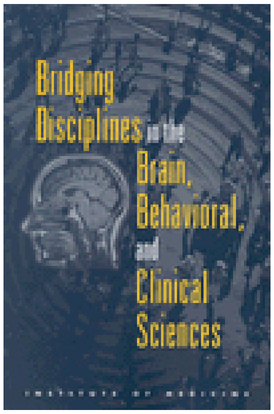

Bridging Disciplines in the Brain, Behavioral, and Clinical Sciences

Terry C. Pellmar and Leon Eisenberg, Editors; Committee on Building Bridges in the Brain, Behavioral, and Clinical Sciences; Division of Neuroscience and Behavioral Health

ISBN: 0-309-56324-0, 144 pages, 6 x 9, (2000)

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Division of Neuroscience and Behavioral Health
INSTITUTE OF MEDICINE

NATIONAL ACADEMY PRESS
Washington, D.C.

NATIONAL ACADEMY PRESS 2101 Constitution Avenue, N.W. Washington, DC 20418

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This project was supported by Task Order No. 52, under Contract No. N01-OD-4-2139 from the National Institutes of Health.

International Standard Book Number 0-309-07078-3

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Willing is not enough; we must do."

—Goethe

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Preface

As never before, behavioral and neurological diseases are moving to the forefront of public health concerns; witness the Surgeon General's Report on Mental Health. Many of the leading causes of morbidity and mortality in the United States are recognized as having major social and behavioral determinants. Psychological stress has been linked to many health outcomes; researchers and public health officials are becoming increasingly interested in unraveling the mechanisms behind this relationship. Sociologists have identified changes in the age, ethnic, racial, and cultural makeup of the American population, changes that have an impact on biological, psychological, and social processes. As scientists and health care providers examine the intricate interplay among genes, environments, behaviors, and diseases, health problems newly emerging, as well as those that have plagued us over time, present complex challenges for research. The biomedical advances of the past decades have dramatically increased our understanding of the links between behavioral and neural processes and disease. These advances make it clear that fuller understanding demands the integration of knowledge and concepts from multiple disciplines.

To make that understanding possible, we must create an environment to promote interdisciplinary research and training. Although its importance has been stressed many times in the past decades, there is now a groundswell of support for interdisciplinary research. Universities, funding agencies, and groups of investigators are looking for ways to make it occur. New research centers are being created with the specific goal of promoting interactions among the disciplines.

Peer review at NIH has been recently revamped, in part to facilitate interdisciplinary research. Nonetheless, obstacles persist.

This Committee was charged with examining the need for interdisciplinary research and training, identifying the obstacles that stand in the way, and defining the components of training necessary to create scientists able to bridge disciplines in the brain, behavioral, and clinical sciences. The committee includes members with expertise ranging from sociology to neurophysiology, from basic science to the clinic, from investigators with a single discipline to leaders of broad interdisciplinary programs. We met four times. At our first meeting, we heard from the Directors of the National Institute of Mental Health and the Office of Behavior and Social Science Research. They described their goal of developing scientists able to bring an integrated approach to the health problems facing today's society. NIH and NSF program officers described the mechanisms currently available to fund training programs.

At the workshop we convened, university and industry program directors described their existing training programs and the obstacles they encounter. We discussed potential solutions with an invited panel of scientists and university administrators. The directors of several NIH institutes were invited to comment on whether and why they felt interdisciplinary research and training were necessary. There was a clear consensus that such is an appropriate direction for today's science, but the evidence on the best way to proceed is limited. IOM staff read through dozens of funded grant proposals, reviewed program descriptions and brochures, and talked with program directors to learn the scope of the mechanisms currently in use. They reviewed hundreds of requests for applications to identify the interests and opportunities of the funding agencies.

Early in our deliberations we agreed that that interdisciplinary research itself is not the goal; rather the need for it emerges from research questions. Some problems are best tackled with the methods and concepts of a single discipline; others require integration across disciplines. It is important to define the issues appropriate for interdisciplinary techniques and to carefully consider the disciplines that should be involved in developing the solutions.

Examples of interdisciplinary efforts are diverse. They include the collaboration of investigators working together on a difficult problem, the stimulation of thought and direction that occurs with facilitated interactions, the translation of clinical and basic science findings through exchanges between clinicians and researchers. Because definitions of interdisciplinary research are so varied, identifying interdisciplinary publications, grants, training, and research proved to be extremely challenging. Furthermore, data on the successes (or failures) of existing funding mechanisms are limited. Without outcome data, we cannot assert definitively what are the “best” or the “necessary” approaches to encourage interdisciplinary training. For future evaluations, this gap needs to be filled. It will not be easy to develop mechanisms to track training outcomes, but to do so is essential and merits a major investment of effort.

Training in existing single disciplines should be broadened so that all graduates become aware of the ideas and methods at the borderlines of their own fields. On the one hand, basic scientists should be introduced to the scope of clinical problems; clinical investigators should be kept abreast of laboratory research. The aim is to create “informed consumers,” able to understand other disciplines and to recognize ideas applicable to their own work.

The many obstacles that discourage interdisciplinary efforts are summarized in our report. The point we emphasize here is that they can be surmounted with the support of universities and funding agencies. With appropriate incentives, trainees can be encouraged to broaden their horizons. Not all those trained with an interdisciplinary perspective will do interdisciplinary research, but the education they receive should provide the capacity to integrate information from other disciplines when, and as, it becomes appropriate over a lifetime in research. Funding agencies can deploy the large variety of mechanisms available to them to promote interdisciplinary training in order to overcome obstacles and enhance research.

Because interdisciplinary research is flourishing at many universities, some might feel that additional attention is unnecessary. We believe that despite this activity, there is a need to set directions, facilitate training, and evaluate the programs. We view our recommendations as guidelines to enhance training opportunities for all scientists and allow them to participate in interdisciplinary efforts to solve today's complex health problems.

Leon Eisenberg
Chair

Acknowledgments

The committee wishes to thank the many people who contributed to this report. Terry Pellmar, as Study Director, made the work of this Committee possible by her intellectual clarity, her resourcefulness in identifying and providing background materials, and her diligence in keeping us on task. Deborah Yarnell's assistance as research associate was exceptional. She was tireless in tracking down information, identifying programs, and obtaining interviews. Her insights and her dedication were much appreciated. Amelia Mathis took wonderful care of the committee, handling their travel and meals and all the meeting logistics. Wendy Blanpied was invaluable in her program support, especially for the workshop. We also thank Linda Leonard for administrative assistance, Kathi Hanna for consultation and writing, Carlos Gabriel for financial accounting, Claudia Carl for guiding the report through review, Norman Grossblatt for expert editing, Susan Fourt for help with library resources, and Linda Kilroy for contract support. Clyde Behney provided valuable guidance throughout the study process. Many other individuals from government, private industry, foundations, and academia provided expert consultation and are acknowledged in Appendix B.

REVIEWERS

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their participation in the review of this report: Boris Astrachan, University of Illinois; Jack D. Barchas, Weill Medical College of Cornell University and Weill Cornell Medical Center; Samuel H. Barondes, University of California at San Francisco; Michael Gazzaniga, Dartmouth College; Zach W. Hall, University of California at San Francisco; Robert Langer, Massachusetts Institute of Technology; Joe L. Martinez, Jr., The University of Texas at San Antonio; and Anne Petersen, W. K. Kellogg Foundation.

While the individuals listed above have provided constructive comments and suggestions, it must be emphasized that responsibility for the final content of this report rests entirely with the Committee on Building Bridges in the Brain, Behavioral, and Clinical Sciences and the Institute of Medicine.

Contents

Executive Summary

Never before have there been such opportunities to understand the human brain and behavior. The advances in biomedical science of the last 50 years have provided the foundation for addressing the complex health problems of today's society. Building on those advances, science is now poised for substantial progress as investigators are ready to bridge disciplines. To achieve the health goals of the 21st century, scientific training and research must bring together many scientific fields that offer different insights and technologies. Interdisciplinary efforts need to be facilitated at all levels of teaching and research. This report offers recommendations to delineate, enhance, and accelerate a process that is already reflected in many training and research programs. Although this report focuses on examples from brain and behavioral science, the principles presented should be broadly applicable in scientific research.

Newly emerging health problems, as well as those that have plagued us over time, are proving to be surprisingly complex as scientists and health care providers begin to recognize and appreciate the intricate interplay among environment, behavior, and disease. Within broad fields, such as mental health research, the need to understand the entire human organism, not just one part of it, is driving disciplines toward each other as scientists seek better ways to prevent, diagnose, treat, and control such illnesses as schizophrenia and bipolar affective disorders, and learning disabilities. Solutions to existing and future health problems will likely require drawing on a variety of disciplines and on approaches in which interdisciplinary efforts characterize not only the cutting edge of research, but also the utilization of knowledge. The next generation of scientists must be prepared to integrate the advances of rapidly progressing disciplines.

The history of science and technology demonstrates that many important advances have come from an interdisciplinary approach. For instance, laser surgery, which involved ophthalmologists, anatomists, and physicists, and has saved thousands of people from severe vision impairment or blindness; “designer” seeds, which were developed by geneticists, bioengineers, and botanists to create crops that resist damage from insects and herbicides. Examples in neuroscience and behavior include cloning the gene associated with Huntington's disease and understanding the contribution of stress to disease.

CHARGE TO THE COMMITTEE

In recognition of the need to train scientists who can address the highly complex problems that challenge us today and fully use new knowledge and technology, the National Institute of Mental Health (NIMH), the National Institutes of Health (NIH) Office of Behavioral and Social Sciences Research (OBSSR), the National Institute on Nursing Research (NINR), and the National Institute on Aging (NIA) asked that an Institute of Medicine (IOM) Committee:

- Examine the needs and strategies for interdisciplinary training in the brain, behavioral, social, and clinical sciences to enhance the translation of brain/ behavior to clinical settings and vice versa.
- Define necessary components of true interdisciplinary training in these areas.
- Examine the barriers and obstacles to interdisciplinary training and research.
- Review current educational and training programs to identify elements of model programs that best facilitate interdisciplinary training.

The task of the committee is based on the premise that interdisciplinary research and training are important. Because input from nine NIH institute directors indicated full agreement with the premise, the committee focused on how, rather than if, interdisciplinary research and training should be pursued. The committee broadly interpreted its charge as a request to provide guidance on how to bring together scientists from different fields to explore new frontiers and to train new scientists so they would be prepared to interact with multiple disciplines.

Because evaluations of the success of interdisciplinary training programs are scarce, the committee could not specify the “necessary components” or identify the elements that “best facilitate” interdisciplinary training. Instead, after reviewing existing programs and consulting with experts, the committee identified approaches likely to be successful in providing direction for interdisciplinary endeavors at various career stages. The committee is aware of the costs that might be incurred in implementing its recommendations. In many instances, it will be a matter of shifting resources; in others, new resources will be needed. Until program plans are established, detailed accounting cannot be developed.

For the purposes of this report, the following definitions were adopted:

- Interdisciplinary research is a cooperative effort by a team of investigators, each expert in the use of different methods and concepts, who have joined in an organized program to attack a challenging problem. Ongoing communication and reexamination of postulates among team members promote broadening of concepts and enrichment of understanding. Although each member is primarily responsible for the efforts in his or her own discipline, all share responsibility for the final product.
- Translational research is a subset of interdisciplinary research that integrates information from clinical settings and basic research laboratories.
- The aim of interdisciplinary training should be to produce researchers who are capable of participating in or directing interdisciplinary research. These researchers are critical to an interdisciplinary team. It is analogous to an orchestra, whose leader (the conductor or the director of an interdisciplinary team) coordinates highly specialized individuals to produce harmonious outcomes. The leader would be expected to be able to converse freely with persons in disparate fields and to facilitate the interactions among team members. The team members would be responsible for issues involving their expertise and would develop a working knowledge of each others' fields. The composition of the “orchestra” would not be fixed, but, rather, would change depending on the particular problem at hand. With time, participants would expand their understanding of other fields while continuing to contribute their own expertise.

THE POTENTIAL OF INTERDISCIPLINARY RESEARCH

Both single disciplinary research and interdisciplinary research are needed to develop methods for prevention, diagnosis, and treatment of disease and to understand the basic mechanisms of brain and behavior. Many problems are best approached within a single discipline. Investigators in single disciplinary work have contributed enormously to our understanding of basic biology and human health—B. F. Skinner in operant conditioning, von Bekesey in audition, and Hodgkin and Huxley in nerve conduction are examples. Interdisciplinary approaches often build on single disciplinary discoveries. Disciplines evolve from interdisciplinary efforts as exemplified by neuroscience. This relatively new discipline developed as scientists from different fields came together to solve common scientific problems about the nervous system. Neuroscience is a dynamic discipline in which new fields continue to be integrated.

Many research problems facing today's society require coordinated efforts from multiple disciplines. Cross-fertilization between clinical and basic scientists can stimulate research and enhance understanding of pathologies. For example, genetic analyses and imaging techniques have significantly advanced our understanding of the pathophysiology of schizophrenia. Clinical observations of patients with memory loss, in conjunction with basic research on memory, provided insights into the numerous types of memory that exist. Funding of Alzheimer's Disease Research Centers brought together clinical and basic scientists from multiple disciplines and produced striking progress in the development of promising interventions. A great many interdisciplinary programs currently exist. Whether developed through the encouragement of a funding agency or the leadership of an individual, these programs illustrate the breadth of what can be achieved when disciplines come together to solve a problem. To ensure the future of interdisciplinary research for solutions to complex problems, training is essential to prepare the next generation of investigators to tackle these interdisciplinary tasks.

Interdisciplinary research is an approach, not an end. It should arise out of a challenge; that is, it should develop in response to a problem that cannot be embraced by a single discipline. Interdisciplinary research should not be conducted for its own sake, but, rather, as a deliberate response to specific research needs. It is important to identify the scientific problems for which an interdisciplinary focus is important and to avoid indiscriminate support of anything interdisciplinary. To assist funding agencies in this identification process, the scientific community should be consulted.

RECOMMENDATION 1

Federal and private research sponsors should seek to identify areas that can be most effectively investigated with interdisciplinary approaches. This should be done by engaging the scientific community through symposia, working groups, or ad hoc committees. Funding mechanisms, such as Requests for Applications or Proposals, should be developed to address the identified areas.

BARRIERS TO INTERDISCIPLINARY RESEARCH AND TRAINING

The literature is replete with descriptions of the traditional and persistent barriers to interdisciplinary research. Disciplinary jargon and cultural differences among disciplines are serious problems. Surveys show concerns among researchers about perceptions of interdisciplinary science as second-rate. A sense of superiority within each discipline and the view that other disciplines are less rigorous or important also present barriers. Good communication skills help to alleviate such problems, but scientists often lack the appropriate training and proficiency. Interactions among investigators (both planned and unplanned) can promote communication and encourage interdisciplinary collaboration; the creation of central facilities or common areas can increase the probability of such interactions.

There are concerns that training in interdisciplinary fields will not prepare graduates for a career. The explosion of information within each scientific discipline raises concerns about how long it would take to attain expertise in one, let alone two or more, fields. The duration and cost of education are increasing, and added interdisciplinary requirements could be discouraging. Debt is an issue, especially for medical students, among whom the mean debt of graduates was over $80,000 in 1997. To encourage clinicians to engage in research, NIH's loan repayment programs can repay educational loans up to $35,000 per year for eligible researchers employed at NIH. Extending these debt repayment programs could provide an increased incentive to pursue interdisciplinary research training.

Because publications and successful grants are essential for promotion and tenure, the concern that interdisciplinary research will reduce the likelihood of first-authorship and of funding presents an additional obstacle. New journal policies that call for defining the contribution of each author of multiauthor papers can offer a means to provide appropriate credit for a collaborative effort. NIH recently developed a new peer review system intended to eliminate any disadvantage for translational and interdisciplinary science. It will be important to monitor the new system for the success of interdisciplinary proposals relative to single disciplinary proposals. Despite the abundance of requests for interdisciplinary proposals from funding agencies and interagency collaborations that bring together multiple perspectives, scientists express concerns about obtaining support for interdisciplinary research. Partnerships among NIH institutes, among government agencies, or between government and the private sector often provide a broad base of support for interdisciplinary research and training.

Interdisciplinary programs are growing at academic institutions. Institutions vary, however, in their policies on distribution of credit for interdisciplinary efforts. Some allocate resources among the investigators and their units, but others credit only the person listed as the principal investigator. University leadership can promote collaboration by crediting participating faculty fairly. Some funding programs call for evidence of institutional commitment to an interdisciplinary effort, which can range from an annual meeting with investigators and university administrators to substantiation of a supportive infrastructure.

RECOMMENDATION 2

Funding agencies and universities should remove the barriers to interdisciplinary research and training.

To that end, funding agencies should:

- Require commitments from university administration to qualify for funding for interdisciplinary efforts. These should include supportive promotion policies, allocation of appropriate overhead, and allocation of shared facilities.
- Facilitate interactions among investigators in different disciplines by funding shared and core facilities.
- Encourage legislation to expand loan repayment programs to include investigators outside NIH who are engaged in funded interdisciplinary and translational research.
- Support peer review that facilitates interdisciplinary research. In reviewing interdisciplinary research proposals, they should use peer review groups that include scientists in multiple disciplines who are themselves actively engaged in interdisciplinary research. The system recently has been modified at NIH with encouragement of interdisciplinary and translational efforts in mind. Resulting changes should be tracked to determine their impact on funding of interdisciplinary grants.
- Continue and expand partnerships among funding agencies to provide the broadest base for interdisciplinary efforts. These can be inside an agency through the formation of new alliances among institutes or divisions; they can also be among agencies—such as NIH, NSF, the Department of Defense, and Department of Energy—or between the private and public sectors.
- Indicate in funding announcements that training is an integral component of the interdisciplinary research project.

Universities should:

- Allocate appropriate credit for interdisciplinary efforts. They should include a fair allocation of research overhead costs to the home departments of all investigators and a fair crediting for faculty contributions to interdisciplinary research and teaching.
- Review and revise appointment, promotion, and tenure policies to ensure that they do not impede interdisciplinary research and teaching.
- Facilitate interaction among investigators through support for shared facilities. Universities can provide common gathering areas and ensure that new facilities are designed to promote interaction.
- Encourage development, maintenance, and evolution of interdisciplinary institutes, centers, and programs for appropriate problems.

PREDOCTORAL AND POSTDOCTORAL TRAINING PROGRAMS

There is currently a multitude of interdisciplinary predoctoral and postdoctoral training programs. The committee examined over 100 of these training programs and the variety of mechanisms they use to promote interdisciplinary research. Most predoctoral and postdoctoral training programs try to provide trainees with grounding in a particular discipline while encouraging interdisciplinary interactions. Often they focus on a particular problem, such as emotion, sleep, aging, or affective disorders. In addition, the programs aim to provide the skills necessary to understand other disciplines and to communicate with those in other fields. Training mechanisms include coursework, seminar series, journal clubs (to promote critical thinking about the scientific literature), laboratory rotations (to expose students to a range of faculty, techniques, and experimental approaches), and research presentations (to improve communication skills). Interdisciplinary programs often encourage mentorships from more than one sponsor to ensure multiple perspectives. Many provide students with a forum (e.g., summer courses, symposia, and off-site meetings) in which to interact with experts in relevant fields. These gatherings are generally intended to encourage bonding of students with each other and the faculty and to provide students with a network of experts that includes both their contemporaries and more senior scientists, creating a resource for interaction and collaboration throughout the career.

Support for predoctoral and postdoctoral fellows can be provided by an investigator's grant, individual fellowships, and institutional training grants. Under an investigator's award, the postdoctoral fellow is an employee who provides a vector for interaction between two or more laboratories. Fellowships award a stipend directly to the person, who can elect to participate in ancillary training opportunities. Institutional training grants (for example, the T32 National Research Service Award from NIH, the Integrative Graduate Education and Research Training Program from NSF, and some support mechanisms from private foundations) provide coordinated training activities for a cohort of students. The T32 grants do not cover completely the direct costs associated with the administration of the programs. The financial burdens resulting from the administrative costs of training programs can limit the motivation of universities, departments, and faculties to participate. That is especially true of interdisciplinary programs, which are more expensive because they require more coordination.

TRANSLATIONAL RESEARCH TRAINING

In recognition of the need to bridge the bench-to-bedside gap, many federally and privately funded programs support the training of physician-scientists. Foundations have played a key role in encouraging translational research and training through funding efforts such as the Markey Charitable Trust grants and the Robert Wood Johnson Clinical Scholars Program. Programs leading to MD/PhD degrees, such as the Medical Scientist Training Program (MSTP) of the National Institute of General Medical Sciences, can be effective in producing clinical researchers. To support nonphysician clinicians as contributors to translational research, NIH offers training programs for dentists and nurses that are similar to those tailored to MDs. (e.g., the Dental Scientist Training Program and NINR's Career Transition Award).

Although the doctoral training of the MSTP is primarily in the biological, chemical, and physical sciences, the program also will support degrees in social and behavioral sciences, computer sciences, economics, epidemiology, public health, bioengineering, biostatistics, and bioethics. However, it is unusual for universities to implement the provision for degrees outside the traditional biomedical disciplines despite evidence that MD/PhD graduates with a PhD in the humanities are strong contributors to academic medicine. In recognition of the need for MDs to understand the behavioral and sociological aspects of disease, to address the important issues of behavior change and adherence, and to think globally about population and environmental factors in disease, training in these nontraditional fields should be strongly encouraged.

Exposing basic scientists to clinical problems also can enhance translational research. Several university programs now provide clinical experience for trainees that allow students to see patients, handle pathology, and become informed about major diagnostic and therapeutic facilities, as well as to learn about the mechanisms of disease. In addition, to train doctoral fellows in clinical research and drug development, some pharmaceutical companies have developed fellowships in partnership with universities.

CAREER-LONG TRAINING OPPORTUNITIES

Training opportunities need to be available at all stages of a career. Granting mechanisms specifically aimed at junior faculty and new investigators can provide an incentive to move toward interdisciplinary research questions. Training for those established in their careers can encourage scientists to acquire new approaches or to obtain a different perspective in their research efforts. Such opportunities do exist, some geared toward developing an interdisciplinary perspective, but others could easily be adapted to that purpose.

Federal funding agencies and private foundations have several programs that support junior faculty, providing opportunities to broaden their scope. One innovative mechanism available through NIH is the Supplement to Promote Reentry into Biomedical and Behavioral Research Careers (NIH Program Announcement 99-105). It provides up to 3 years of support to people who have been out of research for several years but are ready for an independent research position. Principal Investigators on eligible NIH awards can submit an administrative supplement to support the reentering researcher on an effort directly related to the funded parent grant. The decision to fund a supplement takes about 8 weeks. Administrative supplements are also available for Underrepresented Minorities and Individuals with Disabilities (NIH Program Announcements 99-104 and 99-106). The committee recognizes the potential for this type of mechanism to promote interdisciplinary research.

Foundations have been at the forefront of the effort to support interdisciplinary efforts among faculty. Examples include the Bridging Brain, Mind, and Behavior initiative from the McDonnell Foundation and The William T. Grant Foundation Faculty Scholars Program, which strongly encourage interdisciplinary efforts that otherwise might not be funded by traditional sources. The MacArthur Fellows Program uses an alternative approach, investing in the individual rather than a particular project and allowing the fellows to work in multiple disciplines, to train in a new field, or to change direction in their careers.

Although midcareer training often occurs informally, several funding approaches provide additional opportunities. Career development awards are available through NIH and various foundations for established scientists to expand their scope. Sabbaticals often allow an opportunity for researchers to learn new techniques and explore new ideas. Faculty development programs, including departmental seminars or formalized courses at a person's home institution, can present interdisciplinary perspectives. Meetings and workshops provide informal training to senior investigators. Federal and private programs supporting these approaches are available and should be encouraged.

Consortia and multi-institutional programs also provide opportunities for continued learning and far-reaching integration of research efforts in multiple disciplines. An example of a successful consortium is MacArthur Foundation's Program on Human and Community Development that encompasses several research networks to address economic opportunities, community capacity, child development, and mental health. Each network individually has a broad scope. The full program further integrates the networks in an effort to obtain real solutions for community problems.

Interdisciplinary research is not intended to supplant disciplinary efforts; rather, such training should be available to provide opportunities to explore new areas outside a single discipline. Broad training early in a career and continued training throughout a career can provide the tools to integrate multiple disciplines when required by the research question.

RECOMMENDATION 3

Scientific education at early career stages should be sufficiently broad to produce graduates who can understand essential components of other disciplines while receiving a solid grounding in one or more fields. Criteria for NIH-supported research training should include both breadth and depth of education. Funding mechanisms to support interdisciplinary training in appropriate fields (as identified in Recommendation 1) should provide additional incentives to the universities and the trainees along the following lines:

- **Through the NIH Medical Scientist Training Program, encourage participating universities to support MD/PhD programs in the social and behavioral, as well as biomedical, sciences.** Although existing program language permits such graduate study, training in social and behavioral science (e.g., anthropology, economics, psychology, and sociology) is undertaken infrequently. NIH can highlight the need for such graduates and encourage grantees to recruit them.
- **Promote translational research, an important aspect of interdisciplinary training by (1) Providing clinical experience in PhD programs.** This can range from support for single courses that expose students to human pathophysiology to training programs that require both basic research and clinical experience; **(2) Supporting PhD programs and postdoctoral mentored career development awards for physicians, nurses, dentists, social workers, and other clinicians.**
- **Create partnerships with the private sector to develop and support interdisciplinary training.** Many of today's students will enter private industry to do translational research. Others will go on to careers in teaching, publishing, science policy, science administration, or law. Interdisciplinary perspectives are as important to success in these careers as they are in research.
- **Expand the T32 training grant awards to cover the full direct costs of implementation.** This change will provide the resources necessary to support the greater expenses encountered in an interdisciplinary training program.

RECOMMENDATION 4

Funding agencies should establish a grant supplement program to foster interdisciplinary training and research. This would be administratively modeled after the supplements that exist for minorities and people with disabilities, and for people reentering research after a hiatus. Investigators with research grants who have interdisciplinary training opportunities should be able to obtain supplemental funds for qualified candidates through a relatively short application form with expedited review. Successful pilot efforts will provide data to support further applications for career development and research.

RECOMMENDATION 5

Funding opportunities for interdisciplinary training should be provided for scientists at all stages of their careers.

- **Implement career development programs that encourage junior faculty to engage in interdisciplinary research.** Junior faculty need to be successful in the early phases of their research, so they are less likely than senior faculty to pursue interdisciplinary research.
- **Support midcareer investigators in developing expertise needed for interdisciplinary research.** These programs should include sabbaticals, career development awards, and university-based, formal courses for faculty development to enhance interdisciplinary and/or translational research.
- **Continue funding for workshops, symposia, and meetings to bring together diverse fields to focus on a particular scientific question.** In such an environment, cross training of the investigators and encouragement of collaboration would develop naturally.
- **Support consortia and multi-institutional programs that provide integration of research efforts from multiple disciplines.**

EVALUATION—HOW DO YOU KNOW WHICH PROGRAMS WORK TO ENCOURAGE INTERDISCIPLINARY EFFORTS?

Despite decades of discussion about interdisciplinary needs, data to support the requirement for and effectiveness of the available mechanisms are scanty. Why is there a lack of data when there is so much interest? The committee faced this obstacle in its review of interdisciplinary programs and determined that a process for evaluation of programs is needed. The collection and evaluation of interdisciplinary training outcomes, however, are tremendously complex and difficult. To know whether interdisciplinary training promotes interdisciplinary research, it is necessary to have a method of identification for interdisciplinary research and training programs. To measure the outcome of the programs, it is necessary to have methods that will accurately reflect their success in promoting interdisciplinary research.

The challenges of deciding what is classified as "interdisciplinary," defining the markers of "success," and providing mechanisms to identify and track the efforts are daunting. Universal and meaningful definitions of *interdisciplinary* and *translational* are needed to begin developing evaluation methods. Once these definitions are agreed on, an appropriate labeling mechanism would allow the funding agencies to define which training programs are to be tracked as interdisciplinary and to define which projects are interdisciplinary for outcome analysis.

Defining success is complex. The general measures of success for those who conduct interdisciplinary research are the same as for those who conduct single disciplinary research—grants awarded, publications, tenure and rank, and laboratory size. To address the effectiveness of interdisciplinary training programs, however, requires additional measures, such as whether graduates maintain an interdisciplinary approach in their work, as reflected by the nature of their collaborations, joint appointments in multiple departments, publishing of interdisciplinary papers, or obtaining grants with interdisciplinary themes. Most funding agencies require training programs to report on the achievements of previous trainees. Reporting provides data for the evaluation of each individual program; but because data are not collated across programs, reporting does not allow assessment of the granting mechanism. Furthermore, it does not answer the question, Did the training produce more interdisciplinary research? The success of interdisciplinary initiatives can also be evaluated through the resulting changes in universities and in funding agencies. Opportunities for interdisciplinary research and training might encourage academic institutions to revise promotion policies, actively encourage collaborations across departments, or promote training programs with interdisciplinary perspectives. Funding agencies might alter the peer review system, improve profiles for funding of interdisciplinary proposals, or introduce new mechanisms to support interdisciplinary efforts. Devising an approach to track and evaluate interdisciplinary training and research programs will be extraordinarily challenging and should be the subject of extensive analysis by people with appropriate expertise.

RECOMMENDATION 6

NIH should develop and implement mechanisms to evaluate the outcomes of interdisciplinary training and research programs.

- **Identify interdisciplinary research and training as such in all federal grants to facilitate future analyses.** The committee suggests a box on the cover sheet of grant applications indicating whether the applicant considers the work to be interdisciplinary. If so, the applicant should list on a continuation sheet the participating disciplines represented among the investigators and mentors and the interdisciplinary aspects of the research or training.
- **Establish a task force to develop a plan to track outcomes of interdisciplinary training and research programs.** Outcomes should encompass, but not be limited to, career patterns and interdisciplinary efforts of trainees (for example, research focus, findings, and publications), changes in universities (for example, in administrative structure, in interdisciplinary research, and in interdisciplinary training opportunities), and changes in funding agencies (for example, funding profiles for interdisciplinary proposals).

The committee encourages interdisciplinary training and research, not from a philosophic belief in "interdisciplinarity," but from the knowledge that many scientific problems are refractory to solution by the methods of a single discipline and require the incorporation of concepts and methods from several disciplines simultaneously. Interdisciplinary research is flourishing in our institutions—despite the barriers. The question is how best to facilitate, direct, and evaluate its growth.

RECOMMENDATION 1

Federal and private research sponsors should seek to identify areas that can be most effectively investigated with interdisciplinary approaches.

RECOMMENDATION 2

Funding agencies and universities should remove the barriers to interdisciplinary research and training identified in this report. To that end, funding agencies should:

- Require commitments from university administration to qualify for funding for Interdisciplinary efforts.
- Facilitate interactions among investigators in different disciplines by funding shared and core facilities.
- Encourage legislation to expand loan repayment programs to include investigators outside NIH who are engaged in funded interdisciplinary and translational research.
- Support peer review that facilitates interdisciplinary research.
- Continue and expand partnerships among funding agencies to provide the broadest base for interdisciplinary efforts.
- Indicate in funding announcements that training is an integral component of the interdisciplinary research project.

Universities should:

- Allocate appropriate credit for interdisciplinary efforts.
- Review and revise appointment, promotion, and tenure policies to ensure that they do not impede interdisciplinary research and teaching.
- Facilitate interaction among investigators through support for shared facilities.
- Encourage development, maintenance, and evolution of interdisciplinary institutes, centers, and programs for appropriate problems.

RECOMMENDATION 3

Scientific education at early career stages should be sufficiently broad to produce graduates who can understand essential components of other disciplines while receiving a solid grounding in one or more fields. Criteria for NIH-supported research training should include both breadth and depth of education.

- Through the NIH Medical Scientist Training Program, encourage participating universities to support MD/PhD programs in the social and behavioral, as well as biomedical, sciences.
- Promote translational research, an important aspect of interdisciplinary training by (1) Providing clinical experience in PhD programs; (2) Supporting PhD programs and postdoctoral mentored career development awards for physicians, nurses, dentists, social workers, and other clinicians.
- Create partnerships with the private sector to develop and support interdisciplinary training.
- Expand the T32 training grant awards to cover the full direct costs of implementation.

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Funding opportunities for interdisciplinary training should be provided for scientists at all stages of their careers.

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- Continue funding for workshops, symposia, and meetings to bring together diverse fields to focus on a particular scientific question.
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- Establish a task force to develop a plan to track outcomes of interdisciplinary training and research programs.

1

Introduction

We are not students of some subject matter but students of problems. And problems may cut right across the borders of any subject or discipline.

— Karl Popper

Biomedical and behavioral research scientists, among others, have long recognized the value of interdisciplinary research and collaboration. Many public and private reports over the last 25 years have detailed the need for and recommended development of interdisciplinary training activities to produce scientists capable of working on complex problems, but cooperative efforts remain difficult to achieve.

The history of science and technology demonstrates that many important advances have come from an interdisciplinary approach. Examples abound: plate tectonics, which brought together geologists, oceanographers, paleomagnetists, seismologists, and geophysicists to advance the ability to forecast earthquakes and volcanic eruptions; laser surgery, which involved ophthalmologists, anatomists, and physicists, and has saved thousands of people from severe vision impairment or blindness; “designer” seeds, which were developed by geneticists, bioengineers, and botanists to create crops that resist damage from insects and herbicides; and transistors, with which chemists and physicists revolutionized the technology of electronic devices. Examples in neuroscience include the cloning of the gene associated with Huntington's disease, which required the work of neurologists, psychologists, sociologists, and geneticists; elucidation of important aspects of the pathophysiology underlying Alzheimer's disease, which required the expertise of neuropathologists, molecular biologists, neurologists, geneticists, and protein chemists; development of medical and surgical treatments for Parkinson's disease, which stemmed from the efforts of neurologists, neuropharmacologists, neuropathologists, neurophysiologists, and neurosurgeons; and development of medical and surgical treatments for temporal lobe epilepsy, which resulted from the efforts of neurologists, electroencephalographers, neurophysiologists, neuropharmacologists, and neurosurgeons.

The need for interdisciplinary research appears to be increasing. Newly emerging health problems, as well as those that have plagued us over time, are proving to be surprisingly complex as scientists and healthcare providers begin to recognize and appreciate the intricate interplay among environment, behavior, and disease. One need only point to HIV infection, heart disease, and drug abuse (including tobacco use) as three prime examples of the intersection of behavior and health. Within broad fields, such as mental health research, the need to understand the entire human organism—not just one part of it—is driving disciplines toward each other as scientists seek better ways to prevent, diagnose, treat, and control such conditions as schizophrenia, bipolar affective disorders, and learning disabilities. Many of the chronic conditions that challenge us today do not respond well to the single investigator, single discipline model that worked well in the past, as in the paradigm of infectious disease.[3] Solutions to current and future health problems will likely require drawing on a variety of disciplines and on approaches in which interdisciplinary efforts characterize not only the cutting edge of research, but also the utilization of knowledge. The next generation of scientists must be prepared to integrate the advances of rapidly progressing disciplines.

The basis of many health problems is not well understood, and it is increasingly recognized that many disorders have a wide array of causes. Defining the causes of disorders is itself an important emerging field, and fuller understanding will require input from many disciplines. Furthermore, addressing the burden of illness requires understanding of both the biology of the disorder and the cultural and psychosocial aspects of living with it. The problems are complicated, and the solutions are not easy to come by; this might explain why, despite the good intentions and fine recommendations of numerous previously convened groups, change has been slow to come. Long-held biases, beliefs, educational practices, and research funding mechanisms have created a system in which it is easier to conduct unidisciplinary than multidisciplinary work. Creation of environments in which interdisciplinary research and training occur will probably require many changes and multiple integrated approaches. Although it might be difficult, it is well worth the effort because many of today's disciplines (e.g., neuroscience, biochemistry, and bioinformatics) started as interdisciplinary efforts and many of today's interdisciplinary efforts will become tomorrow's disciplines.

INTERDISCIPLINARY RESEARCH

Over the last 10 years, as interdisciplinary research has been discussed with increasing frequency, several authors have offered definitions of *interdisciplinary research* as a first step to developing a common understanding of its challenges.

The dictionary defines it as involving two or more academic, scientific, or artistic disciplines. Some have made distinctions among the terms *interdisciplinary, multidisciplinary,* and *transdisciplinary.*[7] For the purposes of this report, the following definition (modified from Luszki, 1958) of *interdisciplinary research* was adopted:

Interdisciplinary research is a cooperative effort by a team of investigators, each expert in the use of different methods and concepts, who have joined in an organized program to attack a challenging problem. Ongoing communication and reexamination of postulates among team members promote broadening of concepts and enrichment of understanding. Although each member is primarily responsible for the efforts in his or her own discipline, all share responsibility for the final product.

INTERDISCIPLINARY TRAINING

Interdisciplinary training encompasses many approaches, from broadening the graduate and postgraduate education of students so that they can understand more than one discipline to exposing a midcareer single discipline trained investigator to a second discipline to broaden her or his research capabilities. Regardless of the method, the outcome is to produce individuals who are capable of research focused on complex problems that require interdisciplinary solutions —in short, interdisciplinary research.

Training in a single discipline is most likely to lead to future research with the tools of that discipline. Interdisciplinary training broadens the possibilities by providing additional tools. Training does not necessarily predict a researcher's approach throughout a career. Some scientists trained in traditional disciplines go on to conduct interdisciplinary research, and some trained in interdisciplinary programs go on to conduct focused research in a single discipline. The human factors involved in making these decisions are complex and unpredictable, as are the situations that trigger them. However, it is generally expected that interdisciplinary training will lead to more interdisciplinary research than will single discipline training and that providing a broad-based interdisciplinary background will facilitate the integration of disciplines by making concepts more accessible.

TRANSLATIONAL RESEARCH

One of the important aspects of interdisciplinary research is translating findings from the laboratory to the clinic or from the clinic back to the laboratory. One historic example is the discovery of the gene mutation in sickle cell anemia: a clinical investigator communicated his findings to a physical chemist; the chemist then tested his hypothesis in the laboratory and provided an explanation for the clinical findings (see chapter 2). This type of research requires both clinical and basic science input—sometimes difficult to achieve. Basic scientists and clinical investigators not only speak different languages, but often are not fully aware of the scientific problems that activate disciplines outside their own. Can we continue to interest a subset of basic scientists in focusing their technologies and perspectives on problems that ultimately will help us to understand specific illnesses? Can we enhance the exchange of information between basic and clinical scientists and encourage their application of each other's findings?

INTERDISCIPLINARY RESEARCH IN THE BRAIN, BEHAVIORAL, AND CLINICAL SCIENCES

Information emerging from the behavioral sciences, genetics, molecular biology, and neuroscience is revealing the interconnectedness of the questions being asked. Who poses the questions is likely to determine how the questions are answered and what tools are used. Collective framing of the questions could lead to better answers. At the very least, some scientists are recognizing that the tools of other disciplines might be useful in their own work. For example, psychologists increasingly are using artificial intelligence, brain imaging, and molecular biology to map behaviors. Cognitive scientists are using imaging to measure brain blood flow and metabolism in efforts to examine memory and attention. Psychiatric researchers are turning to epidemiologists to help them to identify risk factors, which in turn will lead to appropriate treatments or preventive interventions.

Interest in promoting interdisciplinary research in the brain and behavioral sciences is not new. As far back as 1951, a committee on research methodology in mental health research reported to the Research Study Section of the National Institute of Mental Health (NIMH) suggesting a series of interdisciplinary work conferences to explore the "problem of interdisciplinary team efforts."[6] The Mental Health Study Act of 1955 put forward the policy of solving "the complex and interrelated problems posed by mental illness by encouraging the undertaking of nongovernmental, multidisciplinary research" into all aspects of mental illness (see Joint Commission on Mental Illness and Health, 1961[5]).

In 1961, the Joint Commission on Mental Illness and Health reported findings and recommendations for the national mental health program.[5] One recommendation stated, "efforts should be made to increase contacts between researchers and practitioners so as to increase mutual understanding of each other's problems and approaches." In 1961, the predecessor of the National Institute of Neurological Disorders and Stroke funded the first program projects and clinical centers, which provided environments for interdisciplinary research. Shortly after, Schermerhorn[8] published a psychiatric index for interdisciplinary research to facilitate literature searches for investigators interested in collaborating outside their own fields.

Despite nearly 50 years of reporting on the need to do more, in 2000 the necessity of interdisciplinary efforts to integrate the brain, behavior, and clinical sciences is even more pronounced. Norman B. Anderson, director of the NIH Office of Behavioral and Social Sciences Research (OBSSR) has stated that "we simply will not have a complete understanding of behavioral or biological processes by studying [biology and behavior] separately" (as quoted in Azar 1998,[2] see also Anderson, 1998[1]).

The Public Health Service has documented that many of the leading causes of illness and death in the United States have social, behavioral, and lifestyle components, such as tobacco use, lack of exercise, poor diet, and alcohol abuse. Numerous studies have also documented that psychological stress is linked to a variety of health outcomes, and researchers and public health officials are increasingly interested in understanding the nature of this relationship. In addition, sociologists have recognized the changing age, ethnic, racial, and cultural composition of America's population;[4] the increasing diversity of the population generates a need for interdisciplinary collaborations among researchers to understand the multifaceted biological, psychological, and social issues that are generated.

The breadth of expertise needed in many fields of research—such as mental illness, drug abuse and addiction, and aging—spans many disciplines, including behavioral science, neuroscience, pharmacology, genetics, epidemiology, computer science, engineering, medicine, social structures, law enforcement, and the mass media. Through interdisciplinary investigations, behavior and responses to environmental conditions can be usefully linked to neurobiological processes and brain structures. Many fields of inquiry require approaches and methods that can be linked to a more complete understanding of complex relationships among brain mechanisms, behavior, and pathology. Current advances in clinical and behavioral research—if better integrated with research in molecular biology, neurochemistry, and other neuroscience research—might have a substantial effect on numerous health-related problems.

COMMITTEE PROCESS

The present study was requested by the directors of the NIMH, OBSSR, the National Institute on Nursing Research, and the National Institute on Aging in response to the need for interdisciplinary research to bridge the gaps among the brain, behavioral, and clinical sciences. The NIH institutes are interested in developing interdisciplinary training programs to increase the number of scientists capable of studying brain/behavior problems. Creating this new breed of scientists might require rethinking of the training process, including redesigning research training programs and funding mechanisms to support interdisciplinary training, research, and practice.

In remarks to the committee on Building Bridges in the Brain, Behavioral, and Clinical Sciences at its inaugural meeting, OBSSR Director Anderson indicated that this study is directly related to one of the major goals of his office: to integrate a biobehavioral or interdisciplinary perspective across NIH. He expressed the need for behavioral health researchers who integrate the science in a multilevel approach. At the same meeting, NIMH Director Steven Hyman cited numerous examples where limited interaction among scientists in different disciplines is hindering progress (e.g., mapping behavior onto the brain, understanding the genetic basis of behavior, or relating functional imaging of the brain to clinical phenomena). Hyman indicated that the "old models of training are not providing what we need, and will need, to make the best of new knowledge and technology."

In requesting this study, the sponsors asked the committee to:

- Examine the needs and strategies for interdisciplinary training in the brain, behavioral, social, and clinical sciences to enhance the translation of brain/behavior to clinical settings and vice versa.
- Define necessary components of true interdisciplinary training in these areas.
- Examine the barriers and obstacles to interdisciplinary training and research.
- Review current educational and training programs to identify elements of model programs that best facilitate interdisciplinary training.

The committee had to consider some complex questions. For example, assuming that interdisciplinary health and behavioral research contributes to scientific knowledge, there is still no consensus about the most appropriate strategies for strengthening the capacity of the scientific community to conduct such research. Is it more productive to address the weakness of the knowledge base by strengthening individual disciplines or by encouraging interdisciplinary research? Is there a benefit to be gained by forcing integration, that is, causing fields to work together, or must this occur naturally?

To address its charge, the committee began by defining *interdisciplinary research* as that described in the *Interdisciplinary Research* section in this chapter. It identified *translational research* as a subset of interdisciplinary research that translates information between clinical settings and basic research laboratories. Within the context of translational research, clinician-scientists' training was considered as a possible method for producing scientists that can bridge the gap between clinical and basic sciences.

The committee gathered information through a workshop, interviews, a review of selected training grants, and a survey of the literature. During the workshop, *Opportunities for Interdisciplinary Training* (Appendix A), 11 directors of current interdisciplinary educational programs were selected to present their training methods and describe barriers they had to overcome. Speakers were invited to two of the four committee meetings to provide additional insight (Appendix A). Interviews and consultations were conducted with representatives of pharmaceutical companies, foundations, government agencies, and academic institutions (Appendix B) and with the directors of 10 NIH institutes (Appendix B). The committee reviewed 137 training programs (Appendix C) identified as interdisciplinary by IOM staff, committee members, or funding agencies; and it analyzed over 250 Requests for Applications (RFAs) or Program Announcements (PAs). It also reviewed such written materials as commentaries, editorials, training program descriptions, and reports from professional organizations.

The task of the committee is based on the premise that interdisciplinary research and training are important. The committee obtained the opinion of nine NIH institute directors on the requirement for this approach. The responses unanimously supported the need, although many acknowledged an absence of data to support this belief. With this input, the committee focused on how, rather than if, interdisciplinary research and training should be pursued.

The committee broadly interpreted its charge as a request to provide guidance on how to bring together scientists from different fields to explore new frontiers and to train new scientists so they would be prepared to interact with multiple disciplines. While the report focuses on examples from brain and behavioral sciences, the principles that developed from the deliberations should be widely applicable in scientific research. Much of the committee effort was focused on interdisciplinary research and training programs generally and on review of a representative sample of specific programs. In reviewing programs, the committee examined the role of university structures and the availability of training and mentors in influencing change. Changing academic structures and practices to support interdisciplinary research is a long and painstaking process that requires involving and educating academic decision makers, rewarding outstanding interdisciplinary scientists, and attracting excellent behavioral and biological scientists to explore interdisciplinary approaches. To that end, the committee examined means of encouraging interdisciplinary activities and overcoming obstacles.

Because evaluations of interdisciplinary training programs are scarce, the committee could not specify the "necessary components" or identify the elements that "best facilitate" interdisciplinary training. Instead, after reviewing existing programs and consulting with experts, the committee identified approaches that were likely to be successful in providing direction for interdisciplinary endeavors at various career stages. The committee is aware of costs that might be incurred in implementing its recommendations. In many instances, it will be a matter of shifting resources; in others, new resources will be needed. Until program plans are established, detailed accounting cannot be developed.

SCOPE AND STRUCTURE OF THIS REPORT

This report presents recommendations regarding the overall need for interdisciplinary scientists in behavioral science and neuroscience, the type and extent of training and funding mechanisms that might be needed to support interdisciplinary training programs and research, and the overcoming of barriers to the development and support of interdisciplinary education, programs, and research.

Chapter 2 begins by providing concrete examples of health problems that require an interdisciplinary approach. It provides the context of the rest of the report.

Chapter 3 describes the obstacles to interdisciplinary research and training, ranging from personal obstacles to institutional barriers. It recommends approaches to overcome these obstacles.

Chapter 4 describes several approaches to interdisciplinary training. It reflects on the programs reviewed by the committee and the lessons learned. It recommends approaches to improving the number and quality of such programs.

Chapter 5 brings together the committee's vision of interdisciplinary training and defines the need for future assessments of training programs.

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2

The Potential of Interdisciplinary Research to Solve Problems in the Brain, Behavioral, and Clinical Sciences

All knowledge begins with a question.

— Neil Postman

To address the health needs of the new millennium, both single disciplinary research and interdisciplinary—including translational—approaches will be needed. This chapter focuses specifically on the contributions, past and expected, of some fields of interdisciplinary science. The research questions described in this chapter will call for integrated efforts to develop methods for prevention, diagnosis, and treatment of disease and to understand the basic mechanisms of brain and behavior. Approaches to interdisciplinary research are diverse. The examples in this chapter illustrate translational research that applied clinical findings to basic science and vice versa, collaborations across disciplines, integration of past disciplinary efforts to create a new perspective, and the synergy created by central facilities that bring people together. The committee emphasizes that interdisciplinary research is an approach, not an end. It should arise out of a challenge; that is, it should develop in response to a problem that cannot be embraced by a single discipline.

Many problems require single disciplinary scientific approaches. Historically, single disciplines grew out of bodies of knowledge in efforts to promote a coherent and ordered focus of investigation and study. Single disciplines enable in-depth and technically adroit approaches to complex problems. As described in chapter 3, the constraints of training and getting started in a career make single disciplinary research the preferred route for many young investigators. The disciplinary approach to research is intellectually rewarding and leads to important findings. Investigators in single disciplinary work have contributed enormously to our understanding of basic biology and human health
—B. F. Skinner

in operant conditioning, von Bekesey in audition, and Hodgkin and Huxley in nerve conduction are examples. Furthermore, single disciplinary efforts often feed into interdisciplinary and translational efforts.

NEUROSCIENCE: EVOLUTION OF A DISCIPLINE

The brain has been studied for millennia. As early as the fourth century BC Hippocrates recognized the involvement of the brain with sensation and with epilepsy. In the mid-1600s, Thomas Willis, an English anatomist, provided a detailed description of the structures of the brain. Two hundred years later scientists began to correlate structures with functions. For example, Paul Broca related a clinical pathology to a structural defect noted on autopsy and Eduard Hitzig and Gustav Fritsch found that electrical stimulation of specific cortical areas produced movement. By the mid-1800s many histologists were describing the cellular components of the nervous system. (For example, see the section on Ramon y Cajal that follows.) Early in the nineteenth century, neurophysiology was gaining momentum with the efforts of scientists such as Charles Sherrington and Edgar Adrian, and neurochemistry was developing, with Henry Dale's isolation of acetylcholine.[25,53]

Up until a few decades ago scientists engaged in these endeavors identified themselves as anatomists, physiologists, psychologists, biochemists, and so on. In 1960 the International Brain Research Organization was founded to promote cooperation among the world's scientific resources for research on the brain.[41] In 1969, the Society for Neuroscience was founded to bring together those studying brain and behavior into a single organization; its membership has grown from 1000 in 1970 to over 25,000 in 2000.[86] Within the new discipline, neuroscientists are integrating a variety of perspectives to gain insights into fundamental questions about the nervous system in health and disease. Neuroscience is a clear example of a discipline of today arising from interdisciplinary approaches of the past. The discipline of neuroscience arose by combining the efforts of scientists in different fields to solve common scientific problems. It is a dynamic discipline in which new fields continue to be integrated (for example, informatics and molecular biology). The growth of this discipline has been so prodigious, the territories it covers so broad, and the methods it employs so varied that neuroscience itself is beginning to fragment into subdisciplines. One such subdiscipline is cognitive neuroscience, which is itself evolving as a new discipline.

DISCIPLINARY WORK PROVIDES A FOUNDATION

Disciplinary research has an important place in the scientific enterprise. As the examples here illustrate, the efforts of scientists in their own fields can create the tools or provide the basis for many future efforts. Interdisciplinary approaches often build on single disciplinary discoveries.

Human Genome Project

The Human Genome Project was established in 1988.[85] Before it could become a reality, however, decades of disciplinary efforts were necessary to lay the foundations. In 1944, Avery et al.[5] discovered that DNA carried the genetic message. The structure of DNA was first unraveled by Watson and Crick[99] in 1953, and the genetic code was worked out in the middle 1960s.[22] In the early 1970s, the methodology of recombinant DNA was published.[103] Years of basic research on enzymes such as restriction endonucleases, polymerases, ligases, and reverse transcriptases, provided the tools that are the basics of the methodology for the Human Genome Project. For example, when Temin and Mizutani[93] and Baltimore[7] first described reverse transcriptase in 1970, they were focused on how some viruses copy their genetic messages from RNA to DNA in host cells. The enzyme became the focus of biochemists and virologists trying to understand its characteristics. On the basis of their findings, the enzyme was recognized as important for the analysis of the genome.

Having evolved from independent, single disciplinary efforts, the Human Genome Project has expanded into a prime example of interdisciplinary research, involving scientists in a variety of disciplines, such as biology, chemistry, genetics, physics, mathematics, and computer science. The enormous data management problems arising from the wealth of information generated in genomic analyses require new and more powerful computational methods. In addition, important contributions to the analysis of the ethical and legal implications come from philosophy, jurisprudence, and ethics. The developing knowledge base is expected to serve as the foundation for new interdisciplinary efforts to understand the function of genes and the contribution of genetic diversity to both health and disease. The implications go beyond medicine and human health to applications in energy, environmental protection, agriculture, and industrial processes.[63,64,70,95]

Neuroanatomy of Ramon y Cajal

Santiago Ramon y Cajal won the Nobel Prize in 1906 for his work on the histology of the nervous system. Because Ramon y Cajal used the newest stains, optical microscopy, and anatomical approaches, one could argue that this innovator's research reflects the coalescence of multiple disciplines into a single discipline. His methods became the standard tools of the neuroanatomist. He shared the Nobel Prize with Camillo Golgi, whose principal contribution was a stain with a unique property: it revealed an entire cell and its processes. Despite the discrete entities stained, Golgi continued to support the prevailing belief that the nervous system was a continuous network of fibers. Ramon y Cajal, however, reinterpreted the observations to support the “neuron doctrine,” which today is basic to our understanding of central nervous system organization. His histological studies provided detailed representations of cells from many parts of the nervous system and created a starting point for understanding their connections, their physiology, and their pathophysiology. Ramon y Cajal's work is still cited in reports on subjects as varied as gene expression in rat brain,[51] electrophysiology of synaptic currents,[8] and axonal regeneration in spinal cord.[23]

TRANSLATIONAL RESEARCH: TO THE CLINIC AND BACK AGAIN

The following examples illustrate how clinical and basic researchers can join together to advance a field. In one case, a chance conversation about a clinical observation led to a basic science breakthrough in understanding pathology. In the other case, a patient's unfortunate circumstances created the stimulus for a field that continues to integrate basic and clinical investigation.

Breakthrough in Sickle Cell Anemia

While they served together on an advisory committee, William Castle, a clinician, described to Linus Pauling, a physical chemist, his observation that in sickle cell disease the red blood cells were abnormally shaped only when deoxygenated. Pauling hypothesized that the abnormal shape of the red blood cells in the patients was a result of an altered shape of the oxygen-carrying hemoglobin molecule. On his return to his laboratory, Pauling and a young colleague, Harvey Itano, attempted to distinguish normal hemoglobin from sickle cell hemoglobin by using a variety of physical and chemical methods. With a new electrophoresis technique, they found a difference in mobility suggesting that the two forms of hemoglobin had different electrical charges.[89] The results were published in a *Science* paper titled, “Sickle Cell Anemia, a Molecular Disease.”[72] The paper reasoned that genetic control of the amino acid composition of hemoglobin was responsible for the hereditary nature of the disease. The field of genetic medicine was born of the interaction between a bedside clinical investigator and a basic laboratory scientist. From this first recognition of the molecular basis of the pathology has followed the development of treatments: drugs that address the pathophysiology of the disease[16] and nitric oxide,[35] bonemarrow transplantation,[98]and the promise of gene therapy.[49,55,92] The development of animal models[71,76] promises to continue to bridge the gap between laboratory and clinic.

THE STORY OF PATIENT HM

In an effort to control a severe case of epilepsy, a patient known as HM had most of the temporal lobes of his brain removed bilaterally in the early 1950s. The consequences were unexpected. HM was unable to form new memories. He could remember his childhood and he could recognize his mother. But, although he could learn a name or memorize a number for a very short time, the information was lost to him after a few minutes.[81] HM's condition provided a clinical model that stimulated extensive laboratory efforts to understand the neurobiology of memory. Mishkin[59] reproduced the lesions of HM in primates to develop an animal model to study the process of memory. With the evidence of hippocampal and medial temporal lobe involvement in memory formation, many basic laboratory investigations focused on neurophysiological mechanisms, neuroanatomic substrates, and behavioral deficits in animal models. As the understanding of memory grew, the impairment in HM and other unfortunate patients was reevaluated.[20,21,58,75,88] For example, the testing of HM's capabilities supported the laboratory-generated hypothesis that there are different kinds of memory processes. Although HM does not recall having met a visitor or recall the process of learning a task like mirror writing, he can improve his skill at mirror writing at a normal rate and even retain the skill for weeks.[29] Clinical observations of memory loss continue to stimulate the basic animal research efforts with clinically relevant questions.[87] The advent of new imaging technologies, such as functional magnetic resonance imaging, and new noninvasive recording methods, such as magnetoencephalography, continue to enhance the interactions between clinical and basic research.[21,28,87]

INTERDISCIPLINARY RESEARCH: MAKING PROGRESS

Several interdisciplinary programs have been running long enough to demonstrate the added value of interactive efforts. Whether developed through the encouragement of a funding agency or through the leadership of an individual, these programs illustrate the breadth of what can be achieved when disciplines come together to solve a problem. The role of the leader of an interdisciplinary team is analogous to that of an orchestra conductor who coordinates highly specialized experts to produce harmonious outcomes. The leader would be expected to converse freely with persons in disparate fields and to facilitate the interactions among team members. The expectation for the team members is to be responsible for issues involving their expertise and to develop a working knowledge of each others' fields. The composition of the “orchestra” would not be fixed, but, rather, would change depending on the particular problem at hand. With time, participants would expand their understanding of other fields while continuing to contribute their own expertise.

Cardiovascular Health and Behavior

In recent years, fields that have not traditionally embraced interdisciplinary research have begun to recognize that it is essential. For example, the National

Heart, Lung, and Blood Institute Task Force on Behavioral Research in Cardiovascular, Lung, and Blood Health and Disease concluded in 1998 that collaborations between behavioral and medical researchers would provide a better understanding of disease. Many Americans are living with heart disease, including more than 13 million who have angina pectoris or who have suffered a myocardial infarction.[65] Management of their disease and prevention of recurrent disease are foci of attention for behavioral and clinical scientists.

Recent studies have demonstrated that such behaviors as smoking, lack of exercise, and inappropriate diet can increase the risk of heart disease. Epidemiological studies, clinical investigation, and experiments in animal models have provided new understanding of the physiological links between behavior and pathology. In addition, personality traits, exposure to stress, socioeconomic status, and social support have been found to influence the risk of cardiovascular disease. Extensive research collaborations among experts in many fields—including psychologists, neurobiologists, cardiologists, and comparative pathologists—provided evidence that stress, anger, and lifestyle influence the pathophysiology of coronary heart disease.[43,46] Large interdisciplinary clinical trials are in progress to determine whether psychosocial interventions can reduce morbidity and mortality in heart diseases.[10,84] Continued interdisciplinary research is likely to produce new advances in the prevention and management of cardiovascular disease.

Schizophrenia

Schizophrenia is a chronic and disabling mental disorder. Diverse symptoms encompass abnormalities in perception, thinking, speech, affect (expression of emotion), and behavior. Hallucinations, delusions, and social withdrawal are commonly associated with the disease. Schizophrenia usually first manifests itself in young adults. Patients suffer from public stigma because of their unusual behavior. Although treatments are available, adherence to treatment regimens is a problem, in part because of the side effects of the pharmaceutical agents. Although we are using schizophrenia as though it were a single disease, it would be more accurate to use the schizophrenias because of the likelihood of underlying disease heterogeneity.

There is now general agreement among experts in schizophrenia that abnormal brain development from many causes underlies the disease.[9] Advances in neuroimaging have shown that some people with schizophrenia have abnormally large ventricles (fluid-filled cavities) within the brain.[52,100] Schizophrenia has been associated with impaired migration of neurons in the brain during fetal development.[2] Both genetics and environmental factors influence development of the disease. Twin studies and other genetic epidemiological assessments indicate clearly that a genetic predisposition to the disease exists.[44,45,73] Some data suggest a link between schizophrenia and maternal viral infection during gestation.[101]

Recent studies have brought together multiple disciplines in attempts to understand the disease in its entirety. For example, the combined use of such neuroimaging techniques as positron emission tomography (PET) to look at blood flow and magnetic resonance imaging to look at structures, genetic analyses, cognitive testing, and clinical trials of pharmaceutical agents to evaluate patients with schizophrenia is allowing progress toward the development of interventions for the disease.[4] Continued interdisciplinary efforts in schizophrenia research—including epidemiology, genetics, structural brain abnormalities, development, behavior, and virology—should advance the understanding and treatment of the disease.

INTERDISCIPLINARY RESEARCH: FUTURE DIRECTIONS

Major advances in human health are increasingly contingent on interdisciplinary research that requires close collaboration between biomedical and behavioral scientists. Although research in single disciplines has made and will continue to make important contributions to understanding chronic diseases, current efforts are needed to solve problems that stem from multiple domains. The committee heard from the directors of several of the National Institutes of Health (NIH) about fields ripe for interdisciplinary research (see Appendix B), including:

- The management of symptoms at the end of life: the complex interaction of clinical symptoms (including biochemical, neurological, endocrine, immune, and psychological status), therapeutics, and ethics.
- Alcoholism: integration of neuroscience, genetics, molecular biology, neurochemistry, electrophysiology, imaging, and more.

  The "oldest old:" complex health and social concerns in those over 85 years old.
- Vulnerability to addiction: merging genetics, environmental risk, protective factors, behavior, and neuroscience.
- Treatment research, including adherence issues: bringing to bear behavioral, psychosocial, pharmacological therapeutic, and clinical concerns.

Clearly, many problems that face today's society require coordinated efforts in multiple disciplines. The following examples can give a flavor of the benefits that an interdisciplinary approach could provide.

Pain

Pain is one of the most frequent reasons for visits to the doctor and costs society greatly in medical expenses and loss of productivity.[15,50] The effect of pain on immune function and mental attitude can influence patient outcomes and prolong hospital stays.[47] Gender, genetics, and cultural background affect how a person responds to painful stimuli; stress also modulates pain. There are many types of pain, and they have different neural pathways and different underlying mechanisms. Some painkillers are addictive, and the risk of chemical dependence needs to be considered in studying pain and its control (for reviews see: Melzack, 1999[56] and Good, 1999[34]).

The study of pain requires coordinated efforts in a number of disciplines to develop therapeutic approaches (for example, see Dubner and Gold, 1999[24]). Imaging technology can provide a better understanding how the of brain functions during painful experiences. Cellular electrophysiology can elucidate the neuronal mechanisms involved and define potential sites for pharmacological intervention. Neurochemistry can identify and characterize trophic factors and neurotransmitters that influence the modulation and perception of pain. Genetic analyses can elucidate inherited susceptibility to pain. Social, psychological, and cultural approaches can provide a better understanding of the interaction of sociocultural environments and the neurophysiological substrates of pain. Such understandings will provide new insights into pharmacological and behavioral means of coping with pain.[67]

Injuries

Injuries, both intentional and unintentional, are the leading cause of death of people 1–44 years old. They continue to be the cause of many deaths and serious disabilities throughout life, although other causes (e.g., heart disease, cancer, stroke) become more common in later life.[13,14] Many injuries that do not cause death result in lifelong serious disabilities, such as spinal cord paraplegia and quadriplegia. Injury in the elderly is often the precipitating event in terminal illness, especially pneumonia.[62,94] The term *unintentional injury* is now used, rather than *accidents,* to indicate that they are subject to the same epidemiological analysis of the interaction of host, agent, and environment as any other cause of death or disability.[39,40] Unintentional injuries result from characteristics of the injured (e.g., temperament and neurological status) and from agents in the physical and social environment. Prevention programs can control the environment (for example, with safety caps on medicines and poisons, seatbelts and airbags in automobiles, safer and more engineered roads) or change individual behavior (for example, with helmet use by bicycle riders, and reduction in drinking and driving).[40] Future research will be greatly enhanced by interdisciplinary efforts of psychologists, neuroscientists, engineers, regulatory agencies, and device manufacturers working together on epidemiological studies and interventions.

Obesity

In late 1999, Jeffrey Koplan, director of the Centers for Disease Control and Prevention, issued a report on the growing obesity epidemic in the United States.[60] The report documents the alarming increase in obesity during the 1990s. According to the report, the prevalence of obesity (defined as 30% over ideal body weight) increased from 12% in 1991 to 17.9% in 1998. Obesity increased in all states and all demographic groups, including race, education level, and age. Over the same interval, physical inactivity, a major contributor to obesity, was essentially unchanged. Since obesity is associated with many chronic illnesses, including heart disease and diabetes, those trends pose a major public health concern. According to Koplan, "overweight and physical inactivity account for more than 300,000 premature deaths each year in the United States, second only to tobacco-related deaths."[12] Even in children as young as 5 to 10 years old, over half those considered overweight already show at least one risk factor for heart disease.

Obesity prevention and control provide fertile ground for interdisciplinary research. Both genetic and environmental factors influence body weight. Understanding of the behavioral components that contribute to obesity, including inactivity and overeating, is necessary for effective interventions.[36] Sociocultural differences in the prevalence of obesity among ethnic and socioeconomic groups require clarification. In addition, the physiological mechanisms that regulate appetite and metabolism need to be elucidated. In the middle 1990s, a concerted effort was made to find genes that contribute to obesity.[18] The hormones mediating appetite (including leptin, neuropeptide Y, and melanocyte-stimulating factor) are under active investigation. Additional physiological factors that control dietary intake, energy expenditure, and energy regulation must be better understood.[11] New information on hypothalamic pathways that influence food intake[26,78] has increased theoretical understanding of body weight regulation but is still far from clinical application. Understanding and clinically addressing dietary behavior require an integration of the genetic, endocrine, metabolic, and neurophysiological components with environmental factors and cultural factors.

EFFECTIVE FUNDING INITIATIVES IN INTERDISCIPLINARY RESEARCH

Many interdisciplinary efforts arise out of serendipity, but many arise out of need and the ripeness of research problems. Targeted programs in interdisciplinary research have yielded valuable knowledge and clinical results. Two such programs supported by NIH are described below as examples of initiatives that the committee found to be model programs.

Alzheimer's Disease Centers

Research in Alzheimer's disease has made rapid progress as a direct result of opportunities for interdisciplinary investigation fostered by NIH. Almost 2 decades ago, despite the great need for research on the medical and social problems resulting from Alzheimer's disease and related dementias associated with aging, there was little activity. The lack of interest was coupled with the widespread misunderstanding that dementia is a natural consequence of aging.

The National Institute on Aging (NIA) recognized that advances in understanding Alzheimer's disease required the coordinated efforts of neurologists, psychiatrists, neuropathologists, psychologists, neurochemists, molecular biologists, geneticists, and epidemiologists in an interdisciplinary approach to address the neurological, behavioral, familial, and social implications. To address that need, NIA developed a Request for Applications (RFA) for Alzheimer's Disease Research Centers (ADRCs). These clinical centers were required to have both cores and scientific projects. The mandated cores were *clinical* to recruit patients with dementing illnesses, *neuropathological* to archive neuropathology specimens, *educational* to provide scientists and the general public with information about the dementias, and *administrative*. The scientific projects were investigator-initiated clinical or basic neuroscience studies of dementing diseases and included at least two pilot projects.[69] A small number of ADRCs were created at first. As the ADRCs proved effective, additional funds were allocated and the number of centers grew. Later, NIA created Alzheimer's Disease Core Centers (ADCCs), which supported only core facilities with the expectation that other investigator-initiated studies would be stimulated by the availability of the funded cores.[68] NIA now funds 29 Alzheimer's Disease Centers around the country.[6]

The development of the Alzheimer's Disease Center programs was scientifically beneficial. Advances in understanding of the basic pathophysiology of Alzheimer's disease have been striking, with promises of effective preventive strategies in the near future. Among the advances arising from the centers is delineation of the neuropathological changes, including the deposition of senile plaques, the development of neurofibrillary tangles, and the loss of neurons from critical brain regions.[17,33,61,82,102] Discovery of the alleles of apolipoprotein E revealed an important risk factor for Alzheimer's disease.[19,38,48,74,77,80,90,91] With the development of transgenic mice that express some of the neuropathological changes of Alzheimer's disease, an animal model is available to further the understanding of the basic biology of the disease and to test promising therapies.[30] Those advances are leading to medications to improve cognition and others that might even prevent symptoms.[79]

PET CENTERS

The targeted allocation of federal funds by NIH led to the development of PET as a means of studying the metabolism and biochemistry of the brain. In the late 1970s and early 1980s, PET technology had matured enough to be highly promising, but requiring further development to make a scientific impact. In 1985, NINCDS put out an RFA to create "Brain Imaging Research Centers" to advance the use of the technology in studying dynamic changes in the brain under normal and pathological conditions.[66] The terms of the RFA required the interdisciplinary collaboration of clinicians and scientists, including areas such as nuclear medicine, neurology, psychiatry, and neuroradiology. Members of the team needed to comprehend each specialist's field at some level to understand the possibilities of the new technology. The RFA asked for proposals that included development of cores facilities and hypothesis-driven scientific research projects. Following peer review, five centers were funded.

The effort led to substantial advances in understanding of biochemical processes in the human brain in health and disease. The studies included examination of regional cerebral blood flow, glucose metabolism, oxygen metabolism, and localization and concentration of biochemical substances, such as dopamine receptors, gamma-aminobutyric acid receptors, and opiate receptors.[97] The PET centers also advanced understanding of numerous neurological disorders, including stroke, epilepsy, Alzheimer's disease, Parkinson's disease, multiple system atrophy, and alcoholism, to name just a few.[1,3,27,31,32,37,42,54,57,96] Cognitive psychology was advanced by combining psychological activation of the resting brain with PET studies of cerebral blood flow as a marker of changes in metabolic rate of the relevant brain regions (for a review, see Sergent 1994[83]). The recent development of functional magnetic resonance imaging has superseded PET for activation studies because of the lower costs involved. The development of single photon emission computed tomography, which can be performed with radioactive pharmaceuticals that have a long half-life, led to widespread imaging of the brain's metabolic and biochemical processes.

FINDINGS AND RECOMMENDATIONS

A great many interdisciplinary programs currently exist. Whether developed through the encouragement of a funding agency or the leadership of an individual, these programs illustrate the breadth of what can be achieved when disciplines come together to solve a problem. To ensure the future of interdisciplinary research for solutions to complex problems, training is essential to prepare the next generation of investigators to tackle these interdisciplinary tasks.

Funding agencies can be influential in moving fields forward by organizing funding mechanisms around specified opportunities, technologies, or problems. To allow optimal use of funding dollars, it is important to target the problems that would most benefit from interdisciplinary approaches. Only after these problems are recognized should resources be allocated toward them. To identify such problems, lines of communication between sponsors and researchers should be established.

> **Recommendation 1: Federal and private research sponsors should seek to identify areas that can be most effectively investigated with interdisciplinary approaches. This should be done by engaging the research community through symposia, working groups, or ad hoc committees.** Funding mechanisms, such as Requests for Applications or Proposals, should be developed to address the identified areas.

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3

Barriers to Interdisciplinary Research and Training

In science, novelty emerges only with difficulty, manifested by resistance, against a background provided by expectations.

—Thomas Kuhn

The literature is replete with descriptions of the traditional and persistent barriers to interdisciplinary research, including attitudinal resistance, differing research methods and communication barriers among disciplines, the length and depth of training in a single field necessary to develop scientists who will be successful in competing for funds, the difficulty in forging a successful career path outside the single disciplinary structure, impediments to obtaining research funding for interdisciplinary research, the scarcity of interdisciplinary departments in academe, and the perceived lack of outlets for the publication and dissemination of interdisciplinary research results. The heterogeneity of institutions, structures, and value systems at the private, state, and federal levels compounds the complexity of these obstacles. The barriers might best be presented in five major categories: attitude, communication, academic structure, funding, and career development. Despite the hesitation of some scientists to engage in interdisciplinary research, the nature of the complex scientific challenges that we face creates a need to ensure that it can occur.

ATTITUDINAL BARRIERS

Most scientists recognize a need for interdisciplinary research, many are reluctant to abandon their disciplinary focus.[52] In the 1980s, Sigma Xi, The Scientific Research Society, surveyed its members as to whether they agreed with the statement that "more interdisciplinary research should be funded because many of the most significant scientific problems cannot be accommodated within arbitrary disciplinary structures." Almost three-fourths (2,995 of 4,071) of the responding society members reported that they "agreed" or "agreed emphatically." The perception exists, however, that interdisciplinary science is viewed as second-rate.[50,52] At the committee's workshop (IOM Workshop, 1999), Dr. Paul Smolensky pointed out that disciplines have been able to investigate a given subject in depth. But when research bridges disciplines and this same depth cannot be attained, the quality of the research is perceived as poor. In another survey of its members, "Removing the Boundaries: Perspectives on Cross-Disciplinary Research," Sigma Xi received responses from over 120 members representing seven scientific disciplines, including psychology and medicine who expressed opinions on obstacles to interdisciplinary research.[52] Some of the comments indicated concerns: working in interdisciplinary research was not "pure"; it was "less challenging" or "high risk"; those who do collaborative work could not succeed in their own discipline; they would be lost in a team effort and "lose their professional identity." Others have expressed similar views:

> While they pay lip service to the principle [of interdisciplinarity], most scientists look upon their own discipline as either too incomplete or too immature to be coupled with another one.
>
> —De Mey, as cited in Bechtel[10]

Despite the hesitation of some about venturing into an interdisciplinary effort, many have embraced it enthusiastically. The motivation for moving into interdisciplinarity is varied. Some scientists working in their own disciplines might see after working on a problem for some period that their scientific approaches are insufficient to answer their questions. Scientific interactions can stimulate ideas that are new and exciting but require additional expertise or techniques to pursue. Funding opportunities might provide an impetus to seek out collaboration to answer broad scientific problems identified by funding agencies. Some might be attracted by the challenge and the need for answers to a larger problem and the satisfaction that would come from making progress.

COMMUNICATION BARRIERS

Jargon

Scientists trained in a discipline learn to speak a specific language and adopt the analytical and methodological constructs that have accumulated in that discipline. This constitutes a form of professional socialization that serves as an important part of the training experience, but it can present obstacles to interdisciplinary research.

> We speak the language of our discipline, which raises two problems: first, we may not understand the languages of the other disciplines; second, more dangerously, we may think that we understand these, but do not, because although

> the same terms are used in different disciplines, they mean something very different in each.
>
> — Margaret A. Somerville[55]

In addition, the problem exists that "different disciplines are continually rediscovering one another's discoveries, because they all have different names for them" (P. Smolensky, IOM Workshop, 1999).

Communicating with another discipline requires time and work. An extensive effort must be made to learn the language of another field and to teach others the language of one's own. Many have recognized that this barrier must be overcome before successful collaboration can occur.[8,29,40,52]

Intellectual Turf

By definition, interdisciplinary efforts bring together researchers who have different expertise. Pride in one's discipline and its methods can be instilled during graduate school.[59] As a consequence, other disciplines might be viewed as less rigorous or important. To work together, people must understand and appreciate the value and limitations of both their own and others' methods. Groark and McCall[24] have written about the distrust between researchers and clinical providers: each group believes in its own superiority. The same can occur between disciplines.[16,38] Heated discussions can result when people with different backgrounds try to assert the correctness of their views (D. Tracer, IOM Workshop, 1999; P. Smolensky, IOM Workshop, 1999).

Team Building

Teamwork requires trust in another's skills and expertise. If these are outside one's field, as implied in interdisciplinary research, they might be difficult to evaluate.[52] Interdisciplinary team members sometimes have difficulty in evaluating each other's performance on a given project because the criteria that are appropriate for such an evaluation are not familiar.[6] Moreover, reward systems and practices regarding authorship differ among disciplines.[33,41] Good communication skills are helpful in alleviating such problems, but most members of interdisciplinary teams lack training and proficiency in such skills.[15]

Relationships among team members affect productivity.[9] Team members need to be able to compromise and cooperate.[24,40,52] A feeling of community can facilitate interactions in an interdisciplinary team.[17] Many stress that good communication among team members is essential for the process to succeed.[8,18,40]

In building an interdisciplinary team, clarity regarding roles, expectations, and authority—particularly with regard to sharing of data and resources—is important for success.[12,22] Mutually acceptable policies for disseminating research results (including authorship) and facilitating achievement of team members' personal and professional goals need to be developed.[40] A possible consequence of not having a team process is that crucial voices will be missing in defining and solving the research problem.[39] All that suggests that it takes interpersonal skills to conduct interdisciplinary research and that expertise in disciplinary methods alone might not be sufficient.

Leadership

Interdisciplinary research teams need leaders who understand the challenges of group dynamics and who can establish and maintain an integrated program. Leaders need to have vision, creativity, and perseverance. To establish a successful interdisciplinary program requires education of scientific colleagues and administrators about the potential value of interdisciplinary research. To coordinate the efforts of a diverse team requires credibility as a research scientist, skill in modulating strong personalities, the ability to draw out individual strengths, and skill in the use of group dynamics to blend individual strengths into a team. Some have suggested that the best persons to direct interdisciplinary teams are mature scientists with well-established research careers who have conducted interdisciplinary research of their own.[52]

Facilitating Interactions

In the experiences of the committee members, chance interactions can promote interdisciplinary collaborations. The casual discussion of research at the coffee machine, the fortuitous meeting in the corridor with a colleague from another department, an interesting seminar, or interactions among students and postdoctoral scientists—all can trigger collaboration. Buildings that isolate laboratories and research groups from one another can limit this type of interaction. But, bringing people together through the creation of central facilities or common areas can increase its probability.

Common location of faculties leads to interactions, scientific discussions, and possibly new insights on research data. For example, Washington University invested $28 million in a new laboratory building to house a shared imaging facility, animal facility, and psychology laboratories with the intent of encouraging interdisciplinary collaboration.[43] More recently, the University of California, Berkeley launched an interdisciplinary “Health Sciences Initiative” that includes the construction of two buildings that will house laboratories of researchers from several departments.[51] The intent is to encourage daily interactions among the investigators in a variety of fields, such as physics and molecular biology. Similarly, in an effort to integrate the intramural neuroscience research, NIH is planning a center that will co-localize the basic and clinical neuroscientists from nine institutes.[53]

Architectural design can promote interactions,[11] but virtual proximity, through the Internet or videoconferencing, provides another opportunity for achieving intellectual proximity as needed and deserves further research and consideration.

ACADEMIC AND PROFESSIONAL BARRIERS

Academic Structures

A 1998 editorial in *Science*[21] asserted that the modern university is "partitioned along academic lines that no longer truly reflect today's intellectual life. These academic groupings are now just categories that accountants and business managers use to build a budget. The issue is most pronounced in the scientific disciplines." Others have written about the conflict between the scientist's professional need for autonomy and identity and the organization's need for an efficient bureaucratic structure.[18] Despite some pioneering approaches (e.g., Rockefeller University's absence of departments and the University of California, Berkeley Health Science Initiative, which coordinates hundreds of scientists in multiple schools[51]), institutions change slowly. Thus, in considering interdisciplinary research and training, the continued presence of some system of academic departmentalization must be acknowledged.

Academic departments create an environment within which training and research occur. Discipline-oriented departments constitute a functional authority structure in charge of teaching, faculty recruitment, advancement, and promotion—as well as degree programs and courses. Funding processes reinforce the departmental structure. The departmental structures of universities have evolved primarily on the basis of scientific advances. However, departmental organization changes relatively slowly. The priority given to contributions in fields that correspond to departmental structures can inhibit interdisciplinary approaches.

Institutional policies regarding allocation of laboratory space, hiring, and promotion policies vary considerably, but the department chair generally has a major influence. Institutions vary in how they distribute credit for successful grants. Some allocate funds and resources among the investigators and their units, but others credit only the person listed as the principal investigator. That can penalize coinvestigators in other departments, in that their home departments might get no credit. The cross-departmental nature of interdisciplinary research is likely to compound the problems of allocation of credit and research resources when grants are funded across departments or schools.[52]

Promotion and tenure policies and practices are major motivators and controlling devices for academic scientists. In a survey of 366 faculty spanning five disciplines in six universities, Moore[41] found that quality and quantity of publications, followed by grantsmanship, were the most important criteria for tenure but that departmental politics guided all these considerations. It can be difficult, therefore, for junior faculty whose interests range beyond the formal subject matter of a given department to be viewed as either making substantial contributions or as being appropriate for advancement in a given department.

To counter some of those concerns, many universities have established interdisciplinary programs or centers that cross departments. For example, at the committee's workshop (IOM Workshop, 1999), Dr. David Tracer described a program in Health and Behavioral Science at the University of Colorado, and Dr. Donald Heistad described a center for aging research at the University of Iowa. Faculty members in such programs have a “home department” but participate in the research and training functions of the interdisciplinary effort. This approach does not eliminate the obstacles to interdisciplinary research within a department, but it does formally recognize the interdisciplinary endeavor.

Interdisciplinary research requires a commitment from university administration. A cross-departmental program can suffer if the administration does not consider the needs for faculty, space, and funds. Through control of faculty positions, the university leadership can promote collaboration, for example, by requiring a position to be jointly supported by two departments (T. Detre, IOM Workshop, 1999) or by ensuring that interdisciplinary programs do not drift back to a primarily single disciplinary perspective (A. Binder, IOM Workshop, 1999).

Funding agencies can facilitate commitment from high-level university administrators. For example, the National Science Foundation (NSF) Integrative Graduate Education and Research Training (IGERT) program requires support from the university administration to develop an application. Each year, NSF brings together the principal investigators for the grants and a high-level university administrator to discuss obstacles. This educates and involves the administrative officers and promotes the sharing of approaches among funded universities. Similarly, some National Institutes of Health (NIH) funding mechanisms call for institutional commitments. For example, the National Cancer Institute's Specialized Program of Research Excellence (SPORE) in Breast Cancer, which supports translational research, requires applicant organizations to supply a statement of institutional commitment that describes the mechanisms by which the program is given high institutional priority; the infrastructure for establishing, maintaining, and monitoring the program; and the plans for recruitment to strengthen the scientific capabilities of the program.[46] In addition, the institution is required to provide evidence of tangible commitment of space and money.

Requirements of institutional commitment as a condition of application and funding are likely to bolster institutional support. This support could influence the departments, eventually affecting tenure and promotion decisions. The IGERT administrator at NSF reported, for example, that some institutions are now making changes to their tenure procedures for young faculty to decrease the problem of tenure “jeopardy.” This problem results from the lack of recognition by the institution and faculty of interdisciplinary efforts in the tenure decision process (W. Jennings, Third IOM Committee meeting, 1999).

Publications and Professional Organizations

Professional organizations and journals are key ingredients of disciplinary identity.[10] Their major impact is in providing an outlet for dissemination of information. Whitley[58] commented that "the existing set of journals in a science constrain and direct research topics and ways of working on them." Although some societies (e.g., the Society for Neuroscience) are interdisciplinary by design, many are discipline-specific. Similarly, some journals (e.g., *Science, Nature,* and the *New England Journal of Medicine*) are broad-ranging, but the vast majority are discipline-specific. Multidisciplinary researchers, as opposed to more discipline-identified professionals, face problems of professional identity and outlets for publication in prestigious journals.

Research reputation is essential to obtaining support for research, gaining employment, getting promotions, and winning grants. Authorship of papers is perhaps the most important predictor of one's success in these activities.[26] The size of collaborative groups can limit the frequency of first-authorship and thereby pose problems for interdisciplinary researchers. New editorial policies on authorship are arising out of ethical concerns about multiauthor papers.[32] To protect against fraud, there is a growing call to define the contribution of each author.[28,34,57] Acknowledging individual contributions to a research effort might provide a means to provide credit to people involved in interdisciplinary research, above and beyond senior authorship.

FUNDING BARRIERS

Federal Funding

Scientists perceive that they will encounter difficulties in obtaining support for and conducting successful interdisciplinary research because funds for such research come from many agencies with different programmatic emphases. In contrast with that perception is the apparent consensus among federal research sponsors that interdisciplinary research and training are essential (NIH directors, consultation, 1999 and W. Jennings, Third IOM Committee meeting, 1999). The importance of interdisciplinary research to NIH is reflected by a review of the Requests for Applications (RFAs) that are posted to encourage research in fields of special interest. An average of 23% of all RFAs issued in 1992–1999 by the National Institute on Aging (NIA), the National Institute of Neurologic Disorders and Stroke (NINDS), the National Institute of Mental Health (NIMH), Office of Behavioral and Social Sciences Research (OBSSR), the National Institute on Alcohol Abuse and Alcoholism (NIAAA), the National Institute of Nursing Research (NINR), and the National Institute on Drug Abuse (NIDA) addressed interdisciplinary research (Figure 3-1). In addition, interagency collaborations bring together multiple perspectives. As examples in chapter 4 illustrate, partnerships among NIH institutes, among government agencies, or between government

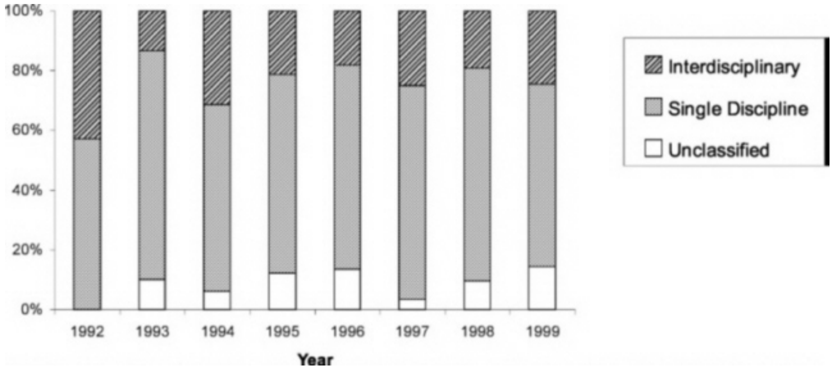

FIGURE 3-1 Annual distribution of Requests for Applications.

and the private sector often provide a broad base of support for interdisciplinary research and training.

Peer Review

Although strong peer review is considered to be the basis of a successful funding system, it is a long-held perception that it puts interdisciplinary research proposals at a disadvantage. Many have suggested that the traditional proposal evaluation by discipline-specific study sections makes it difficult for interdisciplinary proposals to compete successfully.[52] In an “open letter” to NIH, Howard Morgan[42] wrote that, “peer review of cross-disciplinary research presents the problem of the definition of a peer.” Even if all disciplines covered by a proposal are represented in a review committee, unless the committee members themselves have tried to do interdisciplinary research in the field in question, they might not appreciate the issues. Morgan called on NIH to correct the problems associated with the review of interdisciplinary grants. In their responses, representatives of NIH acknowledged the legitimacy of the concern.[23,37]

To address those concerns, NIH's Center for Scientific Review initiated a major overhaul of its system with the creation of a Panel on Scientific Boundaries for Review in 1998. In redesigning the integrated review groups (IRGs), the panel tried to ensure that all biomedical sciences were encompassed by the IRGs, each IRG (comprising several study sections) could cover the full range of expertise necessary for review, and all studies (basic and clinical) related to a particular disease would be covered within a single IRG (or a related set if necessary).[2] Within that structure are the four IRGs for the neuro- and behavioral sciences created in response to the incorporation of NIMH, NIDA, and NIAAA into NIH from the former Alcohol, Drug Abuse, and Mental Health Administration (ADAMHA).[1] The new peer review system is specifically intended to be more supportive of translational and interdisciplinary science. The first phase of the peer-review reform, completed early in 2000, created the IRGs. The next phase, expected to take another 2 years or so, will define the constituent study sections.[2] It will be important to monitor the new system and to track whether it increases the number of shared funding arrangements and collaborations and whether interdisciplinary proposals fare as well as single disciplinary proposals in the review process.

CAREER BARRIERS

Duration of Training

The length of time required to complete training in more than one field—whether in the basic or clinical sciences or in a combination of the two—can be discouraging. The explosion of information in each scientific discipline raises concerns about how long it would take to attain expertise in one, let alone two or more, fields. The requirement for depth of knowledge in one field during graduate school might seem to preclude obtaining breadth in other disciplines within a reasonable period.[52] The length of graduate training is increasing and the time spent in postdoctoral positions is also on the rise.[45,48] Interdisciplinary requirements might worsen the delay in starting a career.

That concern is especially relevant to clinician-scientists. To complete general and subspecialty training in most medical specialties requires 5 years or more after medical school. Little or none of this clinical training is directed toward research, so those interested in research must complete an additional 2 years or more either in the graduate student or at the postdoctoral level. The additional years of training burden come at a time when trainees are also trying to advance other parts of their lives, such as having families; this is a problem particularly for female physicians.

Debt

Educational costs are increasing. To pay for their training, many students are taking loans for their undergraduate or professional education. A 1997 survey of recent doctorates in psychology revealed that 63.8% of the graduates reported debt.[4,35] Of them, nearly one-third had debt of $41,000 or more. Debt was greater for those who specialized in clinical subfields (average, $35,000) compared with research (average, $15,000). The debt was greater for graduates with clinical PhDs from professional schools (average, $60,000). Medical students can carry an even higher debt. In 1997, the mean debt of graduates was over $80,000; some owed more than $100,000.[7,19,31] In fact, at the University of Medicine and Dentistry of New Jersey, the reported debt exceeded $100,000 for 40% of the 1998 graduating class.[7] Such a burden of debt is a strong factor against a decision to continue in research, let alone interdisciplinary or translational research.

An additional disincentive is the relatively low salary in academic research careers compared with positions in clinical practice or private industry (for example,see the American Psychological Association, Full-Time Salaries of Psychologists[5]), especially in the face of large debt. Although some surveys have suggested that debt does not influence choice of specialty (for example, see Kassebaum and Szenas[30]), it could influence the choice to pursue interdisciplinary or translational research. Graduates from an academic pediatric residency program were surveyed on factors that influenced their career paths; over half those responding indicated that salary expectation discouraged them from entering research.[36] Furthermore, the financial concerns might have a particular influence on the career paths of minorities and women. Analysis of data from an Association of American Medical Colleges survey revealed that "being a woman and being an underrepresented minority were associated with plans to enter salaried clinical practice."[25]

To encourage clinicians to engage in research, Congress passed a law in 1998 establishing Loan Repayment Programs (LRPs) related to AIDS research (AIDS-LRP), general research (General-LRP), and clinical research (CR-LRP).[27,47] These programs allow NIH to repay up to $35,000 per year in eligible education loans for participants who obtain research employment at NIH. Most graduate degrees (for example, PhD, DDS, DVM, DNSc) qualify a candidate for consideration, but the emphasis is on physicians. In addition, to qualify for the CR-LRP, a person must have a "disadvantaged background." Others have recognized the value of these loan-repayment programs to encourage careers in clinical investigation and have urged Congress to pass legislation to address the national need.[44] The committee similarly believes that extending these loan repayment programs could provide an increased incentive to pursue interdisciplinary research training.

Job Opportunities

There is a concern among junior scientists that training in interdisciplinary fields will not prepare them for careers. "Jack of all trades, master of none" is a refrain that is often heard when interdisciplinary training is proposed.[50] It raises the question, Is there a market for people trained with an interdisciplinary perspective? Some have reported difficulties in finding positions for graduate students who received interdisciplinary training.[52] But, a sampling of the employment opportunities posted in *Science* in 1975–1999 would suggest that the market is growing. In November 1975, 6.7% of the employment ads reflected multidisciplinary requirements. By November 1985, the percentage had grown to 11%. In November 1995, 19% directly or indirectly indicated the need for integration of approaches or suggested collaborative opportunities. In November

1999, 31% of the ads mentioned a collaborative environment or stressed team efforts. Furthermore, the development of large common laboratory space to facilitate joint research, as described above for the University of California, Berkeley and for Washington University, would be expected to accelerate employment of scientists who are competent in more than one field.

Private industry offers another avenue for those with interdisciplinary training. Representatives of industry indicated that they are looking for people who can work in an interdisciplinary environment (A. Cato, IOM Workshop, 1999).[13] The process of moving a drug from the discovery process to clinical trials requires teamwork. The growth of biotechnology requires scientists who can work in more than one discipline. There has been a strong trend toward increasing employment of scientists in industry compared with academe. Data from the American Psychological Association indicated a dramatic shift of employment settings for PhD psychologists between 1973 and 1997 away from colleges, universities, and medical schools and toward for-profit settings.[3] A 1995 membership survey of the Society for Neuroscience similarly showed an increase in the percentage of members working in industry from 3% to 10% since 1982.[54] A survey by the Federation of American Societies for Experimental Biology showed a similar trend for biomedical scientists in general.[20] In response to those trends, a study by the Committee on Science, Engineering, and Public Policy of the National Academies recommended that graduate programs provide greater scope and interdisciplinary training.[45]

Staying Current

As the volume of information grows in a given subspecialty, the number of publications that a person needs to read to stay current in his or her own field forms another deterrent to becoming more interdisciplinary. Figure 3-2 illustrates the exponential growth in publications in selected fields of neuroscience. A search on key words in MEDLINE and various psychological and sociological databases yielded many times more references on each term in 1998 than in 1974. Keeping up to date in any of these fields is challenging. Keeping up to date in several would be daunting. A similar analysis in 1986 revealed the rapid increase in the occurrence of the word interdisciplinary in the title of papers between 1951 and 1982, perhaps suggesting a concurrent increase in interdisciplinary research.[14]

It is entirely possible that on-line journals will begin to break down the barriers of access to information. Accessibility at the speed of the Internet is making it far easier to learn what is being done in other disciplines, although the language and jargon barriers cited above will continue to haunt those developing the search engines for on-line publications. Citation services, such as Cite Trak, are now available to alert one to papers published in a particular field of interest. The scientific equivalent of bulletin boards or chat rooms, such as Brain Research

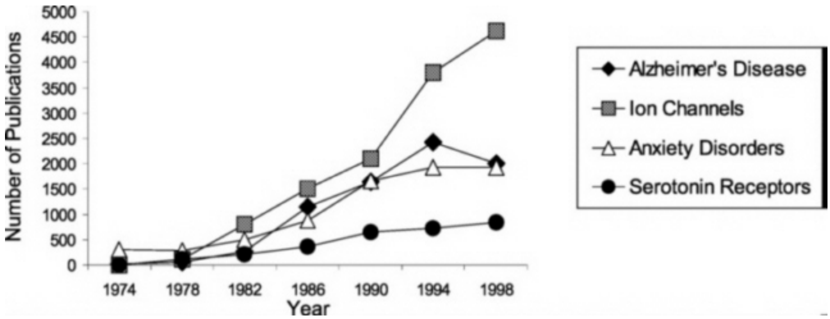

FIGURE 3-2 Yearly number of publications in selected topics.

Interactive (an on-line version of papers that are later published in *Brain Research*), could provide an important forum for examination and interchange of ideas.

Midcareer Retraining

It is not just newly minted doctoral and postdoctoral scientists that face challenges in advancing interdisciplinary interests. A midcareer scientist who decides to retool or shift focus faces a difficult task. To continue a productive research career, funding mechanisms must be available to allow midcareer scientists to update themselves or retrain in another, quickly moving field. Such educational experiences require the opportunity to add to basic knowledge in one or more disciplinary skills or to broaden one's knowledge, not necessarily to create the capacity to conduct wholly different research alone, but, rather, to learn enough about other disciplines to work as a productive team member.

Special Challenges for the Clinician-Scientist

For decades, concerns have existed about the decreasing number of clinician-scientists.[49,56,60] Such people are needed to bring basic science into the clinic; they do clinical investigations. The percentage of graduating medical students with an interest in research has been declining.[49] The large debt, long training period and low academic salaries described above contribute to the problem. Other disincentives are lack of encouragement to pursue this career path and the clinical demands of academic health centers that draw staff away from research.

The participation of the clinician-scientist in interdisciplinary research poses additional challenges for professional advancement in most university systems. In some measure, this is due to the longer initial development times of most interdisciplinary projects before they yield results adequate for publication.

If studies are concerned principally with the etiology of human disease, the transfer of preclinical principles to the bedside, or strategies for reducing the burden of illness, the problems of lead time to publication are amplified. Because many academic institutions have promotional policies that allow 4–10 years before faculty are "up or out," there is a general perception that entry-level faculty should not participate in such studies. One strategy would be to delay participation in interdisciplinary research until midcareer, when tenure and other forms of job stability have been achieved. Unfortunately, that strategy could eliminate people from interdisciplinary research at the height of their creativity. Similarly, people who wait until midcareer for such a transition might lack necessary interdisciplinary strategies or approaches unless mechanisms of continued career development are in place.

FINDINGS AND RECOMMENDATIONS

The committee identified many barriers to interdisciplinary training and research. Many of them are at the level of the university and need to be addressed within the institution. Funding agencies have the capability to encourage changes in the university that would facilitate interdisciplinary efforts. The committee cautions that interdisciplinary research should not be encouraged for its own sake but, rather, to solve appropriate research problems.

Recommendation 2: Funding agencies and universities should remove the barriers to interdisciplinary research and training. To that end, funding agencies should:

- **Require commitments from university administration to qualify for funding for interdisciplinary efforts.** These should include supportive promotion policies, allocation of appropriate overhead, and allocation of shared facilities.
- **Facilitate interactions among investigators in different disciplines by funding shared and core facilities.**
- **Encourage legislation to expand loan repayment programs to include investigators outside NIH who are engaged in funded interdisciplinary and translational research.**
- **Support peer review that facilitates interdisciplinary research.** In reviewing interdisciplinary research proposals, they should use peer review groups that include scientists in multiple disciplines who are themselves actively engaged in interdisciplinary research. The system recently has been modified at NIH with encouragement of interdisciplinary and translational efforts in mind. Resulting changes should be tracked to determine their impact on funding of interdisciplinary grants.

- **Continue and expand partnerships among funding agencies to provide the broadest base for interdisciplinary efforts.** These can be inside an agency through the formation of new alliances among institutes or divisions; they can also be among agencies—such as NIH, NSF, the Department of Defense, and the Department of Energy—or between the private and public sectors.
- **Indicate in funding announcements that training is an integral component of the interdisciplinary research project.**

Universities should:

- **Allocate appropriate credit for interdisciplinary efforts.** They should include a fair allocation of research overhead costs to the home departments of all investigators and a fair crediting for faculty contributions to interdisciplinary research and teaching.
- **Review and revise appointment, promotion, and tenure policies to ensure that they do not impede interdisciplinary research and teaching.**
- **Facilitate interaction among investigators through support for shared facilities.** Universities can provide common gathering areas and ensure that new facilities are designed to promote Interaction.
- **Encourage development, maintenance, and evolution of interdisciplinary institutes, centers, and programs for appropriate problems.**

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4

Interdisciplinary Training Programs

The only person who is educated is the one who has learned how to learn and change.

— Carl Rogers

Alone we can do so little; together we can do so much.

— Helen Keller

The goal of scientific training is to provide the skills necessary to ask questions and seek answers to them. Science can move rapidly. Researchers have to be able to maintain a broad base of knowledge in a single discipline and be willing to change direction and pursue advances in other disciplines through collaboration or further training. Research training does not stop when a degree is obtained or a postdoctoral fellowship is over. Throughout a career a scientist continues to learn. For interdisciplinary training, the challenges are greater because the scope is wider. Formal mechanisms can provide opportunities to learn in new disciplines.

This chapter explores a variety of mechanisms for training and retraining at different career stages. It is not a comprehensive review, but, rather, a sampling to provide an overview of the possibilities. Many of the approaches described here have already been applied to interdisciplinary efforts. Others could easily be adapted to facilitate interdisciplinary training. To encourage interdisciplinary research, the available mechanisms need to be expanded and enhanced. In reviewing the programs, the committee found that outcome data were sparse. Each training program provides information on the successes of its trainees in grant renewal applications, but a more general assessment of the effectiveness of funding mechanisms was usually absent. Because evidence on the relative merits of various programs was unavailable, the committee members used their professional experience to judge what was likely to be effective in promoting future interdisciplinary research. The problem of assessing outcomes of training programs is addressed further in chapter 5.

UNDERGRADUATE PROGRAMS

Undergraduate education lays the foundation on which all future education is built. Some scientists have expressed a need to broaden the scientific base at the undergraduate level in order to encourage interdisciplinary research.[63,79] Traditional majors, focused in a single department, have not encouraged or rewarded interdisciplinary work. The virtue of the traditional approach of requiring narrow expertise is that students begin to feel a sense of mastery and develop a professional identity. However, neither the expertise nor the professional identity is suited for rapid changes in the life sciences. For instance, an undergraduate who majors in molecular biology without exposure to systems physiology might be unprepared to envision many kinds of clinical applications.

An alternative is the interdisciplinary undergraduate major, which requires coursework in several traditional departments but still requires expertise in a specific topic. A major in neuroscience, already a popular choice at many colleges, provides an interdisciplinary approach to the complex problem of understanding brain function. Typically, it requires a background in mathematics, physics, chemistry, and biology, but it includes specific courses in molecular, cellular, systems, and behavioral neuroscience with instructors in the departments of psychology, biology, and anthropology. A required thesis based on original research in one field of neuroscience ensures that students will develop proficiency in at least one field. Several excellent colleges (for example, Brown, Emory, and Harvard universities) have implemented such programs. The popularity of the Neuroscience and Behavioral Biology Program at Emory University, for example, is demonstrated by the doubling in the number of students each year the last 3 years (T. Insel, personal communication).

PREDOCTORAL AND POSTDOCTORAL TRAINING

When a student continues into graduate school, the educational focus is usually on learning a field of science in depth and developing the research tools necessary to become an independent investigator. In the past, it was rare for a predoctoral student to be exposed to multiple disciplines. As a postdoctoral fellow, the emphasis is on further development of research skills, training in new techniques, and preparation for a research career. As postdoctoral fellows, trainees are commonly encouraged to broaden their horizons by pursuing research experience in fields that differ from the foci of their dissertations. Formal interdisciplinary training at this stage is more likely, but still not the norm.

There are now a multitude of interdisciplinary predoctoral and postdoctoral programs. The committee examined over 100 training programs and the variety of mechanisms they use to promote interdisciplinary research. The programs were identified as interdisciplinary by the funding agency, the committee, Institute of Medicine staff, or themselves. A goal of many of the programs was to provide trainees with a broad perspective in a particular problem, such as emotion, sleep, aging, or affective disorders. Most strove to provide trainees with grounding in a particular discipline while encouraging interdisciplinary interactions. Some of the training programs covered both predoctoral students and postdoctoral fellows. Others focused primarily on one or the other. Because the goals for each are different, they are considered separately below.

Interdisciplinary Training Mechanisms for Predoctoral Students

Most doctoral programs begin with coursework that builds on the undergraduate degree, expanding each trainee's knowledge in fields relevant to the scientific focus and filling in gaps. Nearly all training programs provide trainees with the substantive knowledge and skills necessary to do research. The challenge faced by interdisciplinary programs is to provide a broader, more diverse experience. The goals, in addition to teaching the substance of a field or fields, are to provide the skills necessary to understand other disciplines, and to communicate with those outside one's own field. Students need to learn how to frame research questions and present hypotheses that extend beyond their primary expertise. They need to recognize the contributions that other disciplines can make to their research questions. As suggested by a National Academy committee, graduate students need to acquire a greater versatility by obtaining breadth in their scientific education, by learning to work in interdependent teams, and by developing communication skills with those outside their field.[22]

To accomplish those goals, the interdisciplinary graduate programs that the committee reviewed (Appendix C) used a variety of approaches, from didactic training to laboratory rotations and networking. Formal coursework is often used to introduce trainees to a broad, multidisciplinary field. Program requirements can include a number of courses that span multiple disciplines but are related to the focus of the program. In addition, many programs offer courses in which the faculty lecture on their fields of expertise and describe current investigations in these fields. Other programs use seminar series to expose students to multiple research topics. And, many training programs attempt to provide students with an overview of the diverse methodological approaches available to address relevant research questions, using formal courses and other processes.

Journal clubs are often used to supplement didactic training. In these forums, students learn to think critically about the scientific literature in their own and related disciplines. Some journal clubs encompass more than reviewing a single journal article by encouraging faculty or student presentations that form the basis of discussion. In some programs, the journal clubs meet in an informal atmosphere, such as at a home in the evening. The environment is intended to facilitate discussion and encourage interaction.

A key component of any training program is the laboratory research effort. Many graduate programs require laboratory rotations in the first couple of years of training. These are designed to expose students to a range of faculty, techniques, and experimental approaches. In many cases, students are offered opportunities to experience quite different aspects of the biomedical and behavioral sciences. Interdisciplinary programs often encourage mentorships of more than one sponsor to ensure input from at least two perspectives. Laboratory meetings are a common component of the educational experience. Some programs formally require attendance at laboratory meetings; some require attendance at meetings in more than one laboratory so that students will continue their exposure to the research questions and methods of more than one discipline.

The research skills learned by working in the laboratory are sometimes supplemented by formal coursework. As required by the National Institutes of Health (NIH) and the National Science Foundation (NSF), all programs provide some formal training in the responsible conduct of research. In addition, some of the programs reviewed offer training in other career skills, such as preparing grant applications, teaching, writing manuscripts, and reviewing the literature. Research seminar presentations are used by many programs to improve trainees' communication skills. In one program, students are required to prepare a journal article for formal presentation to the other students and faculty. In another, trainees are asked to present a research plan for group discussion. Those approaches not only provide an opportunity to obtain comments on their writing and thinking, but also require them to consider the opportunities and limitations of other approaches. The Research Survival Skills Seminar at the University of Pittsburgh exemplifies some of those approaches.[93] In the course of the seminar, students prepare and present a research proposal that is then critiqued by the other students. Through such peer review, the trainees learn firsthand how the system works. Just as important, perhaps, they are exposed to a rigorous evaluation of a wide array of experimental methods.

A goal of many of the interdisciplinary programs reviewed is to provide students with a forum in which to interact with experts in relevant fields. Several mechanisms were used to achieve that goal, such as summer courses, symposia, and off-site meetings. In the programs reviewed, the duration of those types of meetings ranges from a single day to several weeks. Common features include presentations by the trainees, presentations by experts from outside the faculty, and scheduling of time for trainees and experts to interact. The gatherings are generally intended to encourage bonding of students with each other and the faculty and to provide students with a network of experts that includes both their contemporaries and more senior scientists (see Box 4-1); this network is expected to provide a resource for interaction, discussion, and collaboration throughout the trainee's lifetime.

BOX 4-1 PREDOCTORAL TRAINING CONSORTIUM IN AFFECTIVE SCIENCE, SAN FRANCISCO BAY AREA

The Predoctoral Training Consortium in Affective Science* in the San Francisco Bay Area aims to broaden the disciplinary training of predoctoral students while providing exposure to varied approaches to affective science. The program attempts to instill an appreciation and understanding of the theories, methods, and data of many aspects of affective science in an effort to lay the groundwork for better communication among subspecialties, more interdisciplinary collaboration, and a greater interaction between affective science and other fields.

Students are selected from the psychology and health sciences programs at four Bay Area universities (the Berkeley, Davis, and San Francisco campuses of the University of California and Stanford University) to participate in a 3-year training sequence leading to the conduct of dissertation research. Training takes place in a year-long seminar at Berkeley and at specialized workshops and an annual workshop. Trainees are closely mentored and monitored throughout. The program focuses on predoctoral students early in their training in the belief that the impact of interdisciplinary training in affective science will be greater than in a postdoctoral program.

The program also addresses important needs in the “socialization” of scientists-in-training. First, there is exposure to scientists at various career levels, ranging from relatively new investigators, through scientists at midcareer, to the most senior figures in a given field. That kind of exposure is intended to provide role models who are close in age to the trainees and those who are more senior. Second, the program hopes to develop a sense of “cohort” among the trainees that spans disciplines and approaches and a sense of scientific community in affective science that trainees will carry with them throughout their careers and will impart to their own trainees in the future.

Interdisciplinary Training Mechanisms for Postdoctoral Fellows

In the 1920s, the Rockefeller Foundation established a fellowship in physical sciences for people who had just completed their doctoral training.[4] These early postdoctoral training fellowships recognized that the field of physics had become too complex for a student to prepare for a research career adequately with only graduate school training. The postdoctoral training mechanism has greatly expanded since then. Postdoctoral fellows are developing both technical and professional skills.[4,71] Interdisciplinary training at this point might focus less

*Affective Science refers to study of the emotions and emotion-related processes.

on didactic training and more on conducting collaborative research, establishing networks, exploring concepts and approaches of other disciplines, and developing skills in interacting and communicating with people in other fields. Many of the same mechanisms described for graduate students to those ends would also benefit postdoctoral fellows.

The committee heard from several program directors that postdoctoral fellows are the glue that holds interdisciplinary efforts together. They are the ones with the time to pursue collaborative research—to bring two or more laboratories together in a research project. Whether projects are initiated by the trainees, or by mentors, all benefit. Trainees obtain experience with multiple perspectives or approaches. By virtue of mentoring trainees who are crossing laboratories, mentors are exposed to and learn about other disciplines. New interests and new insights provide motivation to continue interdisciplinary interaction.

Funding Mechanisms for Predoctoral and Postdoctoral Fellows

Investigator Awards

Graduate students and postdoctoral fellows are often supported on an investigator's grant, whether it is an R01, a P01, or another mechanism (see Appendix D for a table of mechanisms). Training comes primarily with doing—a hands-on effort. If two laboratories are collaborating, it is often the postdoctoral fellow who provides the vector for the interaction. The research-intensive effort can present an excellent opportunity to integrate the efforts of two or more laboratories.

Fellowships

Some fellowships are awarded directly to individual applicants. If enrolled in a doctoral program (F31) or in an MD/PhD program (F30) or as a graduate of a doctoral program (F32), a trainee can apply individually for a National Research Service Award (NRSA).[53] These fellowships provide a stipend for a trainee, tuition remission, and a small sum for miscellaneous expenses. Because trainees are self-supported through the fellowships, it is their prerogative whether to participate in available ancillary training programs.

Fellowships for postdoctoral fellows, but not for predoctoral students, carry a payback provision. This obligation is incurred only during the first year of training and can be met by a year of research or teaching or a second year of training. Fellowships, unlike grant support, do not provide employee fringe benefits. Consequently, some used to consider these awards less desirable. Until just recently, the fellowships provided health insurance only for the fellows, not for their families. In the government's fiscal year 2000, NIH changed this to provide NRSA fellows with health insurance coverage for families.[59]

The fellowships, like investigator-funded awards, can be used to support interdisciplinary efforts. A fellow working with a mentor who spans disciplines can be trained across disciplines. Alternatively, multiple mentors can provide interdisciplinary training. In one example reviewed by the committee, the postdoctoral fellow was sponsored by two scientists at two separate, but close, institutions. One mentor used animal models to study the development of a conditioned reflex in the rat; the other focused on the ontogeny of learning in human infants. With guidance from both, the postdoctoral fellow developed a program to look at conditioned reflexes in the two systems and learned to translate the animal findings to human issues.

Institutional Awards

Some training grants for predoctoral students and postdoctoral fellows are awarded to institutions. NIH uses the NRSA Institutional Training Grant (T32) mechanism; NSF uses the Integrative Graduate Education and Research Training (IGERT) mechanism specifically to support interdisciplinary efforts. These awards are oriented toward providing training activities for a cohort of students on a regular basis. In addition to training students, institutional programs enrich institutions and provide a framework for research.

NIH T32 Awards. The institutional NRSA (T32) is widely used to support both predoctoral and postdoctoral training (see Box 4-2). This mechanism provides awards in all areas of research training that fall within the NIH mission. Emphasis is placed on the research training of physicians, and special consideration is given to MDs who agree to pursue at least 2 consecutive years of training in biomedical or behavioral research.[53] The award requires a strong research program in the proposed field of training, evidence of institutional commitment, a minority recruitment plan, and training in the responsible conduct of research.

To address topics of particular interest, NIH puts out program announcements. These are expected to increase training and hence promote future research efforts in the specified area. One such program is the NIH-wide initiative that called for multidisciplinary training on sleep research: “Innovative, multidisciplinary and collaborative training programs with interactive training provided by investigators from different disciplines and with complementary skills are strongly encouraged.”[52] Another example is a recent announcement from the National Institute of Mental Health to encourage translational research through postdoctoral training in intervention trials.[43] These T32s are intended to

BOX 4-2 INTERDISCIPLINARY RESEARCH TRAINING PROGRAM ON AGING, UNIVERSITY OF IOWA

An NRSA from the National Institute on Aging was awarded to the University of Iowa in 1991 to establish this training program that currently supports eight predoctoral and eight postdoctoral trainees each year. The program centers on four cores: cardiovascular and pulmonary disease in aging, mechanisms and consequences of aging, degenerative neurological disease and stroke, and social and psychological aspects of aging. The program builds on related programs in research, clinical service, and education.

Trainees work closely with sponsors to develop their research and plan other activities to enhance the interdisciplinary experience. Collaboration and multiple sponsorship are common mechanisms that promote interaction and broaden perspectives. The program requires the trainees to participate in monthly seminars on aging and an additional seminar series, journal club, or colloquium. They are also encouraged to attend national conferences related to their research interests. Because the Center for Aging does not grant degrees, students receive their degrees from the participating departments and colleges.

increase the number of clinical investigators interested in the treatment, rehabilitation, and prevention of severe mental disorders. To achieve that goal, the announcement requires a minimal commitment of 2 years from the trainees, a focus on training in multisite trials and community health, and training in statistics, bioethics, epidemiology, experimental therapeutics, data interpretation, and other specified fields.

The T32 award provides primarily stipends for the trainees. As with the fellowships, some tuition is also covered. Like fellowships, the institutional NRSA does not pay fringe benefits and requires a payback provision for the first 12 months of the award to postdoctoral fellows. Funding is limited to 5 years at the predoctoral level and 3 years at the postdoctoral level. However, justified extensions are available. Among the specified grounds for an extension is the additional training time required by clinicians in postdoctoral programs or people in combined MD/PhD programs.[53] One major drawback of these training grants is that the indirect costs for facilities and administrative expenses are limited to 8% of the total direct costs. And, they do not cover the direct costs associated with administration of the program.

Curtis et al.[11] recently analyzed the costs and benefits of an NRSA program at the University of North Carolina at Chapel Hill that provides doctoral training in public health for clinicians. Taking into account both clinical care and academic activities, the authors calculated that the program imposed a net financial burden on the departments. Although they recognize the nonfinancial benefits of having trainees, Curtis et al. noted that additional administrative funds for NRSA faculty would relieve some of the budgetary pressures.

Interdisciplinary efforts cost more to administer than single disciplinary programs. Coordination efforts are greater, requiring additional investigator and staff time to organize meetings, integrate administrative input from multiple units, prepare multiple proposals and reports, and so on. Furthermore, telephone, travel, and other costs are greater. The motivation of universities, departments, and faculties to participate in such programs might be limited because of their financial burdens. Consequently, the committee expressed concern about the ability to provide the best of interdisciplinary programs where administrative and support staffs are inadequate.

IGERT Awards. In 1998, NSF initiated the agency-wide IGERT Program specifically to encourage interdisciplinary training of scientists, mathematicians, and engineers.[67] The program is based on the premise that careers of the future will require multidisciplinary backgrounds. Consequently, IGERT awards require that several disciplines come together to address a defined multidisciplinary research theme. The projects are expected to offer training through exposure to research that spans disciplines, development of communication and teamwork skills, and training experiences relevant to both academic and nonacademic (industry and government) careers. The projects are expected to focus on predoctoral training. However, training of postdoctoral fellows, undergraduates, or master's students can be incorporated if it adds value to the IGERT program. A plan for tracking the achievements of the IGERT program that may include an assessment of the effectiveness of the "multidisciplinary enterprise" is required by NSF.

An IGERT award is for up to $500,000 per year for up to 5 years. The dollar limit includes both direct and indirect costs. Another $200,000 is available during the first year for necessary equipment or research materials to support the training program. Because NSF recognizes that IGERT projects are likely to require substantial administrative support, funds can be used for program administration. The funds are expected to cover the expenses associated with recruitment of students, development of courses and other training activities, and program evaluation. No faculty research or faculty salaries are supported. The funds for administrative support are expected to relieve faculty of some administrative burdens connected with a project, but not relieve them of their responsibility to organize and lead the project and to play active roles in recruitment, teaching, and mentoring of students. IGERT award funds must go primarily toward training activities. In addition to a graduate-student stipend, an IGERT award provides a cost-of-education allowance up to $10,500 per year per student; this allowance covers tuition and fees that include institutionally required health insurance. Consequently, students covered by an IGERT award are expected to be exempt from tuition and fees. The institution can claim up to 8% overhead on direct costs minus the equipment and cost-of-education allowances.

Foundations. In addition to government initiatives, nonprofit organizations provide funding for predoctoral and postdoctoral training. For example, the Flinn Foundation, in Arizona, supports university-based interdisciplinary research programs.[13] The funds are directed toward stipend support, expenses associated with guest lectures and symposia, and other costs. In an effort to build on the successes of research in such fields as cellular and molecular biology, genetics, immunology, and neuroscience to provide new therapies, improved diagnostic methods, and preventive interventions, the foundation funds programs that have a multidisciplinary faculty doing collaborative research on a common theme, or a single organ or disease. Nine interdisciplinary research groups have received grants totaling over $5 million under the foundation's Biomedical Research Initiative.

Implementation of Programs

Training programs have used the funding mechanisms described above to provide support within departments, across departments in programs, to separate schools within a university, and even across institutions. For example, the doctoral program in Health and Behavioral Sciences at the University of Colorado at Denver is a cross-departmental program in which several departments contribute faculty, overhead, and so on. At Johns Hopkins University (see Box 4-3), the program is incorporated into a department. The School of Social Ecology at the University of California at Irvine was established as an independent school with degree-granting departments, integrated around muitidisciplinary problems. At the University of California Los Angeles, the Brain Research Institute established a training program on sleep (and grants a PhD degree) that allows trainees to do their laboratory work anywhere in the nation and belong to a consortium of universities and laboratories focused on this subject. The options are endless and are subject only to the imagination of the investigators and the constraints imposed by the subject of study (see Box 4-4).

Translational Research Training

Clinician-scientists are an important resource for interdisciplinary research that seeks to translate from bench to bedside and back. Clinician-scientists from a variety of clinical fields understand the impact of diseases on human functioning and well-being and are in a prime position to ask the appropriate translational questions. The training of clinician-scientists is inherently interdisciplinary. Grounded in both clinical and basic science, the clinician-scientist is well positioned to participate in collaborative efforts that bridge the bench to bedside gap.

BOX 4-3 COGNITIVE SCIENCE OF LANGUAGE AND THE DEPARTMENT OF COGNITIVE SCIENCES: AN IGERT PROGRAM, THE JOHNS HOPKINS UNIVERSITY

The Johns Hopkins University Department of Cognitive Sciences received funding for an IGERT program in 1999. The program brings together several disciplines to understand the cognitive functions and pathology of language. Research tools for computational and mathematical modeling, neuropsychology of language processing, pathology of language deficits, neuroimaging of brain activity, and grammatical analysis are brought to bear. The program aims to integrate multiple disciplines into a new field of science but to train graduate students who will be competitive in a disciplinary culture.

The program offers coursework in several areas of cognitive science, including philosophy of mind, linguistics, computational approaches, neuroscience, and psychology. Departmental courses and seminars are designed to integrate them. The training aims to provide a background that will give students expertise in their primary research subject, but allow them to understand, appreciate, and critically evaluate work in related disciplines. The Department of Cognition grants the degree to predoctoral students.

BOX 4-4 INTERDISCIPLINARY TRAINING, UNIVERSITY OF PITTSBURGH

Over 2 decades, the program at Pittsburgh has grown into an exceptional model of interdisciplinary research and training. Through the years, centers were established on affective disorders, Alzheimer's disease, drug abuse, alcohol abuse, neuroscience of mental disorders, obesity, bipolar disorders, and more. Each center created a site for interdisciplinary research and training. In the context of the centers, collaborations were established across many departments in the University of Pittsburgh Health Center: psychology and psychiatry, medicine, neurobiology, neurology, pathology, pharmacology, and radiology. Other schools in the university were brought in: the Graduate School of Public Health, the Faculty of Arts and Sciences, the School of Nursing, and the School of Social Work. As part of the MacArthur network, collaborations extended to other institutions throughout the country. The network of research centered in Pittsburgh is now far-reaching.

Training of Physician-Scientists

As discussed in chapter 3, concerns about the declining number of physician-scientists have been expressed for decades.[76,86,91] The NIH has a number of programs that are designed to encourage physician-scientists. The National Institute of General Medical Sciences (NIGMS) established the Medical Scientist Training Program (MSTP) in 1964 to train MD/PhD students in both the biomedical sciences and clinical practice. It was intended that these new scientists would span basic and clinical research efforts. The program supports PhD training in the biological, chemical, and physical sciences combined with training in medicine. Additional disciplines supported include social and behavioral sciences, computer sciences, economics, epidemiology, public health, bioengineering, biostatistics, and bioethics. A recent analysis of the MSTP indicated that MSTP graduates have more research-intensive careers, with greater likelihood of research support and academic appointments and higher publication rates, than MSTP trainees who received only an MD degree after withdrawing from the PhD training.[33] In addition, MSTP graduates are less likely to be in independent practice. To judge by the outcomes assessed by the study, the program is successful in encouraging the integration of research activities with the practice of medicine and promoting research programs relevant to human health and disease. Other analyses of MD/PhD programs have also suggested that they are successful in producing physician/scientists.[9,15,20,21,78,89]

Although the MSTP does provide for PhDs outside the traditional biomedical disciplines, implementation of this option is unusual. Of the 103 MD/PhD programs surveyed in 1990, only 10–15% allowed medical students to pursue a PhD in the social sciences, behavioral sciences, or humanities.[16] Even among this limited number, only three were substantial programs: those of Harvard University (supported by the MacArthur Foundation), the University of Chicago (supported by the Pew Trust), and the University of Illinois at Urbana/Champaign (supported by state funds). Reviews of those programs indicate their success in producing academic physicians. The Harvard program, for instance, granted five PhDs in anthropology, and one each in history of science, social psychology, cognitive psychology, political science, and politics/economics/government. All the graduates entered full-time academic positions: nine in medical school faculties and one in an arts and science faculty (Leon Eisenberg, director of the Harvard program, personal communication). A review early in the University of Chicago program indicated similar success with graduates entering research and teaching positions.[92] Yachnin (former director of the Chicago program) et al.[92] concluded that the program produced physicians who are "more deeply concerned with the broader societal issues confronting medicine." Diane Gottheil, director of the University of Illinois program (personal communication), recently conducted a survey of the 52 MD/PhD graduates with a PhD in the humanities and social sciences. Their career paths indicated that they are strong contributors to academic medicine. In recognition of the need for MDs to understand the behavioral and sociological aspects of disease, to address the important issues of behavior change and adherence, to use the advances in biotechnology fully, and to think globally about population and environmental factors in disease, the committee strongly recommends that training in these non-traditional fields should be encouraged.

NIH funds career awards to develop the capacity of physicians to conduct clinical research (see Appendix D). For example, the Mentored Clinical Scientist Development Award (K08) provides 3–5 years of supervised support for people with clinical degrees. The intent is to encourage newly trained clinicians to develop basic and clinical research capability. The Mentored Patient-Oriented Research Career Development Award (K23) provides 5 years of support for physicians who have completed their specialty training and are planning to do clinical research. Programs that address specific needs are often identified through program announcements. These awards provide an opportunity for people committed to research to develop into independent biomedical and/or behavioral investigators.

Private foundations have also tried to promote the physician-scientist. From 1989 to 1994, the Lucille P. Markey Charitable Trust funded general organizational grants to about 20 programs that provided clinical exposure for PhD candidates and postdoctoral fellows or that encouraged MDs to conduct research. The aim was to promote the bench-to-bedside translation of research. The National Research Council is conducting a comprehensive evaluation of the effectiveness of this program, using such indicators as program continuation after grant completion, peer opinion of the program, and student and faculty status.[2,64,85]

The Robert Wood Johnson Clinical Scholars Program provides 2 years of graduate-level training for new physicians in nonbiological sciences important to medical care systems.[75] Disciplines include epidemiology, biostatistics, medical information sciences, economics, the social sciences, anthropology, history of medicine, law, ethics, and the humanities. Up to 20% of the time may be spent in maintaining clinical skills. According to the Robert Wood Johnson Foundation, this program has been successful in training physicians who stay involved with academic research and medicine, public policy, or management of healthcare delivery.[75]

Clinician-Scientists in Fields Other than Medicine

Clinically oriented doctoral programs include not only physicians (MDs and MD/PhDs) but also dentists (DDSs and DMDs), pharmacists (PharmDs), psychologists (PhDs), and nurse scientists (PhDs and DNScs). Some trainees in clinical disciplines obtain the clinical component as part of a master's degree program and then obtain a PhD in a related field to provide the research component (for example, occupational therapy, physical therapy, and speech therapy). All these clinician-scientists can offer particular clinical perspectives in interdisciplinary patient-oriented research.

To support translational research by nonphysician clinicians, NIH offers training programs that are similar to those tailored to MDs. For example, the National Institute of Dental Research[29] supports a Dentist Scientist Award and the institutional postdoctoral NRSA[31] to allow dentists to obtain the PhD in a relevant research field. The institute also supports a Dental Scientist Training Program (DSTP) based on the MSTP model in which trainees concurrently pursue the DDS or DMD and PhD degrees, in an integrated, interdisciplinary program.[30] The National Institute of Nursing Research supports a Career Transition Award (K22 mechanism) that provides up to 5 years of salary and research support, first at NIH and then at an extramural institution, to help bridge the transition to the status of independent researcher.[47]

Nursing doctoral education, at least at the major research universities, is highly interdisciplinary and thus provides a good basis for the bridge scientist role. Consequently, support for education in this inherently interdisciplinary field is support for both translational and interdisciplinary training. Nurse-scientists are generally clinicians who have obtained research education and training through formal doctoral degree programs, either in closely allied fields or in nursing science. The PhD and DNSc are research degrees offered in nursing science by 75 universities in the United States. In addition, many nurse-scientists obtain PhDs in various fields of biomedical and behavioral sciences. The strongest of the nursing science PhDs are built on a highly interdisciplinary base or come out of joint programs in nursing and a biomedical or behavioral science.[12] The strong interdisciplinary programs are clustered in the strong research-intensive universities with large academic medical centers. The same interdisciplinary character applies to the research focus of social workers, who are involved in such issues as child abuse, homelessness, drug abuse, poverty, violence, and mental illness. There are about 55 doctoral programs in social work; these programs are based primarily in large universities that can provide the background to ask integrated research questions that include behavioral sciences, medicine, economics, and sociology.[7,17]

Clinical Training for PhDs

Training basic scientists in clinical sciences is another mechanism for enhancing translational research. This approach does not replace the role of clinician-scientists, but it can focus research efforts on clinical questions and provide a complement to the clinician-scientists.

At the committee's workshop "Opportunities for Interdisciplinary Training," (IOM Workshop, 1999) Irwin Arias reported that a survey of 372 students in basic science departments of medical schools indicated a strong desire to do research with an impact on human health. To encourage that drive and to provide the necessary tools, Tufts University has developed a pathobiology program for PhD students, fellows, and faculty that consists mainly of a one-semester course.[3] The course exposes students to the clinical-pathological and basic mechanisms of 20 major human diseases. Students see patients, handle pathology, and become informed about major diagnostic and therapeutic facilities in a modern hospital. An outcome survey reflected the success of the program in encouraging participants to pursue relevant research careers in industry or academe. Of the 78 students who have completed their postdoctoral training, 33 have excellent positions in biotechnical and pharmaceutical companies, where they are engaged in research that affects human health. The others are in tenure track positions either in basic science departments or in clinical departments of medical schools.

At the June 15–16, 1999, Conference on Physician Scientists and Career Opportunities for Biomedical Research (FASEB, Rockville, Maryland), Franklin Bunn, of Brigham and Women's Hospital in Boston described another program designed to introduce PhD graduate students to human biology and disease. Basic coursework focuses on human pathology. Courses and seminars are attended jointly with medical students. The program is intended to encourage trainees to have mentors from the medical school and to promote collaboration with physicians. The program is new and its effectiveness has not yet been evaluated.

Several university programs are attempting to incorporate translational efforts into doctoral training. For example, Baylor College of Medicine established the Neurobiology of Disease Program to provide interdisciplinary training in molecular, cellular, and clinical neurosciences.[5] The focus is on disease-oriented research and training. At the predoctoral level, a course in neurobiology of disease and a monthly seminar series are offered. Laboratory rotations allow students to select fields of specialization. Frequent visiting speakers and a regular neurobiology of disease journal club are sponsored by the program. In the PhD and MD/PhD programs in behavioral neuroscience at Boston University School of Medicine, students have the opportunity to assist medical staff in providing consultative services and to participate in daily and grand rounds.[6] Students choosing this option have the opportunity for direct observation of clinical pathologies.

The pharmaceutical industry is interested in training doctoral fellows in clinical research and drug development. Some companies have developed fellowships in partnership with universities. An example is the program at the University of North Carolina in collaboration with Burroughs Wellcome.[73] Students in the program pursue a clinical research project, attend an Institutional Review Board meeting, and participate in planning and monitoring clinical trials at the drug company. A survey of the fellows, sent out in May 1986 to look at the trainees' career paths, showed that most had found employment associated with clinical research.

EARLY CAREER OPPORTUNITIES

As described in chapter 3, faculty members are particularly vulnerable early in their careers as they establish themselves and face tenure and promotion decisions. At this juncture in their careers, many feel that it is unwise to follow an unconventional path. Granting mechanisms aimed specifically at junior faculty and new investigators that encourage interdisciplinary efforts could provide an incentive to move toward broader research questions that would otherwise be rejected as poor career choices.

Several career development awards are available through NIH to support junior faculty (see Appendix D). These awards can encourage investigators to pursue translational research, and they provide the freedom to continue learning new approaches to scientific questions. As discussed above in the case of physicians planning to do clinical research, the Mentored Clinician Scientist Development Award (K08) and the Mentored Patient-Oriented Research Career Development Award (K23) provide support. The Independent Scientist Award, K02, aims to promote the research capability of young scientists early in their careers (within 6 years of obtaining their degree), providing 5 years of partial salary support plus a small research allowance. The award is geared toward people whose independent research careers would be encouraged by the additional, intensive scientific experience. The institution must demonstrate support for the development of the scientists and allow them to spend 75% of their time on research-related activities.

Foundations have programs that provide similar support for junior faculty. The William T. Grant Foundation's Faculty Scholars Program provides up to 5 years of salary support (up to 50% effort) for untenured faculty to do social and behavioral research on adolescents and youth.[90] At least one mentor is required. Interdisciplinary efforts are especially encouraged and can be achieved through a choice of mentor from another discipline. More senior faculty are considered only if they are shifting their research focus substantially. The program requires a university to commit to providing the remaining 50% of salary support, laboratory space, and at least 50% free time for the faculty member. By supporting scientists early in their careers and providing them opportunities to broaden their scope, the Grant Foundation expects to encourage multidisciplinary research on the issues concerning youths.

MIDCAREER EDUCATION

The need for interdisciplinary training does not end with the establishment of a career. Scientists working in a field might find that answering the research questions facing them requires new approaches and that different perspectives would benefit their research. Others might find that their specialization no longer generates state-of-the-art research and does not attract funding. And others might simply desire to know more about a hot new subject. These researchers are all candidates for additional training. Several funding approaches are available for midcareer scientists to broaden their scope. Most such interdisciplinary endeavors probably occur without such a funding mechanism, but funding provides support for expanding and formalizing such activities and is likely to go far in encouraging an interdisciplinary approach.

Midcareer Investigator Awards

Career development awards are available through NIH for established scientists, as well as for junior faculty (appendix D). The award mechanisms can easily be focused on interdisciplinary training. The Midcareer Investigator Award in Patient-Oriented Research (K24) supports a clinical investigator to spend up to 50% effort on clinical research. The Senior Scientist Award (K05) provides salary support (minimum, 75%) to established investigators with demonstrated productivity; the intent is to allow them to engage in research activities for the majority of their time. With these funding mechanisms, provisions could be added to encourage investigators to focus on interdisciplinary problems that require research attention.

Foundations also have programs to provide midcareer opportunities for scientists. The MacArthur Fellows Program provides 5 years of salary support to exceptional people to allow them to devote time to promising subjects.[84] The investment is in the person rather than in a particular project. It requires no project proposal; recipients are chosen from recommendations by designated nominators. In this program, interdisciplinary efforts are encouraged. Fellows are free to work in multiple fields, to train in new fields, or even to change directions in their careers. Another example is a recent initiative of the McDonnell Foundation called Bridging Brain, Mind, and Behavior. Its “21st Century Scientist Award” provides substantial funding (up to $450,000 over 3–6 years) for investigators to pursue innovative research spanning neurobiological, cognitive, and behavioral sciences.[80] No indirect or administrative costs are provided. The program especially invites research proposals that might not otherwise be funded by traditional sources because of their novelty or interdisciplinary nature. Investigators at any stage in their careers can apply, but applications from scientists early in their careers are particularly encouraged.

Foundations have supported a number of fellowships that are designed to add skills to people already trained in one field. For example, Robert Wood Johnson's Health Policy Fellowships Program supports midcareer health professionals for a year as they work in a program designed to educate them about policy processes.[74] A combination of didactic training, work experience in a congressional office, and informal meetings with senior government officials, members of Congress, journalists, and academic experts provides an understanding of federal processes. The program not only has helped to reorient the careers of trainees toward policy, but also has enhanced the health policymaking process by providing policymakers with the expertise of health professionals. According to a 1992 evaluation, the vast majority of the alumni continue some effort related to health policy.

Sabbaticals often provide an opportunity for established researchers to try something new. It can be a time to work with a geographically distant colleague to learn new techniques and explore new ideas. Some foundations have programs that support sabbaticals for midcareer scientists. For example, the Burroughs Wellcome Fund's Clinical Scientist Award supports established physician-scientists for up to 5 years to do translational research.[8] During the award period, investigators must spend at least 75% of their time in research. The award will provide up to 1 year of support for a sabbatical at another institution or department for an investigator to obtain new skills for research.

Fellowships and sabbatical programs for midcareer scientists could provide a mechanism for retraining and broadening the scope of established scientists interested in interdisciplinary research. Each approach can be used to encourage people to develop a new approach, learn a new field, or establish collaboration outside their discipline. In this way, it would be possible to expand the cadre of scientists capable of addressing the interdisciplinary problems facing science today.

Faculty Development Programs

Exposure to other disciplines can also be obtained from colleagues within a person's home institution. Interactions among scientists enhance communication and provide alternative views of a research question. For the most part, these interactions are informal. Scientifically pivotal conversations can occur by chance. Some approaches increase the likelihood of these interactions.

One of the most common mechanisms is the departmental seminar series in which a speaker, invited from outside the department or from down the corridor, stimulates new ideas or even collaborations. Another alternative is a formalized course for faculty development as proposed by Ullian and Stritter.[88] An integrated local program uses a core faculty to provide training in a faculty function, such as teaching or research, and requires a commitment of 10–20% effort over 1–2 years. Such a program can be well suited to training in translational research, to provide a clinical perspective to basic scientists or new scientific advances to clinicians. At the committee's workshop (Opportunities in Interdisciplinary Training), Dr. Stritter described how this program was used to train clinical faculty to do collaborative research. The Health Resources and Services Administration funds a program, Faculty Development in Primary Care, that provides fellowships plus planning and operational expenses for these kinds of training programs for physicians who plan to teach.[19] A similar mechanism could be implemented to cover other faculty development programs that enhance interdisciplinary or translational research.

Workshops

Senior investigators often receive informal training through their participation in meetings and workshops. When they come together with investigators from different disciplines, information and ideas are likely to be exchanged and then taken back to the laboratory and used in research. To encourage that type of exchange, several NIH institutes put out a request for applications for Educational Workshops in Interdisciplinary Research.[72] Using an R25 mechanism (Education Project Grant), NIH supports workshops lasting 1–2 weeks that bring together social, behavioral, and biomedical researchers to integrate research efforts across the fields. The educational goal was to promote an interdisciplinary understanding of approaches and theoretical perspectives among investigators early in their careers; the long-term objective was to encourage collaboration and to develop interdisciplinary initiatives. NIH also provides funding for symposia and meetings through R13 and U13 mechanisms. These can also be used to enhance interdisciplinary efforts by supporting programs that bring together people in diverse fields to focus on particular scientific questions. In such an environment, cross training of investigators and encouragement of collaboration would develop naturally.

NIH generally uses the R25 mechanism to fund educational activities that are not adequately supported by other grant mechanisms. The activities typically are brief (less than 3 months) and encompass short courses, workshops, seminars, short research experiences, and development or evaluation of educational programs. Longer research experiences are covered only if adequately justified.[39] A recent request for applications expanded on this, allowing 1–2 years of support for training experiences that fostered translational research as part of a larger "education and training center."[42] Funds can be used, for instance, to encourage clinical research by providing funds for postdoctoral fellows or residents who wish to continue mentored clinical or translational research. This program can also provide support for translational researchers at a critical point in their careers: between the postdoctoral position and the first K award.

Multi-Institutional Programs

Consortia and multi-institutional programs provide forums for a far-reaching integration of research efforts in multiple disciplines. Programs supporting groups of scientists from several disciplines can foster new kinds of research that go beyond one discipline. For investigators involved with a consortium, opportunities abound to learn from colleagues and to broaden the scope of research efforts. Participants learn a good deal about each other's methods, but people need not become expert in the skills of another discipline; rather, the investigators work as a team, with each discipline contributing to a collaborative effort. Funding mechanisms are available from both federal and private sources. Some efforts do not specifically indicate training activities; others include postdoctoral or predoctoral training.

NIH Centers

The specialized center grant (P50 mechanism) supports the full range of research and development from basic to clinical and intervention studies, as well as health services, policy, and surveillance research. These grants differ from traditional program project grants (PO1 mechanism) in that they are more complex and flexible with respect to the activities that can be supported. In addition to support for interdisciplinary research projects, support may be provided for career development research activities, a small number of pilot research projects, and specialized resources and shared facilities aimed at supporting the range of proposed research. Principal investigators are responsible for the planning, direction, and execution of the proposed program.

The requests for P50 grants are centered within the various NIH institutes. Each institute has established its own approach to these grants. For the most part, they are not used for training activities, but there are several notable examples in which either training is explicitly funded by the program or links to training are expected to exist. For instance, the request for Alcohol Research Center grants states that "while the center need not necessarily have formal training of its own, there must be specific provision for coordination between the Center and the training programs at the applicant institution and/or affiliated institutions."[49] In addition, the center must demonstrate the capacity to conduct continuing education and to train predoctoral and postdoctoral students. Similarly, the request for the Silvio O. Conte Centers for the Neuroscience of Mental Disorders requires that there be close coordination between a center and institutional training programs.[41] In contrast, a recent program announcement from the National Institute of Mental Health (NIMH) for Centers for Behavioral Science Research in Mental Health requires that funds from the award be used to support at least two trainees each year.[40] The request for applications for Transdisciplinary Tobacco Use Research Centers takes this further and makes career development a merit criterion for evaluation for funding.[23] The announcement encourages centers to provide "career development [for those] who demonstrate potential for independent research careers in transdisciplinary tobacco-related research or who are established investigators and are changing the direction of their research careers."

P50 awards provide support for a broad interdisciplinary research program consisting of related research endeavors and associated core infrastructure to ensure their effective and synergistic functioning. The activities included in the supported research must be thematically integrated, interdisciplinary, and synergistic. Research supported through this mechanism must reflect in clear ways interdependence of components of the research program that would not arise simply from the mere collection of the individual components. Taken as a whole, a center is expected to enable a level of achievement that exceeds what would be expected on the basis of the sum of its parts. Furthermore, each center is encouraged to address a wide range of research, from basic to clinical applications, around its central theme. Center support should be essential to the achievement of the work that is proposed.

NSF Centers

The NSF initiated the Science and Technology Centers Program in 1987 to encourage multidisciplinary research, technology transfer to nonacademic institutions, and innovative educational approaches. The science supported by the centers is expected to be at the "interfaces of disciplines" or novel approaches within a discipline. The centers are expected to bring together organizations that include separate campuses, schools, government agencies, national laboratories, or industry (see Box 4-5). Like the IGERT program, an important focus of the Science and Technology Centers is the preparation of students for broad career paths.[66] The centers have been judged to be very successful in a number of impartial reviews (most recently, National Research Council, 1996[62]). They provide facilities for research interactions and education that include collaboration with industry and national laboratories. The broad-scope, problem-based research supported by the centers has been effective in addressing complex scientific problems.

The Science and Technology Centers have annual budgets of $1.5–$4.0 million. A successful center grant is funded with an initial commitment of 5 years. After the fourth year, the centers must undergo a comprehensive review. Successful centers are monitored every 18 months for the next 5 years. NSF limits funding to a total of 10 years. It is expected that support for the centers will be supplemented by other sources, including the institution, but no preset amounts are required.

NSF has also created a large consortium for research on violence that is coordinated through Carnegie Mellon University.[70] It brings together researchers from 24 institutions in the United States, Canada, and Europe to address broad issues related to the causes and consequences of violence.

Foundations

Private foundations have a history of funding consortia. An example is the MacArthur Foundation Program on Human and Community Development.[82]

BOX 4-5 NSF SCIENCE AND TECHNOLOGY CENTER FOR BIOLOGICAL TIMING, UNIVERSITY OF VIRGINIA

The Science and Technology Center for Biological Timing brings together investigators of the University of Virginia, Brandeis University, North-western University, and Rockefeller University in a cooperative effort to solve major problems in biological timing and to provide breadth in postdoctoral, graduate, and undergraduate training. In addition, the center supports seminars, workshops, and symposia for center and noncenter participants and provides administrative assistance to the Society for Research on Biological Rhythms and the International Society for Chronobiology.

The unifying goal of the Center for Biological Timing is the elucidation of the molecular, cellular, and systemic processes that generate, synchronize, and integrate critical physiological oscillations in higher organisms. Besides its research program, the center supports numerous educational and outreach programs. The Remote Access Online Real-Time Science Experiment engages K–12 students and teachers in an active program supplementing science learning at the middle school and high school level. Local high school teachers and center staff updated the Biological Timing Tutorial CD-ROM, adding depth and breadth of scientific information and instructional animation. Other educational programs include the Undergraduate Summer Research Experience, a videotape library with copies of center lectures, and Fridays at Four (Virginia) and Clock Watchers (Northwestern), informal weekly seminar programs. The center maintains international contacts with Japanese and Latin American researchers.

The NSF Science and Technology Center for Biological Timing continues to play an important role in biological timing research and education. The technology development efforts are bringing to the field important new techniques that permit long-duration, noninvasive measurements of rhythmic cellular processes. The multi-university framework has also created outstanding training opportunities for graduate and postdoctoral students, and outreach programs have allowed many noncenter investigators an opportunity to visit the center for research collaboration, symposia, and other special events.

The program encompasses several research consortia that address aspects of access to economic opportunity, building of community capacity, child and youth development, and mental health. Each component is linked with the others to enhance the integration of findings and applications. Among almost 20 consortia covered by this program is a Network on Psychopathology and Development, which integrates biological and behavioral approaches and brings together investigators from diverse fields to explore the developmental pathways toward mental illness.[81] Another network supported by the MacArthur program is Network on Early Experience and Brain Development, which integrates the efforts of developmental psychology, neurobiology, and behavioral pediatrics to assess the relationship between the brain and behavioral development.[83] Each of these networks that individually have a broad scope are further integrated under the full program designed in an effort to obtain solutions to community problems.

The William T. Grant Foundation similarly has supported eight consortia, including the Consortium on Chronic Physical Disease in Children, which now continues to operate with federal support. It brought together pediatricians, an epidemiologist, a sociologist, a psychologist, an economist, and a public health administrator who conducted collaborative research with large national data sets.[18]

INTERDISCIPLINARY TRAINING FOR UNDERREPRESENTED POPULATIONS

Underrepresentation of minorities and women is not unique to interdisciplinary training and research. Recruitment from these populations presents a challenge for all scientific fields. However, the problem is exacerbated, perhaps, by the additional obstacles faced by those interested in interdisciplinary problems, as described in chapter 3. Cultural and ethnic diversity that comes from participation of varied populations can enhance interdisciplinary and translational research. An example is bench-to-bedside research that focuses on health disparities within the American population. Minority institutions provide unique opportunities to work cooperatively with patients through community-based organizations where these populations are disproportionately affected.

Many programs exist specifically to encourage underrepresented populations in biomedical and behavioral sciences. Some of these programs are briefly reviewed below with explanations of how they can be extended to support interdisciplinary efforts.

Outreach to Undergraduates and High School Students

It is at the undergraduate level that students often are stimulated to enter research. Outreach programs early in the education of minority students have been observed in a number of assessments to encourage students to enter biomedical careers.[1,10,87]

Several NIH programs are designed to encourage undergraduates, especially members of underrepresented groups, to pursue scientific careers. One such program, supported by NIMH, is the Career Opportunities in Research (COR) Education and Training Program. The COR Honors Undergraduate Research Training Grant (T34 mechanism) provides funds to 4-year colleges or universities that have substantial minority enrollment in an effort to enhance their curriculum in biobehavioral sciences and to prepare students for research careers in mental health.[37] Graduates of the program are expected to be competitive for doctoral-level training programs. NIMH also funds the COR Education Program for Honors High School Students (R25 mechanism).[36] The training grant is awarded to minority institutions already funded through the undergraduate program. It provides mentoring and research experience to minority high school students to encourage them to choose careers in mental health research. As illustrated by the example in Box 4-6, these programs can be useful in providing an interdisciplinary perspective early in the students' careers.

Other NIH institutes also have programs for undergraduates that are intended to encourage members of underrepresented minority groups to enter graduate programs. NIGMS offers the Minority Access to Research Careers (MARC) Undergraduate Student Training in Academic Research (U-STAR) Program with aims similar to those of the COR programs.[35] NIGMS also offers the Initiative for Minority Students: Bridges to the Baccalaureate Degree to facilitate transition from 2-year junior or community colleges to 4-year institutions.[34] NSF awards will also support outreach programs to encourage minority involvement in research (see Box 4-7).

Minority Faculty Development

Many NIH funding mechanisms are oriented toward encouraging minorities to participate in biomedical research. Several of these can provide the mechanisms to encourage the development of an interdisciplinary perspective. The NIMH Scientist Development Award for New Minority Faculty recognizes that minority group members are often in great demand for ancillary activities at their institutions at a time when they most need to focus on establishing their careers.[44] The award is intended to provide untenured faculty with at least 75% time to devote to mentored research. More than one mentor can be selected, and a mentor need not be at a trainee's home institution, although the principal mentor should be available locally.

Other programs focus on faculty at predominantly minority institutions. The National Institute of Arthritis and Musculoskeletal and Skin Diseases (NIAMS) and National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK) provide the Minority Investigator Research Enhancement Award to support minority institution faculty to collaborate with NIH-funded investigators.[28] The Minority Access to Research Careers (MARC) Faculty Fellowship provides full-time faculty from minority institutions with funds to do research at any U.S. institution for some period, and then return to the sponsoring school.[32] The MARC Visiting Scientist Program supports a visiting scientist to spend 3–12 months at a minority institution.[51,60]

Those mechanisms can be used to provide minority faculty with opportunities to expand their knowledge and promote an interdisciplinary perspective.

BOX 4-6 COR HONORS MINORITY PROGRAM, GRAMBLING STATE UNIVERSITY

Grambling State University is an historically black college in Louisiana. This program selects students who are majoring in biology, chemistry, psychology, or criminal justice and have an expressed interest in graduate school in mental health or substance abuse for a 2-year interdisciplinary honors program. Many of the program's activities are oriented toward enhancing the understanding of research as related to clinical problems. The curriculum includes academic training, research experience, field trips, and guidance for future academic careers. The program attempts to provide skills in critical thinking and communication of scientific concepts. During the first year, students take an interdisciplinary course on research methods and develop proposals for their own projects in alcoholism, drug abuse, and mental health to be carried out during a summer internship at a cooperating institution. The trainees also visit mental health facilities to add clinical perspective to their coursework. In their senior year, students are required to provide oral and written presentations of their research findings. Weekly seminars take place throughout the program, some presented by major researchers.

High school students in their junior year are selected to participate in the program. They are paired with a faculty mentor and a COR undergraduate junior and provided the opportunity to do hands-on research. Students are required to do library research on a topic related to biobehavioral sciences. Trainees are counseled about the research career opportunities available.

BOX 4-7 THE CENTER FOR BEHAVIORAL NEUROSCIENCE, ATLANTA, GEORGIA

The mission of this NSF-funded center is to bring together the unique resources from a consortium of Atlanta colleges and universities to build a program that will investigate the brain processes underlying complex behaviors and create a cadre of interdisciplinary investigators focused on behavioral neuroscience. It is hoped that the center will change the study of the brain and behavior and lead to new comprehensive understanding of how brain mechanisms regulate and are regulated by complex behaviors. It is also hoped that the center will transmit the excitement of behavioral neuroscience to the next generation of investigators.

To increase minority access to higher education, the center will develop new programs and participate in existing programs to improve precollege preparation, high school graduation rates, and student success rates in science courses. Among the efforts planned are providing additional positions for teachers to join research projects and design related curricular units, extending the Elementary Science Education Partnership to middle and high school students to provide mentorship for students and partners for teachers, expanding on-line resources with curriculum modules for teachers, conducting teacher workshops, bringing demonstrations and experiments to local schools, and measuring the results of these efforts with formative and summative assessments. Behavioral neuroscience is an ideal focus for these efforts in that it deals with compelling issues for students, and through the center's efforts students will see how science can allow them to explore some of the most mysterious aspects of human experience.

The center will combine radio, television, and Internet technology to deliver a comprehensive multimedia knowledge-transfer program, educating the lay public about brain-behavior relationships and creating educational materials. The center will be linked to the Atlanta Zoo to enhance educational programs. Links to government programs, to national societies and foundations, and to industry will help to build partnerships for both research and education.

The intent would be to allow investigators from institutions where interdisciplinary work would be difficult to establish the opportunity to develop new perspectives, learn new techniques, and establish new contacts. The same goals could be attained through mechanisms similar to those described in Box 4-8. In this arrangement, a consortium reaches out to minority schools to provide mentorship to junior faculty and to promote networking among scientists working in related fields. By encouraging collaboration beyond the walls of the university, funding mechanisms could establish the basis for interdisciplinary interaction and collaborative research programs.

On a smaller scale, travel awards can achieve similar goals. Several NIH institutes offer minority travel awards (Minority Travel Award Program—NIAMS, NIDDKD[27]; Minority Institution Travel Award Program—Human Genome Project[24]) to either students or faculty to attend workshops, meetings, or courses relevant to their missions. To encourage minority scientists to broaden their scope and learn about other disciplines, a travel award could stipulate that the funds be used for interdisciplinary training. The proposal could describe how the travel would promote an interdisciplinary perspective.

BOX 4-8 FAMILY RESEARCH CONSORTIUM III (FRCIII), PENNSYLVANIA STATE UNIVERSITY

FRCIII aims to promote intellectual exchange and collaborative research and training in the study of diversity, family process, and child and adolescent mental health. The consortium comprises a faculty of senior scientists from 12 institutions, an advisory board to provide long-term guidance, five liaisons to related networks and consortia for cooperative research and training activities, junior faculty members from two historically minority universities as “research partners,” a “study group” of new investigators, and postdoctoral trainees. The research partners and study group participate in the consortium's Summer Institute and research collaboration workshop and are teamed with consortium faculty to develop research ideas and grant proposals. The postdoctoral trainees attend an intensive 8-week summer workshop and a weekly seminar, participate in the Summer Institute, and perform collaborative research with at least two faculty members at different sites. Through the consortium, the faculty, new investigators, and students obtain mentoring and create a network that provides scholarly support on complex research issues and connections and collaborations with senior scholars. The trainees have the opportunity to establish lasting scientific partnerships.

Minority Institutions

Existing mechanisms to enhance the research at minority institutions can also be used to promote interdisciplinary efforts at these institutions. Bringing in additional expertise, purchasing an expensive piece of equipment to be shared, or supporting travel for additional training not only will enrich the university in general, but could specifically encourage interdisciplinary research. With the advent of interdisciplinary research, interdisciplinary training can follow. The development of research centers at geographic sites serving large numbers of minority students is considered by some as an effective mechanism of influencing substantial numbers of such students to consider biomedical research as an exciting and rewarding career. Role models of minority institutions, as well as individuals, provide encouragement for students. Examples of existing mechanisms for support of minority institutions follow.

The Minority Research Infrastructure Support Program (M-RISP, R24 mechanism) is sponsored by NIMH to build mental health research programs at minority institutions.[38] The program supports a wide variety of activities designed to enhance the research environment and promote the capabilities ofthe faculty and students. Items covered can include the purchase of shared equipment, support for statistical cores, funding of collaborative arrangements, tuition for training seminars in scientific techniques, expenses for pilot research that will be developed for future funding, and research training for junior investigators, technicians, and assistants. By strengthening the research environment, the program expects to develop existing capacity for research and encourage participating minority students to pursue relevant careers.

Cooperative Agreements at NIH (U mechanisms) have also been used to assist minority institutions in developing their research capability. Under these mechanisms, staff at NIH act as partners to stimulate research activities, providing advice and technical expertise as required. The minority institution might also be required to establish a collaboration with a "research-intensive" institution. For example, the Collaborative Minority Institution Alcohol Research Development (CMIARD) grant encourages alcohol research at minority institutions.[48] The U24 mechanism supports a minimum of three alcohol research projects that can be exploratory or pilot. In addition, the CMIARD provides core funding for such resources as development activities, administrative services, unique clinical facilities, animal facilities, biostatistical and computer services, shared equipment, and meetings to explore collaborative research. Formal research training activities are not supported by this grant mechanism, but participation in the program is expected to have a substantial effect on career development of minority faculty members. The Specialized Neuroscience Research Programs (SNRP) at Minority Institutions (U54 mechanism) fund up to three research projects in a collaborative program that focuses on a problem in neuroscience that requires an interdisciplinary approach.[46] All participating investigators are expected to benefit from the sharing of resources and expertise. By their nature these cooperative agreements encourage interdisciplinary research in minority institutions.

Special Training Issues Concerning Women

Many barriers face women in research. Like the obstacles faced by minorities, these are not unique to interdisciplinary activities. But the additional obstacles imposed by interdisciplinary research can be exacerbating. Family commitments often interrupt careers of women. Interdisciplinary training is generally longer and requires more extensive networking, so an interruption during the career path can be particularly discouraging for interdisciplinary efforts. Awards that encourage reentry of people into scientific careers would benefit those interested in interdisciplinary research.

The Mentored Research Scientist Development Award (K01) provides 3–5 years of supervised research experience for people who have had postdoctoral research experience but need additional supervised development before achieving independence.[58] Some NIH institutes use this award to support people who have interrupted their careers because of illness or pressing family care commitments.

Others reserve it for underrepresented minorities. Other institutes use the mechanism to enhance the qualifications of the trainee.

Another mechanism used to encourage reentry into research is the Supplement to Promote Reentry into Biomedical and Behavioral Research Careers.[57] It provides up to 3 years of support to people who have been out of research for 2–8 years, have at least 2 years of postdoctoral research, and would be ready for an independent research position. The program does not support postdoctoral training. Qualifying interruptions include starting or raising a family, an incapacitating illness of a candidate or candidate's spouse, relocation to accommodate a spouse, and pursuit of nonresearch endeavors to repay debt incurred by doctoral training. Principal investigators can submit an administrative supplement on their NIH awards with at least 2 years of support remaining. The proposed research must be directly related to the funded approved continuing research under the parent grant. The decision to fund a supplement takes about 8 weeks.

Administrative supplements are also available for Underrepresented Minorities[56] and Individuals with Disabilities.[55] They provide support for research experience for minority-group members or people with disabilities throughout the continuum from high school to the faculty level. These supplements, like the reentry supplement, are expected to provide research experience that is an integral part of the approved continuing research. The committee recognizes the potential for this type of mechanism to promote interdisciplinary research and recommends its development. Supplements for new interdisciplinary research should provide salary support for the duration of the original grant that is commensurate with full-time faculty salary. The committee cannot estimate the numbers of such supplements that will be requested, but expects the total to be modest. Given the recent increases in NIH budgets, these supplements should be feasible under existing budgets.

COLLABORATIONS AMONG FUNDING AGENCIES

Because of the disciplinary focus of many funding agencies, support for interdisciplinary research can benefit from collaboration among units. It can include collaboration within NIH, collaboration among government agencies, and collaboration between government and the private sector. Examples of existing interactive efforts are described below.

Collaboration within NIH: NIH Pain Research Consortium

The NIH Pain Research Consortium, established in 1996, brings together over 20 units of NIH to promote research and collaborations on pain, to coordinate intramural and extramural programs, and to foster relationships with patient communities.[54] The consortium is bringing together researchers in basic and clinical sciences for workshops and symposia that take an interdisciplinary view of pain. An intramural Pain Interest Group arranges seminars, informal discussions, and listserve communication and enhances the research efforts at NIH. Multiple institutes cosponsor requests for applications in support of pain research that includes behavioral pain research, research on low back pain and common spinal disorders, complementary and alternative medicine, and management of symptoms at the end of life.

Collaboration Across Government Agencies

The Human Brain Project Phase I Feasibility Studies

Brain and behavioral research produces vast amounts of diverse and complex data. Integrating this information is beyond the scope of an individual researcher. To encourage the development of approaches and technologies needed to address the information overload, five federal agencies joined together to sponsor the Human Brain Project.[45] Representatives of NIH, NSF, the Department of Defense, the National Aeronautics and Space Administration (NASA), and the Department of Energy (DOE) make up the Federal Interagency Coordinating Committee. In addition, NASA will make its supercomputer available for Human Brain Project research.

This funding initiative is designed to encourage scientific collaboration bridging brain and behavioral research and informatics research to accelerate the understanding of the brain by providing the means to make better use and sense of data about the brain and behavior. Informatics research—which draws from computer science, information science, applied mathematics, statistics, engineering, and related fields, can contribute to solutions to the problem of keeping track of and integrating information about the brain and behavior. Projects are expected to include both an informatics research component and a brain- or behavioral-science research component in an interactive approach.

NSF Partnerships

Among the many projects that NSF funds in conjunction with other government agencies is the Plant Genome Research Program.[68] This initiative is sponsored by NSF with DOE and the U.S. Department of Agriculture. The program aims to support research on the structure, organization, and function of plant genomes and aims to develop new knowledge and innovative technologies that will help to elucidate basic biological processes in plants. Another program, cofunded with NIH, is the International Cooperative Biodiversity Groups.[14] This program calls for the development of interdisciplinary programs and institutional relationships that would promote conservation of biological diversity through the development of the economic potential of sustainable biological resources, such as pharmaceuticals from natural products.

NSF partnerships with NIH are relatively few despite the fact that two agencies have complementary missions. NSF supports basic research in the sciences and engineering. Although its mission includes "advanc[ing] the national health, prosperity, and welfare," it does not encompass biomedical research.[69] The latter is within the scope of NIH, whose goal is "to acquire new knowledge to help prevent, detect, diagnose, and treat disease and disability."[61] Where basic biological research stops, clinically relevant biomedical research picks up. To span the full range of translational research—basic mechanisms through clinical trials—the committee found that collaborative efforts between NSF and NIH should be encouraged.

Government–Foundation Collaborations

Tobacco Use Research Centers

The Transdisciplinary Tobacco Use Research Centers were initially funded through a joint effort of the National Cancer Institute (NCI) and the National Institute on Drug Abuse (NIDA) to create a network of centers focusing on the prevention and treatment of tobacco use.[23] In October 1999, the Robert Wood Johnson Foundation (RWJF) formed a partnership with NIH to provide additional support for these centers and complement NCI's and NIDA's existing efforts;[50] seven academic institutions, each organized around a unique theme, were funded. The 5-year program is expected to foster unique collaboration among scientists across many disciplines. The public health concerns about tobacco smoking are long-standing interests of both NIH and RWJF. The development of the program stems from a national conference in July 1998 cosponsored by NIDA and RWJF and from recommendations of NCI's Tobacco Research Implementation Group.

NIH Interactions with Foundations

NIH also collaborates with foundations on a scale that is less grand; cosponsored workshops and symposia are not uncommon. For example, a symposium, "Vaccines for Prevention and Treatment of Autoimmune Diseases" (June 8, 1998), was cosponsored by several NIH institutes and a number of nonfederal organizations. These nonprofit societies included the Juvenile Diabetes Foundation International, the Lupus Foundation of America, the American Autoimmune-Related Diseases Association, the Arthritis Foundation, and the National Multiple Sclerosis Society.[77] In addition, the institutes will work with the non-profit societies to fund complementary components of meritorious investigator-initiated projects.[25,26]

Opportunities with Private Industry: GOALI

The NSF works through many of its programs to strengthen links with industry. The Grant Opportunities for Academic Liaison with Industry (GOALI) program aims to strengthen university-industry partnerships by making funds available to support them.[65] Of special interest is providing opportunities for faculty, postdoctoral fellows, and students to gain experience with industrial processes; for industry scientists to bring their perspectives and skills to academe; for interdisciplinary university-industry teams to conduct long-term projects. High-risk, high-gain research that would otherwise not be tackled is encouraged. The initiative seeks to develop innovative collaborative educational programs and the exchange of knowledge between universities and industry. Although industrial partners are not required to match NSF funds, cost-sharing for the collaborative work at industrial sites and universities is encouraged.

FINDINGS AND RECOMMENDATIONS

In the review of training programs, several themes emerged. Interdisciplinary training seeks to create people who can ask new questions, apply a variety of approaches, and seek appropriate collaborative expertise. Training should provide scientists with the tools to understand and use the information from other fields. In addition to teaching the substance of one or more fields, scientific education needs to provide the skills necessary to understand other disciplines and to communicate with those outside one's own field.

Postdoctoral fellows are frequently considered to be the “vector” in collaborative research. Through participation in a joint effort of two or more laboratories, the trainee has the opportunity to become knowledgeable about more than one discipline. The mentors also benefit from the interaction and learn more about another field, thereby enhancing their scope as well.

Because strong training for predoctoral and postdoctoral students builds on strong research among the faculty, interdisciplinary research should be encouraged for appropriate research problems. Mechanisms to facilitate interdisciplinary efforts should be available at all stages of a career. Special attention needs to be directed toward supporting interdisciplinary efforts of junior faculty who may be discouraged by their vulnerability as they establish their careers and face tenure and promotion decisions.

Many mechanisms already exist but should be refined to address the special needs of interdisciplinary research and training. For instance, the institutional training programs do not adequately support administrative costs. The Medical Scientist Training Program is rarely used to support PhDs in the humanities and social sciences. Funding programs to provide clinical training for PhDs are uncommon.

Partnerships among funding agencies not only allow the coordination of divergent disciplinary perspectives, they also can leverage funds. Partnerships with industry can provide trainees with unique opportunities to explore alternative career paths.

The committee reiterates its perspective that interdisciplinary research should not indiscriminately supplant disciplinary efforts. Broad training early in a career and continued training throughout a career can provide the tools to integrate multiple disciplines when required by the research question.

The committee makes the following recommendations:

Recommendation 3: Scientific education at early career stages should be sufficiently broad to produce graduates who can understand essential components of other disciplines while receiving a solid grounding in one or more fields. Criteria for NIH-supported research training should include both breadth and depth of education. Funding mechanisms to support interdisciplinary training in appropriate fields (as identified in Recommendation 1) should provide additional incentives to the universities and the trainees along the following lines:

- **Through the NIH Medical Scientist Training Program, encourage participating universities to support MD/PhD programs in the social and behavioral, as well as biomedical, sciences.** Although existing program language permits such graduate study, training in social and behavioral science (e.g., anthropology, economics, psychology, and sociology) is undertaken infrequently. NIH can highlight the need for such graduates and encourage grantees to recruit them.
- **Promote translational research, an important aspect of interdisciplinary training by: (1) Providing clinical experience in PhD programs.** This can range from support for single courses that expose students to human pathophysiology to training programs that require both basic research and clinical experience; (2) Supporting PhD programs and postdoctoral mentored career development awards for physicians, nurses, dentists, social workers, and other clinicians.
- **Create partnerships with the private sector to develop and support interdisciplinary training.** Many of today's students will enter private industry to do translational research. Others will go on to careers in teaching, publishing, science policy, science administration, or law. Interdisciplinary perspectives are as important to success in these careers as they are in research.
- **Expand the T32 training grant awards to cover the full direct costs of implementation.** This change will provide the resources

necessary to support the greater expenses encountered in an interdisciplinary training program.

Recommendation 4: Funding agencies should establish a grant supplement program to foster interdisciplinary training and research. This would be administratively modeled after the supplements that exist for minorities, people with disabilities, and for people reentering research after a hiatus. Investigators with research grants who have interdisciplinary training opportunities should be able to obtain supplemental funds for qualified candidates through a relatively short application form with expedited review. Successful pilot efforts will provide data to support further applications for career development and research.

Recommendation 5: Funding opportunities for interdisciplinary training should be provided for scientists at all stages of their careers.

- **Implement career development programs that encourage junior faculty to engage in interdisciplinary research.** Junior faculty need to be successful in the early phases of their research, so they are less likely than senior faculty to pursue interdisciplinary research.
- **Support midcareer investigators in developing expertise needed for interdisciplinary research.** These programs should include sabbaticals, career development awards, and university-based, formal courses for faculty development to enhance interdisciplinary and/or translational research.
- **Continue funding for workshops, symposia, and meetings to bring together diverse fields to focus on a particular scientific question.** In such an environment, cross training of the investigators and encouragement of collaboration would develop naturally.
- **Support consortia and multi-institutional programs that provide integration of research efforts in multiple disciplines.**

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5

The Future of Interdisciplinary Research and Training

The seeds of progress germinate, and the shape of the future unfolds in our conviviality, at the convergence of all our different paths. It is in this gradual cross-fertilization that the future of knowledge—and indeed of the world—resides

— Federico Mayor

As the committee reviewed the many programs, interviewed institutional representatives, and examined funding mechanisms, a key component to interdisciplinary efforts emerged: leadership. The committee heard about the dedicated efforts of individuals, leaders with a vision to establish a program that spanned disciplines. It required vision, creativity, and perseverance. It required education of scientific colleagues and administrators about the potential that exists in interdisciplinary efforts. As discussed in chapter 2, a research question or field of study first needs to be identified. It might be necessary to start with a small effort until it becomes clear to colleagues, administrators, and funders that the collaborations are fruitful and likely to lead to answers that would not otherwise be found. As presented in chapter 3, the leaders must strive to overcome the obstacles that face them. University administrators need to be convinced that an interdisciplinary approach is profitable for them and their institution. An investment (financial and administrative) in interdisciplinary programs can breed additional successes—in research, in obtaining funding, in training the leaders of the future. As described in chapter 4, funding mechanisms exist to support training throughout a scientific career. In their current form, these must sometimes be used creatively, be used in combination, and have multiple sources. With these tools, the training programs can create the leaders of the future who will forge new paths to solve the difficult problems that can be tackled only through an interdisciplinary approach. This chapter looks to some of the opportunities presented by future technologies and asks how we will recognize the success of our interdisciplinary programs.

INNOVATIVE APPROACHES AND OPPORTUNITIES

Programs of the future will be less constrained by geography. A variety of developments in modern communication technology might improve interdisciplinary training by decreasing institutional and geographical barriers. These include advances in Internet communication, electronic journals, and real-time, low-cost telecommunication abilities.

The opportunities of electronic publishing could greatly increase the accessibility of information from diverse fields (although some have expressed concerns about the dangers of this broad dissemination without adequate peer review; see Relman, 1999[16]). Many journals already provide full text on line, allowing access to articles in many disciplines. Publishing on line can go beyond simple text and figures. The capability exists to include complex data in the form of "Java applets," which are computer programs or models that run on a Web browser.[3] The inclusion of links to related papers can yield a network of cross-disciplinary information for interested readers.

Those advances can reduce information-based barriers to the furthering of interdisciplinary research. However, the value of the enormous and growing databases will be in proportion to the ease with which information can be accessed and categorized appropriately. Improved, consumer-friendly search engines are a must for the use of these information resources by the widest possible audience. Current search engines for Web-based searches and for literature-based searches can miss pertinent references and obscure relevant data in a cloud of extraneous citations.

Videoconferences and virtual meetings could become increasingly important for conducting interdisciplinary research. The falling costs of individual cameras for PC-based platforms can enhance communication by allowing real-time transmission of video and auditory images. The growing access to Internet II, the next generation of Internet technology, allows broadband transmission of conferences and lectures. Lectures by world experts in any field could potentially be provided on the Web and made available to people interested in expanding their horizons. Already, for instance, the National Institute of Mental Health has a Web site presenting some of the symposia that it sponsors.[12]

The Internet is important not only for distance learning and virtual meetings, but also for making possible the sharing of data and analytic equipment over long distances. A program at the University of California, San Diego (UCSD) plans to make a high-voltage electron microscope accessible to researchers throughout the country.[5] Specimens sent to UCSD will be inserted into the microscope by local personnel but scanned by the remote investigator through an Internet link. Further processing, such as three-dimensional reconstruction by tomography, can be accomplished on line through a link to a supercomputer. Equipment too expensive for many investigators to own thereby becomes accessible. Shared laboratory access through the Internet for education is already in use at the Center for Biological Timing, where remote students can log onto a Web page to watch hamsters in real time (G. Block, IOM Workshop, 1999). As the technology improves and becomes cheaper and faster, these approaches are likely to become more common. On-line interactions will facilitate collaborative, and hence probably interdisciplinary, interactions.

EVALUATION

With the many mechanisms available to encourage interdisciplinary efforts, how do we know which are effective? Even though there have been almost 50 years of discussion concerning interdisciplinary needs, data to support the need for and effectiveness of the many mechanisms are scanty. Why is there a lack of data when there is so much interest? The collection and evaluation of interdisciplinary training outcomes are tremendously complex and difficult. The committee faced this obstacle in its review of interdisciplinary programs and determined that a process for evaluation of programs is needed. The issues that face anyone undertaking this task are highly complicated. Not all research needs to be, or even should be, interdisciplinary, but the committee expects that successful interdisciplinary training will increase the options available to trainees and lead the trainees to produce, on average, more interdisciplinary research. To know whether interdisciplinary training promotes interdisciplinary research, it is necessary to have a method of identification for interdisciplinary research and training programs. To measure the outcome of the training programs, it is necessary to have methods that will accurately reflect their success in promoting interdisciplinary research.

Identifying Interdisciplinary Programs

It is not possible to evaluate interdisciplinary training programs if they cannot be identified. Perhaps the first hurdle to evaluation of these programs is to agree upon a definition of the term interdisciplinary. *Interdisciplinary* can mean different things to different people. It can apply, for example, to a person trained in two or more disciplines working on a specific problem, to people each trained in one discipline and actively working together to solve a single problem, to collaborations among single discipline trained people working separately to solve a single problem with a coordinator overseeing the operation, and to any combination of the above. A program description might include all or some combination of the above; regardless of the specifics, a universal, meaningful definition of *interdisciplinary* (and of *translational*) among funding agencies (e.g., NIH) would be a start in developing evaluation methods. The committee has offered its working definitions in chapter 1. Once an accepted description is established, an appropriate labeling mechanism will be necessary. One possibility would be to have an interdisciplinary check box on the cover sheet of grant applications with a space to list the participating disciplines. That approach would allow funding agencies to define which training programs are to be tracked as interdisciplinary and to define which projects are interdisciplinary for outcome analysis.

Evaluating Success

How does one define, measure, and track the success of interdisciplinary training programs? What are the appropriate outcome measures for the promotion of interdisciplinary research? How is success defined? Should all trainees work in interdisciplinary research or should all trainees be able to understand interdisciplinary questions? How do you know if the trainees are prepared to tackle interdisciplinary questions should it become important to them? The committee believes that evaluation of training programs is needed, but qualitative assessments of the effectiveness and impact of training efforts are undoubtedly difficult to conduct. Over the last decade, numerous reports have lamented the lack of outcome data on federal training programs, such as the National Research Service Awards.[8,14] For example, past efforts to assess the reasons for the underrepresentation of women and minorities in science have faltered in the face of insufficient data regarding training programs and training outcomes.[8] When outcomes are more easily defined (for example, on the basis of producing successful grant recipients), analyses are more successful. For example, studies have shown that the training grant mechanism (T32) is less effective in inducing trainees to apply for NIH grants than is the fellowship mechanism (F32).[8] The analysis by the National Institute of General Medical Sciences of the Medical Scientist Training Program revealed that graduating MD-PhDs were more likely to apply for and receive NIH grants than graduates with just an MD.[11]

Some funding agencies have attempted more extensive program evaluations. In 1998, the Pew Charitable Trust conducted a review to determine the impact of its McDonnell-Pew Program in Cognitive Science on establishing and promoting a new field.[1] This review resulted in a volume that qualitatively assessed the growth of cognitive science. The Association of American Medical Colleges (AAMC) Group on Graduate Research, Education, and Training (GREAT Group) convened a Task Force on Benchmarks of Success in Graduate Programs in 1997 in recognition of the need to identify indicators of success of training programs. In June 1999, AAMC issued a *Self-Assessment of Graduate Programs in the Biomedical Sciences,* which describes some objectives of training programs and provides a survey instrument as a guideline.[4] Although the GREAT Group's report does not specifically address interdisciplinary training, it does serve as an example of the type of approach that can be used to develop an assessment tool.

Most funding agencies and organizations recognize the importance of a formal assessment of individual training programs. Renewals of NIH training grants require principal investigators to report the career achievements of previous trainees. The National Science Foundation (NSF) Integrative Graduate Education and Research Training (IGERT) programs require tracking and evaluation as well. The outcome measures tracked are generally the success of trainees in completing a degree, obtaining a position in research, publishing in peer-reviewed journals, and obtaining research grants. Those measures are important, but do not address the question, Did the training produce more interdisciplinary research? The answers to the question might lie in changes in the career paths of individuals or in changes within universities and funding agencies that promote further interdisciplinary research.

Career Paths

The general measures of success for those who conduct interdisciplinary research are the same as for those who conduct single disciplinary research—grants awarded, publications, tenure and rank, and laboratory size. The limitations of those indicators have been documented.[2] A scientist in a government laboratory or in private industry might not need grant support, for example. Graduates in nonacademic settings might develop products or patents instead of publications. The number of publications or even citations may not reflect the impact of a research effort.[9] Impact might be economic, health-related, or educational, and these are difficult to measure or attribute to a specific research program. In this regard, interdisciplinary research is no different from disciplinary research.

To address the effectiveness of interdisciplinary programs, additional measures should be included, such as whether graduates maintain an interdisciplinary approach in their work, as reflected by the nature of their collaborations, joint appointments in multiple departments, publishing of interdisciplinary papers, or obtaining grants with interdisciplinary themes. To assess the impact of interdisciplinary training, there also needs to be a point of reference or control group for comparison. How can we tell whether interdisciplinary training is achieving the goal of producing more interdisciplinary research if we do not know how much interdisciplinary research is being created by traditionally (or single disciplinary) trained people? The appropriate data should be collected on both interdisciplinary and single disciplinary trainees.

In some way, measures need to be collated to allow the evaluation of programs. Some assessment tools have been used to evaluate research outcome and could be used to compare interdisciplinary and disciplinary programs. For example, bibliometric analyses constructed around interdisciplinary research could be developed to compare the relative output of research institutions or to compare the relative productivity of one funding mechanism over another.[17,18] Such data would highlight institutions that are producing high-quality interdisciplinary research, and this could lead to a greater understanding of the factors that contribute to the high output. Bibliometric analyses could also be used to determine whether interdisciplinary training programs produced scientists who were more likely to be involved in interdisciplinary research. These analyses would, of course, require a means of identifying which research is interdisciplinary, again presenting the problem of definition and tracking. If universal and meaningful search terms were developed, the databases IMPAC II, MEDLINE, and CRISP might be used to conduct such analyses. In fact, NIH used these databases in the 1980s to conduct bibliometric analyses to determine the effectiveness of different research support mechanisms, such as to determine whether center grants are more effective than R01s in supporting clinical research, or in evaluating whether some categories of investigators or institutions are more likely to conduct research relevant to an agency's mission.[17]

Past tracking of federally funded training efforts has gathered data on the numbers of people trained on a T32, for example, or the percentage of fellows who entered academic versus industry careers after completion of training.[10,13,14] These assessments tend to result in recommendations about the need for more or fewer PhDs, or for increased or decreased efforts in specific fields, such as molecular biology or immunology. Periodic studies track demographic data on graduate degree production, employment by sector, unemployment rates, race, ethnicity, age, and gender. These studies provide useful trend data about the size and demography of the scientific population, but they tell us little about the influence of training on career outcomes and scientific contributions. For example, academic degrees alone tell little about the training that a person received or the type of research he or she will pursue. And, they do not tell us about the research experience of the student—whether he or she worked in the laboratory of a single investigator on a single problem funded by one or two single disciplinary grants or in a group working on related problems funded by multiple grants and funding sources.

The Howard Hughes Medical Institute (HHMI) has developed an approach to tracking. It maintains an extensive database of nearly 2,000 previous HHMI fellows that can be searched by institution, program, research field, fellow, or mentor.[7] A Web-based system records key data from the fellowship applications (for example, educational history) and collects additional information from annual reports of current fellows and career updates of former fellows. Information includes professional activities (for example, research, teaching, and clinical practice) and research involvement (for example, field, grants, faculty or industry appointments, and publications). Using information from fellowship applications, HHMI tracks applicants' prior participation in science education programs supported by HHMI and other funders (at the precollege, undergraduate, graduate, and postgraduate levels). HHMI also collaborates with AAMC to track the career outcomes of HHMI fellows, nonawardees, and graduates of U.S. medical schools, drawing from national databases.[6]

The evaluation of people will not be easy; and even when an appropriate method is devised, collecting this type of data will be plagued with concerns of privacy. Is it appropriate for government or private agencies to expect people to report the details of their careers after graduating from educational training programs? Are people *willing* to report these details, and do they *want* to be tracked? Dealing with those concerns will be tricky and will require the evaluation and input of experts that can assess the ethics and confidentiality elements of the problem.

Changes in Universities and Funding Agencies

Although tracking efforts have focused primarily on the participants of training programs, successful interdisciplinary efforts might also be expected to show evidence of change at the university or institutional level. If opportunities for interdisciplinary research and training increase, particularly with adequate funding for administrative support, changes in academic institutions would be expected. Examples of such changes might be increases in the number and funding of academic research centers that are not aligned with particular departments, increases in collaborative research studies across departments, increases in faculty joint appointments, and increases in training programs that offer interdisciplinary opportunities.

Mechanisms also might be developed to assess the extent to which federal agencies and private foundations actively promote interdisciplinary research (and training). Measures could include counting the number of Request for Applications (RFAs) or ascertaining the level of funds dedicated to interdisciplinary efforts. The determination of the interdisciplinarity of an RFA would require agreed-on definitions of the term and be facilitated by a tracking label. Structural indicators of change in funding agencies might include mechanisms to broaden the scope of expertise of review panels to make interdisciplinary research more competitive within traditional competitions or new mechanisms, such as supplemental grants to support interdisciplinary efforts.

Finally, to understand fully the impact of interdisciplinary training efforts, a broader view of the research enterprise might be needed. Efforts by NSF—through its National Science Board—and AAMC have provided data on funding, student enrollment, characteristics of the science and engineering pipeline, and the size and sectors of employment. Among the data collected by the National Science Board's *Science and Engineering Indicators* (SEI) are measures of joint efforts across academe, industry, and government, including coauthorship and collaborative research initiatives.[15] Measures like these could provide a perspective on national trends following broad initiatives.

A VISION OF INTERDISCIPLINARY TRAINING

The analogy of interdisciplinary research to an orchestra was introduced in chapter 2. Training can produce the orchestra leader who understands enough about each instrument to coordinate individual musicians to create a beautiful composition. Training can also produce the versatile musician who is expert in one instrument but understands enough about his colleagues' instruments to join them in harmony. Each orchestra member can solo, but together they produce more than any one alone.

Interdisciplinary research is happening in our institutions—despite the obstacles. The question we face is how best to facilitate, direct, and evaluate its growth. The committee encourages interdisciplinary training and research, not from a philosophic belief in "interdisciplinarity," but from the fact that many scientific problems are refractory to solution by the methods of a single discipline and require a broadening and a deepening in methodology through incorporation of concepts and methods from several disciplines simultaneously. The committee specifically warns against any attempt to create an interdisciplinary "jack of all trades" who will be master of none. The aim should be the thorough mastery of one discipline, perhaps two disciplines, plus sufficient knowledge and skill of parallel disciplines to work effectively with experts in those disciplines. Basic scientists should be taught about the scope of clinical problems. Clinician-scientists should be trained in research methods. Training cannot be merely theoretical: it must be hands-on as well. Appreciating the additional power for problem solving that arises from applying concepts and methods from several disciplines is possible only through experience of experimental work that exemplifies this approach. Training is a life-long process and should not stop with establishment of a career.

Funding agencies can support this process by expanding existing mechanisms and crafting new ones. Support for interdisciplinary training often will need to be drawn from several institutes or across federal agencies, such as NIH and NSF, or between government and the private sector. The critical problems that need an interdisciplinary approach need to be identified through, for instance, workshops of experts to discuss next steps in grappling with major research problems. The breakdown of institutional barriers can be facilitated through funding initiatives that require commitment from university administrators or through improvements in peer review. Universities can also do much on their own to enhance interdisciplinary training and research. Their commitment to such programs can be demonstrated through reallocation of existing resources, encouragement of shared facilities, creation of faculty positions that span departments, revision of tenure and promotion policies, and so on.

The committee emphasizes the importance of collecting data on the outcomes of interdisciplinary programs, but recognizes the difficulties inherent in follow-up studies. The results demonstrate whether a training program in existence 10 or more years ago (and probably altered in the interim) has had the desired end result when those graduates entered a job world, one that could be very different from that in existence when the evaluation is complete.

FINDINGS AND RECOMMENDATION

Establishing an evaluation process will require a means of identifying interdisciplinary research and training programs and evaluating their success. Devising an approach to track and evaluate interdisciplinary training and research programs will be challenging and should be the subject of analysis by people with appropriate expertise. The committee recommends the following:

Recommendation 6: NIH should develop and implement mechanisms to evaluate the outcomes of interdisciplinary training and research programs.

- **Identify interdisciplinary research and training as such in all federal grants to facilitate future analyses.** The committee suggests a box on the cover sheet of grant applications indicating whether the applicant considers the work to be interdisciplinary. If so, the applicant should list on a continuation sheet the participating disciplines represented among the investigators and mentors and the interdisciplinary aspects of the research or training.
- **Establish a task force to develop a plan to track outcomes of interdisciplinary training and research programs.** Outcomes should encompass, but not be limited to, career patterns and interdisciplinary efforts of trainees (for example, research focus, findings, and publications), changes in universities (for example, in administrative structure, in interdisciplinary research, and in interdisciplinary training opportunities), and changes in funding agencies (for example, funding profiles for interdisciplinary proposals).

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APPENDIX A

Meeting and Workshop Agendas

AGENDA FOR THE FIRST MEETING

National Academy of Sciences Building

2101 Constitution Avenue, N.W.

Washington, D.C.

Thursday May 27, 1999

SPONSORS' PERSPECTIVE

10:30 a.m.	Steven Hyman *Director, NIMH*
11:30 a.m.	Norman Anderson *Director, OBSSR*
12:00 noon	**Lunch**
12:30 p.m.	Della Hann *Associate Director for Research Training, Division of Mental Disorders, Behavioral Research and AIDS, NIMH*
12:50 p.m.	Walter Goldschmidts *Associate Director for Research Training and Research Development, Division of Neuroscience and Basic Behavioral Science, NIMH*
1:05 p.m.	Enid Light *Career Development and Research Training and Fellowship Programs, Division of Services and Intervention Research, NIMH*

1:20 p.m. Alan Kraut
Executive Director, American Psychological Society
1:40 p.m. Bennett Bertenthal
Assistant Director for the Social, Behavioral, and Economic Sciences, National Science Foundation
2:00 p.m. **Discussion**
2:30 p.m. **Adjourn**

AGENDA FOR THE WORKSHOP ON OPPORTUNITIES FOR INTERDISCIPLINARY TRAINING

Foundry Building

1055 Thomas Jefferson Street, N.W.

Washington, D.C.

October 18–19, 1999

Discussants

Robert M. Carney
Professor of Medical Psychology
Washington University in St. Louis

Robert G. Frank
Dean of Health Professions
University of Florida

Philip J. Leaf
Professor of Mental Hygiene, Psychiatry and Health Policy and Management
Johns Hopkins University

Sarnoff A. Mednick
Professor of Psychology
University of Southern California

David Shapiro
Professor of Psychology
University of California at Los Angeles

Thomas P. Detre
Executive Vice President,
International and Academic Affairs
Diversified Services, Inc.
University of Pittsburgh Medical Center Health System

Monday, October 18, 1999

8:30 a.m.	**OPEN SESSION** **Introductions** Leon Eisenberg *Harvard Medical School*
8:45 a.m.	**Interdisciplinary Training to Foster Leadership in Serving Children with Neurodevelopmental Disorders and Their Families** Suzanne M. Bronheim *Georgetown University Child Development Center*
9:00 a.m.	**Multidisciplinary Training in the Health and Behavioral Sciences: Successes and Obstacles** David P. Tracer *University of Colorado*
9:15 a.m.	**Discussion**
10:00 a.m.	**The Evolution of the School of Social Ecology** Arnold Binder *University of California at Irvine*
10:15 a.m.	**NSF Science and Technology Center for Biological Timing** Gene D. Block *University of Virginia*
10:30 a.m.	**Discussion**
11:15 a.m.	**Break**
11:30 a.m.	**Interdisciplinary Challenges in Cognitive Science** Paul Smolensky *Johns Hopkins University*
11:45 a.m.	**Successes and Challenges in the Cato Research Ltd. Clinical Research Fellow Program** Allen E. Cato *Cato Research*
12:00 noon	**Discussion**

12:45 p.m.	**Lunch**
1:45 p.m.	**CLOSED SESSION** Committee only will convene to discuss the presentations
5:00 p.m.	**Adjourn**

Tuesday, October 19, 1999

8:30 a.m.	**OPEN SESSION** **Interdisciplinary Training in Pittsburgh** David J. Kupfer *University of Pittsburgh Medical Center*
8:45 a.m.	**Interdisciplinary Research Training Program in Aging** Donald D. Heistad *University of Iowa*
9:00 a.m.	**Discussion**
9:45 a.m.	**Break**
10:00 a.m.	**Linking Research and Practice Through Discussion: A Collaborative Story** Susan D. Moch *University of Wisconsin-Eau Claire*
10:15 a.m.	**Bridging the Gap Between Basic Science and Medicine: "Demystifying Medicine" for Ph.D. Students, Fellows, and Faculty** Irwin M. Arias *Tufts University*
10:30 a.m.	**Types of Faculty Development Programs** Frank T. Stritter *University of North Carolina*
10:45 a.m.	**Discussion**
11:30 a.m.	**Lunch**

12:30 p.m. **CLOSED SESSION**
Committee only will convene to discuss the presentations
3:30 p.m. **Adjourn**

AGENDA FOR THE THIRD MEETING

National Academy Building

2101 Constitution Avenue, N.W.

Washington, D.C.

November 30, 1999

3:00 p.m. **OPEN SESSION**
Interdisciplinary Training and Publication
Floyd Bloom
Scripps Research Institute and Editor of Science
4:00 p.m. **Funding Experiences with** NSF IGERT **Programs**
Wyn Jenning
National Science Foundation
5:00 p.m. **Adjourn**

APPENDIX B

Interviews and Consultations

James F. Battey, Jr.
Director
National Institute on Deafness and Other Communication Disorders
National Institutes of Health
Bethesda, MD

Marvin Cassman
Director
National Institute of General Medical Science
National Institutes of Health
Bethesda, MD

Tom Dewars
The John D. and Catherine T. MacArthur Foundation
Chicago, IL

Barbara Filner
Howard Hughes Medical Institute
Chevy Chase, MD

Gerald D. Fishbach
Director
National Institute of Neurological Disorders and Stroke
National Institutes of Health
Bethesda, MD

Maria Y. Giovanni
Fundamental Retinal Diseases
National Eye Institute
National Institutes of Health
Bethesda, MD

Murray Golstein
United Cerebral Palsy Research and Education Foundation
Washington, DC

Enoch Gordis
Director
National Institute on Alcohol Abuse and Alcoholism
National Institutes of Health
Bethesda, MD

Diane Gottheil
University of Illinois
College of Medicine
Urbana, IL

Patricia A. Grady
Director
National Institute of Nursing Research
National Institutes of Health
Bethesda, MD

Bettie Graham
Genome Project
National Institutes of Health
Bethesda, MD

Della Hann
Division of Mental Disorders, Behavioral Research, and AIDS
National Institute of Mental Health
Bethesda, MD

Sherrie Lynn Hans
The Pew Charitable Trusts
Philadelphia, PA

Maryanna Henkart
National Science Foundation
Division of Molecular and Cellular Biosciences
Arlington, VA

Richard J. Hodes
Director
National Institute on Aging
National Institutes of Health
Bethesda, MD

Steven Hyman
Director
National Institute of Mental Health
National Institutes of Health
Bethesda, MD

Wyn Jennings
National Science Foundation
Integrative Graduate Education and Research Training and Graduate Research Training Programs
Arlington, VA

Henry Katchaturian
National Institute of Mental Health
National Institutes of Health
Bethesda, MD

Peter Kaufmann
National Heart, Lung, and Blood Institute
National Institutes of Health
Bethesda, MD

Mark Konishi
California Institute of Technology
Pasadena, CA

Carl Kupfer
Director
National Eye Institute
National Institutes of Health
Bethesda, MD

Gerald Lauback
Pfizer Inc.
New York, NY]

Alan I. Leshner
Director
National Institute on Drug Abuse
National Institutes of Health
Bethesda, MD

Dorothy Margolskee
Merck Pharmaceutical Co
Rahway, NJ

Louise Marshall
Brain Research Institute
Los Angeles, CA

Bruce McEwen
Rockefeller University
New York, NY

Guy McKhann
Johns Hopkins University School of Medicine
Zanvyl Krieger Mind/Brain Institute
Baltimore, MD

Stewart Mennin
University of New Mexico
Albuquerque, NM

Glen Morgan
National Cancer Institute
Rockville, MD

David Pendleburry
Institute for Scientific Information
Philadelphia, PA

Robert Rose
The John D. and Catherine T. MacArthur Foundation
Chicago, IL

Ruth Runeborg
The John D. and Catherine T. MacArthur Foundation
Chicago, IL

Joan Schwartz
Office of the Director
National Institutes of Health
Bethesda, MD

Jennifer Sutton
Office of Scientific and Engineering Personnel
National Academies
Washington, DC

Jaylan Turkan
National Institute on Drug Abuse
Rockville, MD

Harold E. Varmus
Director until January 2000
Office of the Director
National Institutes of Health
Bethesda, MD

Jeanne M. Wehner
University of Colorado
Boulder, CO

Terrie Wetle
National Institute on Aging
Bethesda, MD

Marion Wienrich
Boehringer Ingelheim Gmbh
Germany

APPENDIX C

Reviewed Training Programs

Academic-Drug Industry Fellowships
Cato Research, Ltd.
Durham, NC

Academic Leadership Career Award
University of Chicago
Chicago

Advanced Training in Nursing
Outcomes Research
University of Pennsylvania

Advancing Care in Serious Illness
University of Pennsylvania

Atlanta University Center NIMH-COR Honors Program
Morehouse College

Basic Processes and Variation in Cognition
Carnegie-Mellon University

Biobehavioral Nursing Research Training Program
University of Washington

Biobehavioral Research Training Program
Stanford University

Biological Research in Schizophrenia
McLean Hospital
Belmont, MA

Biology of Aging and Age-Related Diseases
University of Wisconsin

CAMP IDEAR—Developing Research Teams to Help Urban Elders
Northeastern University

Candidate Genes with Trimeric Repeats in Neuropsychiatry
Johns Hopkins University
Baltimore, MD

Career Development Program for Building Interdisciplinary Research Careers in Women's Health
The Office of Research on Women's Health
Bethesda, MD

Center for Behavioral Neuroscience
Emory University and other universities and colleges in the
Atlanta, GA area

Center for Drug and Alcohol Programs
Medical University of South Carolina, Institute of Psychiatry and Charleston Alcohol Research Center

Center for Mental Health Services Research
University of Pittsburgh
Pittsburgh, PA

Children's Mental Health Services Research Training
Vanderbilt University
Nashville, TN

Clinical Research Training in Psychiatry
University of Pittsburgh
Pittsburgh, PA

Compilation of Sponsored Research of the Faculty in the Harvard Department of Psychiatry Harvard Medical School
Belmont, MA

Computation and Neural System Program
California Institute of Technology

Consortium on Diversity, Family Process and Child/Adolescent Mental Health
The Pennsylvania State University and 11 other institutions
University Park, PA

COR Honors High School Research Education
Wayne State University
Detroit, MI

CORE—Cognitive/Functional Assessment and Ergonomics
University of Iowa
Iowa City, IA

Cortical Circuitry and Cognition in Schizophrenia
University of Pittsburgh
Pittsburgh, PA

Cortical Mechanisms in Schizophrenia
Yale University
New Haven, CT

Department of Molecular Biotechnology, Graduate Education
University of Washington School of Medicine
Seattle, WA

Doctor of Philosophy Program in Clinical Science
University of Colorado Health Sciences Center
Denver, CO

Doctoral and Post-Doctoral Training in Behavioral and Psychiatric Genetics
Virginia Commonwealth University School of Medicine; Virginia Institute for Psychiatric and Behavioral Genetics
Richmond

Environmental Sciences, Policy and Engineering Program
University of Southern California
Los Angeles, CA

Faculty Development Programs
University of North Carolina
Chapel Hill, NC

Genetic Studies of Psychiatric Disorders
Yale University
New Haven, CT

Georgetown University Child Development Center
Georgetown University
Washington, DC

Geriatric Leadership Academic Award
University of Maryland
Baltimore, MD

Gerontological Nursing Interventions Research Center
University of Iowa
Iowa City, IA

Graduate Program, Department of Behavioral Neuroscience
Oregon Health Sciences University
Portland, OR

Graduate Program in Molecular Biotechnology
University of Washington
Seattle, WA

Graduate Program in Neuroscience
University of Rochester School of Medicine and Dentistry
Rochester, NY

Interdisciplinary Doctoral Degree Program in Health and Behavioral Sciences
University of Colorado
Denver, CO

Interdisciplinary PhD Program in Cognitive Science
University of California, San Diego
La Jolla, CA

Interdisciplinary Research Development Perinatal Health
University of Minnesota Twin Cities
Minneapolis, MN

Interdisciplinary Research Training Program in Aging
University of Iowa
Iowa City, IA

Interdisciplinary Science Program
Trinity College
Hartford, CT

Interdisciplinary Training at the
Western Psychiatric Institute and Clinic

University of Pittsburgh Medical Center
Pittsburgh, PA

Interdisciplinary Training in Gerontology
Pennsylvania State University
University Park, PA

Interdisciplinary Training in Psychiatry and Neuroscience
Johns Hopkins University
Baltimore, MD

Interdisciplinary Training in the Neurobiology of Motor Control
University of Arizona, Barrow Neurological Institute, and Arizona State University
Tucson, AZ

Interdisciplinary Workshop-Population/Health
Rand Corporation
Santa Monica, CA

Limbic Monoamines, Behavior, and Psychopathology
University of California, San Diego
San Diego, CA

Linking Research and Practice Through Collaborative Discussion Groups
University of Wisconsin
Eau Claire, WI

Mental Health and Adjustment in the Early Life Course
University of Minnesota Twin Cities
Minneapolis, MN

MHCRC—Neuroscience of Mental and Behavioral Disorders
University of North Carolina
Chapel Hill, NC

Midcareer Award in Patient Oriented Research on Aging
Yale University
New Haven, CT

Mnemonic Functions of the Basal Ganglia
University of California, Los Angeles
Los Angeles, CA

Molecular Approaches to Mental Illness
University of California, San Francisco
San Francisco, CA

Molecular Elements, Neurocircuits, and Mental Illness
University of Michigan, Ann Arbor
Ann Arbor, MI

Multi-Site Training Program for Basic Sleep Research
University of California, Los Angeles
Los Angeles, CA

Multidisciplinary Training Program in Aging Research
Boston University
Boston, MA

National Institute on Drug Abuse (NIDA) Pre-Doctoral and Post-Doctoral Interdisciplinary Training Program
The University of Michigan Substance Abuse Research Center
Ann Arbor, MI

Neural Circuitry of Prefrontal Cortex
University of Pittsburgh
Pittsburgh, PA

Neurobehavior, Neuroendocrinology, and Genetics of Alzheimer's Disease
University of Washington
Seattle, WA

Neurobiological Brain Abnormalities in Schizophrenia
University of California, Davis
Davis, CA

Neurobiology of Disease Program
Baylor College of Medicine
Houston, TX

Neuroscience Program
University of South Florida
Tampa, FL

Neuroscience Training Grant
University of Miami
Miami, FL

Neuroscience Training Program
University of Colorado Health Sciences Center
Denver, CO

NIMH COR Honors Minority High Program at GSU
Grambling State University
Grambling, LA

NIMH Honors Minority Program at GSU
Grambling State University
Grambling, LA

NSF A New Era in Electronics Education
University of Arkansas
Fayetteville, AR

NSF Biogeochemical Research Initiative for Education
Pennsylvania State University
University Park, PA

NSF Biospheric-Atmospheric Research Training
University of Michigan
Ann Arbor, MI

NSF Center for Biological Timing
University of Virginia
Charlottesville, VA

NSF Computational Molecular Biology Training Group
Iowa State University
Ames, IA

NSF Education and Research Training in Structure and Function of Complex Biological Systems
Montana State University-Bozeman
Bozeman, MT

NSF Evolution of Development and Genomics
University of Oregon
Eugene, OR

NSF Freshwater Graduate Studies Integrating Ecology, Hydrology, and Geochemistry in Regions with Contrasting Climates
University of Alabama at Tuscaloosa
Tuscaloosa, AL

NSF Graduate Training Program at the Interface of the Biological, Mathematical and Physical Sciences
University of Arizona
Tucson, AZ

NSF Graduate Training Program in Computational Science and Bioinformatics
Wayne State University
Detroit, MI

NSF Graduate Training Program in Environmental Manufacturing Management
Clarkson University
Potsdam, NY

NSF Graduate Training Program in Environmental Problems Presented by Freshwater Ecosystems
University of Wisconsin, Madison
Madison, WI

NSF Graduate Training Program in Geographic Information Science
SUNY, Buffalo
Buffalo, NY

NSF Graduate Training Program in Integrated Chemical Sensor Design
Wayne State University
Detroit, MI

NSF Graduate Training Program in Mathematical, Cognitive and Computational Approaches to Understanding Diverse Cognitive Processes
Brown University
Providence, RI

NSF Graduate Training Program in Nonlinear Systems
Cornell University
Ithaca, NY

NSF Graduate Training Program in Optical Bio-Molecular Engineering
University of Texas
Austin, TX

NSF Graduate Training Program in Optical Sciences and Engineering
University of Colorado, National Institute for Standards and Technology, and Joint Institute for Laboratory Astrophysics
Boulder, CO

NSF Graduate Training Program in Photonics
Oklahoma State University, two government laboratories and six industrial laboratories
Stillwater, OK

NSF Graduate Training Program in Research and Development of Specialized Sensors and Integrated Devices
Wayne State University
Detroit, MI

NSF Graduate Training Program in Study of Life in Extreme Environments
University of Washington
Seattle, WA

NSF Graduate Training Program in Transportation Technology and Policy
University of California, Davis
Davis, CA

NSF Graduate Training Program in Urban Environmental Sustainability
University of Southern California
Los Angeles, CA

NSF Integrative Education of the Next Generation of Environmental Scientists and Engineers
Washington State University
Pullman, WA

NSF Integrative Graduate Training of Neuroscientists and Computational/Physical Scientists
University of Minnesota-Twin Cities
Minneapolis, MN

NSF Molecularly Designed Electronic, Photonic, and Nanostructured Materials
University of Michigan
Ann Arbor, MI

NSF Multi-Disciplinary Program on Inequality and Social Policy
Harvard University
Cambridge, MA

NSF Multidisciplinary Training Program in Computational Analysis of Social and Organizational Systems
Carnegie Mellon University
Pittsburgh, PA

NSF Nanophases in the Environment, Agriculture, and Technology
University of California, Davis
Davis, CA

NSF Nanostructural Materials and Devices
CUNY City College
New York, NY

NSF Neuroengineering Training Program
University of California, Los Angeles
Los Angeles, CA

NSF Program in Integrated Computer and Application Sciences
Princeton University
Princeton, NJ

NSF Quantitative Approaches to Neuroscience: From Molecules to Behavior
Brandeis University
Waltham, MA

NSF Science and Engineering of Laser Interactions with Matter
University of Virginia
Charlottesville, VA

NSF Training Program in Manufacturing Logistics
Lehigh University; Wharton School of the University of Pennsylvania
Bethlehem, PA

NSF Training Program in Neuro-Mechanical Systems
Case Western Reserve University
Cleveland, OH

NSF Training Program in the Cognitive Science of Language
Johns Hopkins University
Baltimore, MD

NSF Training Program on Therapeutic and Diagnostic Devices
Purdue University
West Lafayette, IN

NSF Variable Speed Electromechanical Drive Systems
University of Missouri and Purdue University
Rolla, MO

Ontogeny of Trace Conditioning in Animals and Humans
National Health and Environmental Effects Research Lab
Research Triangle Park, NC

Outcomes of a Nurse-Managed Geriatric Day Hospital
University of Pennsylvania
Philadelphia, PA

Pathobiology Course
Tufts University
Boston, MA

Pharmacological Studies of Narcolepsy
Stanford University
Stanford, CA

Pharmacology of Drug Abuse Training Program
University of Rochester School of Medicine and Dentistry
Rochester, NY

PhD Program in Behavioral Neurosciences
Boston University School of Medicine
Boston, MA

Postgraduate Training Program in Psychoneuroimmunology
University of California, Los Angeles
Los Angeles, CA

Postmortem Neurochemical Studies in Suicide
New York State Psychiatric Institute
New York, NY

Predicting Patient Quality of Life Throughout Dementia
Indiana University-Purdue University at Indianapolis
Indianapolis, IN

Predoctoral Training Consortium in Affective Science
University of California, Berkeley
Berkeley, CA

Program in Neuroscience
Harvard Medical School
Boston, MA

Psychobiology of Anxiety Disorders
Columbia University Health Sciences
New York, NY

Psychobiology/Genetics/Treatment of Anxiety Disorders
Columbia University in the City of New York
New York, NY

Quality of Views from Multiple Disciplines
University of Pittsburgh
Pittsburgh, PA

Research Center for Symptom Management
University of California San Francisco
San Francisco, CA

Schizophrenia: A Neuropsychiatric Perspective
University of Pennsylvania
Philadelphia, PA

School of Social Ecology
University of California, Irvine
Irvine, CA

Study of Depression
Duke University
Durham, NC

Study of Schizophrenia
Long Island Jewish Medical Center
New Hyde Park, NY

The Center for the Neural Basis of Cognition Graduate Program
Carnegie Mellon University and the University of Pittsburgh
Pittsburgh, PA

The Consolidated Department of Psychiatry and Eight Other Teaching Institutions in the Greater Boston Area
Harvard Medical School
Belmont, MA

The Drug Abuse Research Training Program
University of California, Los Angeles
Los Angeles, CA

The Emory Research Infrastructure Support Program
Emory University
Atlanta, GA

The Zanvyl Krieger Mind/Brain Institute
Johns Hopkins University
Baltimore, MD

Training in Biologically-Based Nursing Research
University of Illinois at Chicago
Chicago, IL

Training in the Neurobiology of Aging
University of Florida
Gainesville, FL

Training Program in Emotion Research
University of Wisconsin, Madison
Madison WI

University of North Dakota School of Medicine and Health Sciences
University of North Dakota
Fargo, ND

University of Pennsylvania Long Term Care Network
University of Pennsylvania
Philadelphia, PA

Vanderbilt University's Center for Molecular Neuroscience
Vanderbilt University
Nashville, TN

Wayne State University NIMH COR/MHSSEP Training Program
Wayne State University
Detroit, MI

Yale Neuroscience Research Training Program: Drug Abuse/Mental Health
Yale University
New Haven, CT

APPENDIX D

Select National Institutes of Health Mechanisms for Training and Research Support

Select National Institutes of Health Mechanisms for Training and Research Support

Grant	Title	Description
Fellowships		
F30	Individual Predoctoral National Research Service Award for MD/PhD Fellowship	Fellowship award that provides combined medical school and predoctoral PhD support for a maximum of 6 years
F31	Predoctoral Individual National Research Service Award	Fellowship award that provides up to 5 years of support for research training leading to the PhD or equivalent research
F32	Postdoctoral Individual National Research Service Award	Fellowship award that provides postdoctoral research training to broaden scientific background
F33	National Research Service Award for Senior Fellow	Fellowship award that provides opportunities for experienced scientists to broaden scientific background
Career Awards		
K01	Mentored Research Scientist Development Award	Provides salary and fringe benefits for awardees for career development experience
K02	Independent Scientist Award	Provides up to 5 years of salary and fringe benefit support for newly independent scientists
K05	Senior Scientist Award	Provides salary and fringe benefit support for outstanding scientists to enhance skills in their research field
K08	Mentored Clinical Scientist Development Award	Provides salary and fringe benefit support for the development of clinician research scientists
K12	Mentored Clinical Scientist Development Program Award	Provides support to an educational institution for career development experiences for clinicians leading to research independence
K23	Mentored Patient-Oriented Research Career Development Award	Provides salary and fringe benefit support for the development of patient-oriented research scientists

K24	Midcareer Investigator Award in Patient-Oriented Research	Provides salary and fringe benefit support to allow protected time for patient-oriented research and time to act as mentors for beginning clinical investigators
K25	Mentored Quantitative Research Career Development Award	Provides salary and fringe benefit support for career development for scientists with quantitative and engineering backgrounds to foster interdisciplinary collaboration in biomedical research
Program Grants		
P01	Research Program Project	Provides support for an integrated, multiproject research program involving a number of independent investigators who share knowledge and common resources
P20	Exploratory Grant	Provides support for the development of new or interdisciplinary programs or the expansion of existing resources
P30	Center Core Grant	Provides support for shared resources and facilities to a program providing a multidisciplinary approach with existing research funds
P50	Specialized Center Grant	Provides support to assemble “critical masses” of basic and clinical scientists to work together collaboratively
Research Awards		
R01	Research Project Grant	Provides support for a discrete, specified, and circumscribed project that ranges in initial length from 2 to 5 years
R13	Conference Grant	Provides support for a symposium, seminar, workshop, or other formal conference assembled to exchange and disseminate information or to explore a subject, problem, or field of knowledge
R25	Education Project Grant	Provides support to develop a program in education, information, training, technical assistance, or evaluation

Training Grants		
T32	National Research Service Award Institutional Research Training	Provides support to institutions to develop or enhance research training opportunities for predoctoral and postdoctoral students
T34	National Research Service Award-Institutional Undergraduate Research Training	Provides support to institutions to promote undergraduate research training to underrepresented groups in the biomedical and behavioral sciences
T35	Short-Term Institutional Research Training	Provides support to institutions for predoctoral and postdoctoral training focused on biomedical and behavioral research
Cooperative Agreements		
U13	Conference Award	Like R13, provides assistance for symposia, seminars, workshops, and so on, but with substantial programmatic involvement by NIH staff after award
U19	Research Project	Like P01, provides assistance for broadly based multidisciplinary research programs, but with substantial NIH scientific and/or programmatic involvement during performance of research
U54	Specialized Center	Provides assistance for multidisciplinary approaches to a specific disease or biomedical problem with programmatic involvement by NIH staff after award

SOURCES:

- silk.nih.gov/silk/brownbooks/actcod
- grants.nih.gov/training/nrsa.htm
- grants.nih.gov/grants/guide/index.html
- www.nih.gov/training/careerdevelopmentawards.htm
- www.ahcpr.gov/fund/guiderpg.htm