **Academic Institutional Structure**

U-1: Institutions should explore alternative administrative structures and business models that facilitate IDR across traditional organizational structures.

For example, institutions can

- Experiment with alternative administrative structures, such as the matrix model, in which people move freely among disciplinary departments that are bridged and linked by interdisciplinary centers, offices, programs, and curricula or, alternatively, create institutions "without walls" that have no disciplinary departments and are organized around problems rather than disciplines.
- Create numerous interdisciplinary courses for mentors, provide graduate students with multiple mentors, and offer faculty numerous opportunities for continuing education.
- Oversee interdisciplinary programs at the university level rather than that of a single college.
- Review programs periodically with the option of terminating those no longer of high priority so that there is flexibility to respond to emerging opportunities.
  - U-2: Allocations of resources from high-level administration to interdisciplinary units, to further their formation and continued operation, should be considered in addition to resource allocations of discipline-driven departments and colleges. Such allocations should be driven by the inherent intellectual values of the research and by the promise of IDR in addressing urgent societal problems.

- Put in place policies that allow the return of some indirect cost revenues to research units such that interdisciplinary centers and programs with external funding are not disadvantaged.
- Provide support for graduate students who choose to study interdisciplinary fields with mentoring by more than a single faculty member.

- Provide support for generative technologies (for example, shared whiteboard software) that allow the sharing of information and ideas (for example, drawings, slides, or equations) virtually.
- Invest federal funds in activities that lead to the design and implementation of research activities that take full advantage of a distributed information technology infrastructure to coordinate research across institutional lines.
  - U-3: Recruitment practices, from recruitment of graduate students to hiring of faculty, should be revised to include recruitment across department and college lines.

For example, institutions can

- Admit graduate students into broad fields (for example, biological sciences as opposed to microbiology; engineering as opposed to mechanical engineering) with no requirement to specialize until the end of the first or second year.
- Increase the number of joint faculty appointments and PhD programs from a few to many.
- Recruit faculty for positions in both programs and departments so they can teach both within the special sphere of a program and in foundation courses in traditional areas.
  - U-4: The traditional practices and norms in hiring of faculty and in making tenure decisions should be revised to take into account more fully the values inherent in IDR activities.

- Provide robust mechanisms for allocating faculty positions to areas of IDR.
- Provide cross-departmental mechanisms for tenure and promotion review.
- Monitor a tenure-track faculty member's progress toward tenure with both mentors from the faculty member's program and senior faculty in traditional fields of special interest to that faculty member.
  - U-5: Continuing social science, humanities, and information-science-based studies of the complex social and intellectual processes that make for successful IDR are needed to deepen the understanding of these processes and to enhance the prospects for the creation and management of successful programs in specific fields and local institutions.