Appendixes

A

Biographical Information on Members and Staff of Committee on Facilitating Interdisciplinary Research

NANCY C. ANDREASEN (Co-chair) is the Director of The MIND Institute in Albuquerque, N.M.; Adjunct Professor of Psychiatry, Neuroscience, and Neurology at the University of New Mexico; and Andrew H Woods Chair of Psychiatry at the University of Iowa in Iowa City. After obtaining a Ph.D. in English literature, Dr. Andreasen became an Assistant Professor of English before turning to medicine. She obtained her MD in 1970 from the University of Iowa and completed her residency training there. Her research interests include multiple aspects of neuroscience and psychiatry. She has conducted studies of creativity, mood disorders, and schizophrenia. She currently applies multimodality neuroimaging tools, including structural Magnetic Resonance (sMR), functional Magnetic Resonance (fMR), and positron emission tomography (PET) to the study of normal brain development and degeneration and to illnesses such as schizophrenia. She leads an interdisciplinary team that includes cognitive neuroscientists, computer scientists, electrical and biomedical engineers, physicists, and physicians. Dr. Andreasen has won numerous honors and awards, the highest of which is the President's National Medal of Science, presented to her in 2000 for her work in biological sciences. She received the Interbrew-Baillet Latour Heath Prize from the Belgian National Foundation for Scientific Research in 2003 for her work in neuroimaging and schizophrenia. She has received the Rhoda and Bernard Sarnat Award from the Institute of Medi-

cine. She also won the Lieber prize for her research in schizophrenia. Other prizes and awards include Woodrow Wilson and Fulbright Fellowships; Honorary Fellow of the RCSP (Canada); Member of the Institute of Medicine; Research Scientist Award from NIMH; Menninger Award for Psychiatric Research; American Psychiatric Association Prize for Research; the Adolph Meyer Award; the Sigmund Freud Award, and the Distinguished Service and Stanley Dean Awards from the American College of Psychiatrists. She is the author of numerous scientific and scholarly articles and fourteen books, ranging from *John Donne: Conservative Revolutionary* (Princeton, 1976) to *Brave New Brain: Conquering Mental Illness in the Era of the Genome* (Oxford, 2001). She has also authored two widely used textbooks on psychiatry and is Editor in Chief of the *American Journal of Psychiatry*.

THEODORE L. BROWN (Co-chair) is founding director emeritus and professor emeritus of chemistry at the University of Illinois—Urbana Champaign (UIUC). Dr. Brown received his Ph.D. from Michigan State University in 1956. He has been a faculty member in the UIUC Department of Chemistry since 1956 (he assumed emeritus status in January 1994). During 1980-1986, he served as vice chancellor for research and dean of the Graduate College. He was the first director of the Beckman Institute in 1987-1993. He served as interim vice-chancellor for academic affairs during 1993. He is an emeritus member of the Beckman Institute Advanced Chemical Systems Group. He participated in the National Academies Government-University-Industry Research Roundtable from 1989 to1994. Dr. Brown's fields of research interests were inorganic chemistry and organometallic chemistry, with an emphasis on the kinetics and mechanisms of reactions. His current interests are in the cognitive, philosophic, and social aspects of the scientific enterprise. His recent book *Making Truth: Metaphor in Science* (*http://www.press.uillinois.edu/s03/brown.html*) explores the metaphoric foundations of science. He is a fellow of AAAS (1987) and of the American Academy of Arts and Sciences (1994), received the American Chemical Society Award for Distinguished Service in the Advancement of Inorganic Chemistry (1993), and was a Guggenheim fellow (1979-1980).

JENNIFER CHAYES is an expert in the emerging field at the interface of mathematics, physics, and theoretical computer science. She is cofounder and comanager of the Theory Group at Microsoft Research. Dr. Chayes is also an affiliate professor of mathematics and physics at the University of Washington and was for many years a professor of mathematics at the University of California, Los Angeles (UCLA). She is the recipient of a National Science Foundation postdoctoral fellowship, a Sloan fellowship, and the UCLA Distinguished Teaching Award. Dr. Chayes serves on nu-

merous boards, advisory committees, and editorial boards, including the scientific boards of Banff International Research Station and the Fields Institute, the Advisory Boards of the Center for Discrete Mathematics and Computer Science, and the National Academy of Sciences Office for the Public Understanding of Science. She is the chair of the mathematics section of the American Association for the Advancement of Science and is a past vice-president of the American Mathematical Society. Dr. Chayes did her doctoral work in mathematical physics at Princeton and held postdoctoral positions in mathematics and physics at Harvard and Cornell. She has twice been a member of the Institute for Advanced Study in Princeton.

STANLEY COHEN is professor and former chair of genetics and professor of medicine at Stanford University. In 1973, he and Herbert Boyer, of the University of California, San Francisco, invented the technique of DNA cloning, which allowed genes to be transplanted between different species. Their discovery signaled the birth of genetic engineering. He received his B.A. magna cum laude in biological sciences from Rutgers University and his M.D. from the University of Pennsylvania. Dr. Cohen's numerous honors and awards include the National Medal of Science, the National Medal of Technology, and the Albert Lasker Basic Medical Research Award.

JONATHAN R. COLE, John Mitchell Mason Professor of the University and Provost and Dean of Faculties, Emeritus, received a B.A. in American history from Columbia in 1964 and a Ph.D. with honors in sociology from Columbia in 1969. He has been teaching at Columbia since 1966. He served as director of the Center for the Social Sciences from 1979 to 1987, when he became vice president for arts and sciences, a post he held until July 1989, when he became provost. Among his many awards and honors, he has received a John Simon Guggenheim Fellowship, has been a fellow at the Center for Advanced Study of the Behavioral Sciences, and is a member of the American Academy of Arts and Sciences. Dr. Cole has published extensively on historical and social aspects of science; has been a leading international contributor to the understanding of the opportunities, challenges, and obstacles facing women in the scientific community; has led a National Academy of Sciences evaluation of the peer-review system in science; and has published works recently on health risks and on dilemmas facing American research universities.

ROBERT CONN is managing director of Enterprise Partners Venture Capital. He is helping to lead the $350 million Enterprise Partners VI fund, which is targeted to provide early-stage investments in semiconductors, computing, networking, technology-based life-sciences and drug discovery, and enterprise software. He was previously the dean of the University of

California, San Diego (UCSD) Jacobs School of Engineering from 1993 to 2002, and before that served as a professor of engineering and applied science at the University of California, Los Angeles and the University of Wisconsin-Madison. During his tenure as dean, the Jacobs School rose to become ranked among the top 10 public engineering schools in the country. Dr. Conn led efforts to establish major enterprises in key technical areas including the Center for Wireless Communications in 1995 and the California Institute for Telecommunications and Information Technology in 2000. The latter involved a significant partnership between the state of California, the University of California, and industry, with the state contributing $100 million and industry $140 million. He also helped UCSD to win the highly competitive National Partnership for Advanced Computational Infrastructure and the Distributed Terascale Facility at the San Diego Supercomputer Center. Most recently, he established the Jacobs School's William J. von Liebig Center for Entrepreneurism and Technology Advancement, enabled by a $10 million gift from the William J. von Liebig Foundation. Dr. Conn has been a leader in plasma physics, materials research, and fusion-energy development. He has served on many National Academy of Engineering and Department of Energy (DOE) committees and was chair of DOE's primary fusion-energy advisory committee from 1992 through 1996. In the late 1980s, Dr. Conn cofounded a startup company, Plasma and Materials Technologies (PMT), to develop and market semiconductor etching and deposition equipment. Dr. Conn served as chairman of the Board and senior technologist in 1986-1994 and stepped down from affiliation with the company after joining UCSD as dean of engineering. PMT merged in 1997 into what is now Trikon Technologies, headquartered in the UK.

MILDRED DRESSELHAUS is Institute Professor of Electrical Engineering and Physics at the Massachusetts Institute of Technology. She has been active in the study of a wide array of problems in the physics of solids. Her recent interests have been nanoscience, carbon nanotubes, nanowires, and low-dimensional thermoelectricity. Dr. Dresselhaus is a member of the American Philosophical Society (APS) and a fellow of the American Academy of Arts and Sciences, the American Physical Society (APS), the The Institute of Electrical and Electronics Engineers (IEEE), the Materials Research Society, the Society of Women Engineers, and the American Association for the Advancement of Science (AAAS). She has served as president of APS, treasurer of the National Academy of Sciences, president of the AAAS, and as a member of numerous advisory committees and councils. She is now chair of the Board of the American Institute of Physics. Dr. Dresselhaus has received numerous awards, including the National Medal of Science and 18 honorary doctorates. She is the coauthor of four books on carbon science.

GERALD HOLTON is Mallinckrodt Research Professor of Physics and Research Professor of History of Science at Harvard University. He received his Ph.D. from Harvard in 1948, and his chief interests are the history and philosophy of science, the physics of matter at high pressure, and the study of career paths of young scientists. His books include *Thematic Origins of Scientific Thought* (1973; rev. ed., 1988); *Science and Anti-Science* (1993); *The Advancement of Science, and its Burdens* (1998); *Scientific Imagination* (1998); and *Einstein, History, and Other Passions* (2000). In addition to teaching at Harvard University since 1947, Dr. Holton was a visiting professor at MIT from 1976 to 1994 as a founding faculty member of the Program on Science, Technology and Society. He has been a visiting professor at Leningrad University, the University of Rome, the Centre National de la Recherché Scientifique (Paris), and Imperial College (London) and a lecturer in China for the Chinese Academy of Social Science. He has been an officer of numerous professional organizations, including president of the History of Science Society (1983-1984), vice president of the Académie Internationale d'Histoire des Sciences (1981-1988), and founding chairman of the American Institute of Physics Committee for the Center for History of Physics. Dr. Holton is a fellow of the American Physical Society, the American Philosophical Society, the American Academy of Arts and Sciences, and the American Association for the Advancement of Science. His awards include the Sarton Medal (1989) and the Joseph H. Hazen Prize (1998) of the History of Science Society, the J.D. Bernal Prize of the Society for Social Studies of Science (1989), the Andrew Gemant Award of the American Institute of Physics (1989), the Joseph Priestley Award of Dickinson College (1994), the Oersted Medal of the American Association of Physics Teachers (1980), and selection as a Jefferson Lecturer by the National Endowment for the Humanities (1981).

THOMAS KALIL is the special assistant to the chancellor for science and technology at the University of California, Berkeley and an adjunct fellow at the New America Foundation. At Berkeley, he is helping faculty members to develop research and education initiatives that respond to national priorities and that build strong partnerships with government agencies, the private sector, and community-based organizations. He previously coordinated technology policy for the National Economic Council during the Clinton administration and has served as a consultant to the Digital Promise project. He was a trade specialist at the Washington offices of Dewey Ballantine, where he represented the Semiconductor Industry Association on U.S.-Japan trade issues and technology policy. He received a B.A. in political science and international economics from the University of Wisconsin-Madison and completed graduate work at the Fletcher School of Law and Diplomacy. He is the author of articles on nuclear strategy, U.S.-

Japan trade negotiations, U.S.-Japan cooperation in science and technology, the National Information Infrastructure, distributed learning, and electronic commerce. He is a member of the Council on Foreign Relations, the Association for Computing Machinery, the Internet Society, and the Institute for Electrical and Electronics Engineers.

ROBERT W. KATES is a geographer and independent scholar in Trenton, Maine, and university professor (emeritus) at Brown University. His current research focuses on long-term trends in environment, development, and population. He is co-convenor of the international Initiative for Science and Technology for Sustainability, an executive editor of *Environment* magazine, and visiting scholar at the Belfer Center for Science and International Affairs, Kennedy School of Government, Harvard University. Dr. Kates developed and directed three academic interdisciplinary centers: in resource assessment at the University of Dar Es Salaam; on technology, environment, and development at Clark University; and on World Hunger at Brown University. He is a recipient of the 1991 National Medal of Science and the MacArthur Prize Fellowship (1981–85) and is a member of the American Academy of Arts and Sciences and of the Academia Europaea. Dr. Kates received an M.A. and a Ph.D. in geography from the University of Chicago and an honorary D.Sc. from Clark University.

TIMOTHY L. KILLEEN was born in Cardiff, Wales. He received a B.Sc. in physics and a Ph.D. in atomic and molecular physics from University College, London. He is director of the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, and a senior scientist at the NCAR High Altitude Observatory, where he leads an experimental and theoretical program in upper atmospheric research. Before joining NCAR, Dr. Killeen was professor of atmospheric and space sciences at the University of Michigan. During his tenure at Michigan, he was also director of the Space Physics Research Laboratory and associate vice president for research. He has taught many undergraduate and graduate courses, including an innovative introductory course sequence for nonscience majors dealing with the physical and human impacts of global change. He has been honored with the Excellence in Teaching and Excellence in Research awards from the College of Engineering at the University of Michigan and with two National Aeronautics and Space Administration (NASA) achievement awards. His research interests include the experimental and theoretical study of the earth's upper atmosphere. He is a principal investigator and instrument developer for a spaceborne Doppler interferometer on the NASA TIMED spacecraft. He is co-principal investigator for a new National Science Foundation (NSF) science and technology center devoted to numerical modeling of space weather. Dr. Killeen has served as president of the Space Physics

Section of the American Geophysical Union and on various NASA and NSF committees. He is editor-in-chief of the *Journal of Atmospheric and Solar-Terrestrial Physics*.

MARIO MOLINA has been involved in developing our understanding of the chemistry of the stratospheric ozone layer and its susceptibility to human-made perturbations. In 1974, Dr. Molina and F. S. Rowland reported in *Nature* on their research on the threat to the ozone layer from chlorofluorocarbon gases that were being used as propellants in spray cans, as refrigerants, as solvents, and so on. More recently, he has been involved with the chemistry of air pollution of the lower atmosphere. He is also pursuing interdisciplinary work on tropospheric pollution, working with colleagues in many other disciplines on the problem of rapidly growing cities with severe air pollution. Dr. Molina was born in Mexico City, Mexico. He holds a degree in chemical engineering (1965) from the Universidad Nacional Autonoma de Mexico; a postgraduate degree (1967) from the University of Freiburg, Germany, and a Ph.D. in physical chemistry (1972) from the University of California, Berkeley. He went to the Massachusetts Institute of Technology (MIT) in 1989 with a joint appointment in the Department of Earth, Atmospheric and Planetary Sciences and the Department of Chemistry and was named MIT institute professor in 1997. Before joining MIT, he held teaching and research positions at the Universidad Nacional Autonoma de Mexico; the University of California, Irvine; and the Jet Propulsion Laboratory at the California Institute of Technology. Dr. Molina is a member of the United States National Academy of Sciences and the Institute of Medicine, and the Pontifical Academy of Sciences. He has served on the U.S. president's Committee of Advisers in Science and Technology, the secretary of energy advisory board, the National Research Council Board on Environmental Studies and Toxicology, and the boards of the U.S.-Mexico Foundation of Science and other nonprofit environmental organizations. He has received several awards for his scientific work, including the 1995 Nobel Prize in chemistry, which he shared with F. S. Rowland and P. Crutzen for their work in atmospheric chemistry.

PATRICK SUPPES is the Lucie Stern Professor of Philosophy Emeritus at Stanford University and since 1992 has been the director and faculty adviser of Stanford's Education Program for Gifted Youth. He was director of Stanford's Institute for Mathematical Studies in the Social Sciences (1959-1992). He is also professor emeritus by courtesy in Stanford's Department of Statistics, Department of Psychology, and School of Education. Dr. Suppes is a fellow of the American Association for the Advancement of Science (1962), the American Psychological Association (APA) (1964), and

the American Academy of Arts and Sciences (1968) and is a member of the National Academy of Education (NAE) (1965), and a member of the American Philosophical Society (1991). Among his awards are the APA Distinguished Scientific Contribution Award, the Columbia University Teachers College Medal for Distinguished Service (1978) and the National Medal of Science (1990). He is a past president of the Pacific Division of American Philosophical Association (1972-1973), the American Educational Research Association (1973-1974), NAE (1973-1977), and the International Union of History and Philosophy of Science (1976, 1978). Dr. Suppes received his bachelor's degree from the University of Chicago and his doctorate from Columbia University. He has published widely in philosophy, the social sciences, and education.

JAN H. VAN BEMMEL is professor of medical informatics, first at Free University Amsterdam, 1973-1987, thereafter at Erasmus University Rotterdam, the Netherlands, 1987. He was rector magnificus (vice chancellor) of Erasmus University, Rotterdam, 2000-2003. He received his M.Sc. in physics and mathematics from Technical University Delft in 1963, and his Ph.D. in physics and mathematics from Nijmegen University in 1969. He has been editor-in-chief of *Methods of Information in Medicine*, 1986-2001, of the *IMIA Yearbooks of Medical Informatics*, 1992-2001, and of the *Handbook of Medical Informatics*, 1995-97. He was President of the International Medical Informatics Association, 1998-2001. He became a member of Royal Netherlands Academy of Arts and Sciences (KNAW), 1987, member of Dutch Health Council, 1987, and foreign associate member of Institute of Medicine of National Academy of Sciences, 1991. He was chairman of the International Committee of KNAW for the assessment of all biomedical and health sciences research in the Netherlands, 1993-1998, and chairman of the KNAW Committee for the future assessment of all university research in the Netherlands, 1999-2001.

TANDY WARNOW is Professor of Computer Sciences at the University of Texas at Austin, where she is a member of five graduate groups (Computer Sciences, Mathematics, Computational and Applied Mathematics, Molecular Biology, and Ecology, Evolution, and Behavior). Her research combines mathematics, computer science, and statistics to develop improved models and algorithms for reconstructing complex and large-scale evolutionary histories in both biology and historical linguistics. She is on the board of directors of the International Society for Computational Biology and previously was the Co-Director of the Center for Computational Biology and Bioinformatics at the University of Texas at Austin. She received the National Science Foundation Young Investigator Award in 1994, and the David and Lucile Packard Foundation Award in Science and Engineering in 1996.

ROBERT M. WHITE is university professor of electrical and computer engineering and director of the Data Storage Systems Center at Carnegie Mellon University (CMU). He received a B.S. in 1960 from the Massachusetts Institute of Technology and a Ph.D. in 1964 from Stanford University. In addition to an active program of research in data-storage systems, Dr. White has longstanding interests in technology policy. His policy interests are focused on federal science and technology policy. He is exploring the effects of various government policies on technology innovation, whereby new technology appears in a competitive product or process. Examples of issues include the effects of federal funding and the management of intellectual property. Before joining CMU, he served during the first Bush administration as the first undersecretary of commerce for technology. Earlier, he was vice president of Microelectronics and Computer Technology Corporation (MCC). He was a manager and a principal scientist at Xerox PARC and then moved on to serve as vice president of Control Data Corporation before his position at MCC. Dr. White's professional memberships include the American Physical Society, the Institute of Electrical and Electronics Engineers, and the American Association for the Advancement of Science. He serves on the boards of directors of several companies, including ST-Microelectronics and Silicon Graphics.

MARY LOU ZOBACK is a senior research scientist with the U.S. Geological Survey (USGS) Earthquake Hazards Team in Menlo Park, California. She received a Ph.D. in geophysics from Stanford University in 1978 and joined the USGS earthquake-studies staff permanently in 1979 after a year National Research Council postdoctoral fellowship at USGS. From 1986 to 1992, she led the World Stress Map project, a task group of the International Lithosphere Program that involved 40 scientists in 30 countries in an effort to compile and interpret geological and geophysical data on the present-day tectonic stress field. Dr. Zoback has served on a National Research Council panel to evaluate the proposed Yucca Mountain site for long-term disposal of radioactive waste, on a steering committee for the National Aeronautics and Space Administration (NASA) Solid Earth Sciences program to define 20- to 25-year goals for that program, and on a USGS team to define a 10-year science strategy for the Geologic Division of USGS. She is a past president of the Geological Society of America and served as president of the Tectonophysics Section of the American Geophysical Union (AGU) and as a member of the AGU Council. Her honors include the AGU Macelwane Award (1987), a USGS Gilbert Fellowship Award (1990-1991) for a one-year sabbatical in Karlsruhe, Germany, and the Meritorious Service Award from the U.S. Department of the Interior (2002).

Professional Staff

DEBORAH D. STINE (Study Director) is associate director of the Committee on Science, Engineering, and Public Policy (COSEPUP) and director of the Office of Special Projects. She has worked on various projects at the National Academies since 1989. She received a National Research Council group award for her first study for COSEPUP, on policy implications of greenhouse warming; a Commission on Life Sciences staff citation for her work in risk assessment and management; and two awards from the Policy and Global Affairs Division for her efforts in dissemination of National Academies' reports. Other studies have addressed human reproductive cloning, setting priorities for NSF's large research facilities, science and technology presidential appointments, science and technology centers, international benchmarking of U.S. research fields, graduate and postdoctoral education, responsible conduct of research, careers in science and engineering, and many environmental topics. She holds a bachelor's degree in mechanical and environmental engineering from the University of California, Irvine; a master's degree in business administration; and a Ph.D. in public administration, specializing in policy analysis, from the American University. Before coming to the National Academies, Dr. Stine was a mathematician for the U.S. Air Force, an air-pollution engineer for the state of Texas, and an air-issues manager for the Chemical Manufacturers Association.

LAUREL HAAK (Program Officer) is a program officer for the Committee on Science, Engineering, and Public Policy (COSEPUP). She received a B.S. and an M.S. in biology from Stanford University. She was the recipient of a predoctoral National Institutes of Health (NIH) National Research Service Award and received a Ph.D. in neuroscience in 1997 from Stanford University Medical School, where her research focused on calcium signaling and circadian rhythms. She was awarded a National Academy of Sciences (NAS) Research associateship to work at NIH on intracellular calcium dynamics in oligodendrocytes. After working at NIH, she joined the staff at the American Association for the Advancement of Science and was editor of Science's Next Wave Postdoc Network. While a postdoctoral scholar, she was editor of the *Women in Neuroscience* newsletter, and she is now president of this organization. She has served on the Society for Neuroscience Committee for the Development of Women's Careers in Neuroscience and the Biophysics Society Early Careers Committee, and she was an adviser and mentor for the National Postdoctoral Association.

B

Charge to the Committee

The committee conducting this study will examine the scope of interdisciplinary research and provide findings, conclusions, and recommendations as to how such research can be facilitated by funding organizations and academic institutions. The committee will recognize in its deliberations that the organization of research in academic institutions is driven by teaching and other considerations

Specifically, the committee will address the following tasks:

- Review proposed definitions of interdisciplinary research including similarities and differences from research characterized as cross-disciplinary, intradisciplinary, and multi-disciplinary and develop measures to determine whether research is interdisciplinary or not.
- Identify and analyze current structural models of interdisciplinary research.
- Identify and analyze the policies and procedures of Congress, funding organizations, and institutions that encourage or discourage interdisciplinary research.
- Compare and contrast current structural models and policies and procedures in academic and non-academic settings as well as traditional and non-traditional academic settings that encourage or discourage interdisciplinary research.
- Identify measures that can be used to evaluate the impact on research, graduate students and postdoctoral scholars, and researchers ex-

pected from their engagement in greater interdisciplinary research and cross-professional opportunities.

- Develop findings and conclusions as to the current state of interdisciplinary research and the factors that encourage (or discourage) it in academic, industry, and federal laboratory settings.
- Provide recommendations to academic institutions and public and private sponsors of research as to how to better stimulate and support interdisciplinary research.

C

Convocation Program and Speakers Biographies

WELCOME

Welcome to the National Academies' Convocation on Facilitating Interdisciplinary Research.

The purpose of this convocation is to better understand the concerns of funding organizations, university administrators, faculty, researchers, and students regarding interdisciplinary research and to identify effective practices and structural models, policies, and procedures that could help facilitate interdisciplinary research. The convocation consists of four elements:

- A series of panel discussions with federal, private, and international funding organizations, researchers, research center directors, and educators.
- Poster sessions where attendees can share their experiences.
- A public comment session.
- A survey of convocation participants.

The discussions during these activities will help the committee respond to its charge. We encourage you to fully participate in the convocation and we look forward to hearing your ideas.

Thank you again for coming!

COMMITTEE ON SCIENCE, ENGINEERING, AND PUBLIC POLICY

MAXINE F. SINGER (Chair), President Emeritus, Carnegie Institution of Washington
BRUCE ALBERTS (Ex-officio), President, The National Academies
R. JAMES COOK, R. James Cook Endowed Chair in Wheat Research, Washington State University
HAILE DEBAS, Dean, School of Medicine and Vice Chancellor, Medical Affairs, University of California, San Francisco
GERALD DINNEEN (Ex-officio), Retired Vice President, Science and Technology, Honeywell, Inc.
HARVEY FINEBERG (Ex-officio), President, Institute of Medicine
MARYE ANNE FOX (Ex-officio), Chancellor, University of California, San Diego
ELSA GARMIRE, Sydney E. Junkins Professor of Engineering, Dartmouth College
NANCY HOPKINS, Amgen Professor of Biology, Massachusetts Institute of Technology
WILLIAM JOYCE (Ex-officio), Chairman and CEO, Hercules Incorporated
MARY-CLAIRE KING, American Cancer Society Professor of Medicine and Genetics, University of Washington
W. CARL LINEBERGER, Professor of Chemistry, Joint Institute for Laboratory Astrophysics, University of Colorado
ANNE PETERSEN, Senior Vice President for Programs, W.K. Kellogg Foundation, Battle Creek, Michigan
CECIL PICKETT, President, Schering-Plough Research Institute
GERALD RUBIN, Vice President for Biomedical Research, Howard Hughes Medical Institute
HUGO SONNENSCHEIN, Charles L. Hutchinson Distinguished Service Professor, Department of Economics, The University of Chicago
JOHN D. STOBO, President, University of Texas Medical Branch of Galveston
IRVING WEISSMAN, Karel and Avice Beekhuis Professor of Cancer Biology, Stanford University
SHEILA WIDNALL, Abbey Rockefeller Mauze Professor of Aeronautics, Massachusetts Institute of Technology
WM. A. WULF (Ex-officio), President, National Academy of Engineering
MARY LOU ZOBACK, Senior Research Scientist, Earthquake Hazards Team, U.S. Geological Survey

Staff

RICHARD BISSELL, Executive Director
DEBORAH D. STINE, Associate Director
LAUREL HAAK, Program Officer
MARION RAMSEY, Administrative Associate

ABOUT THE COMMITTEE ON FACILITATING INTERDISCIPLINARY RESEARCH

As part of the National Academies Keck Futures Initiative, the National Academies—under the aegis of the Committee on Science, Engineering, and Public Policy—launched a study to examine how funding organizations and academic institutions can best facilitate interdisciplinary research. The study is funded by the W. M. Keck Foundation.

Charge to the Committee

The committee conducting this study will examine the scope of interdisciplinary research and provide findings, conclusions, and recommendations as to how such research can be facilitated by funding organizations and academic institutions. The committee will recognize in its deliberations that the organization of research in academic institutions is driven by teaching and other considerations

The Committee on Facilitating Interdisciplinary Research is charged with:

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- Identifying and analyzing the policies and procedures of Congress, funding organizations, and institutions that encourage or discourage interdisciplinary research.
- Comparing and contrasting current structural models and policies and procedures in academic and non-academic settings as well as traditional and non-traditional academic settings that encourage or discourage interdisciplinary research.
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- Developing findings and conclusions as to the current state of interdisciplinary research and the factors that encourage (or discourage) it in academic, industry, and federal laboratory settings.
- Providing recommendations to academic institutions and public and private sponsors of research as to how to better stimulate and support interdisciplinary research.

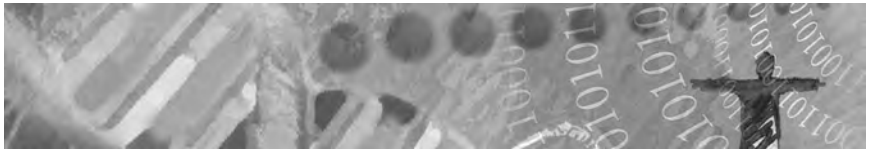
For More Information

Web site: *nationalacademies.org/interdisciplinary*
E-mail: interdisciplinary@nas.edu

ABOUT THE W. M. KECK FOUNDATION

Based in Los Angeles, California, the W. M. Keck Foundation was established in 1954 by the late W. M. Keck, founder of the Superior Oil Company. The Foundation's grant making is focused primarily on pioneering efforts in the areas of medical research, science, and engineering. The foundation also maintains a Southern California Grant Program that provides support in the areas of civic and community services with a special emphasis on children.

In May 2003, the National Academies and W. M. Keck Foundation announced a 15-year, $40 million grant from the Keck Foundation to underwrite the "National Academies Keck *Futures Initiative*," a new program designed to realize the untapped potential of interdisciplinary research. The National Academies Keck *Futures Initiative* was created to stimulate new modes of inquiry and break down the conceptual and institutional barriers to interdisciplinary research that could yield significant benefits to science and society.



CONTENTS

CONVOCATION GUIDELINES

Questions: We expect over 300 attendees at the convocation. So that everyone has a chance to ask their questions and provide their comments, we ask that you limit your time at the microphone to one minute. A timing device will be used to ensure we are fair to everyone. When you ask a question or make a comment please state your name and affiliation.

Survey: Before you leave we ask you to fill out the survey enclosed in this program and drop it in the box located at the front registration desk. Information from this survey will be used only in aggregate form as part of the committee's data collection efforts.

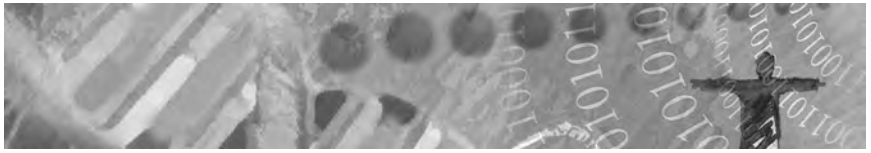
Lunch: Box lunches will be available in the Great Hall directly outside the auditorium. Please take your lunch to one of the following meeting rooms to enjoy. See map below.

Floor 1: 150, 180, Board Room, and Lecture Room

Floor 2: 250 and 280

Committee members and speakers are invited to take meals in the Members' Room located on the first floor.

Cell phones: Please either turn off cell phones or place on "vibrate" mode. Messages can be left at (202) 334-1613.



The National Academies
Committee on Science, Engineering, and Public Policy

Committee on Facilitating Interdisciplinary Research

CONVOCATION ON FACILITATING INTERDISCIPLINARY RESEARCH

January 29-30, 2004

National Academy of Sciences Building
2101 Constitution Avenue, NW
Washington, D.C.

AGENDA

Thursday, January 29, 2004

9 AM **Opening Remarks**
Nancy Andreasen, Co-Chair, Cmte on Facilitating Interdisciplinary Research

9:15 **Federal Research Funding Agency Perspectives on Facilitating Interdisciplinary Research**
Moderator: **Mary Lou Zoback**, Member, Cmte on Facilitating Interdisciplinary Research
- **Rita Colwell**, Director, National Science Foundation
- **Ray Orbach**, Director, Office of Science, Department of Energy
- **William Berry**, Director, Basic Research, ODUSD, Department of Defense
- **Lawrence Tabak**, Director, National Institute of Dental and Craniofacial Research, National Institute of Health
- **Cliff Gabriel**, Deputy Associate Director, Science Division, White House Office of Science and Technology Policy

10:45 **Break**

11:00 **Private and International Foundation Perspectives on Facilitating Interdisciplinary Research**

Moderator: **Jonathan Cole**, Member, Cmte on Facilitating Interdisciplinary Research

- **Maria Pellegrini**, Program Director for Science, Engineering, and Liberal Arts, W. M. Keck Foundation
- **Robert Granger**, President, William T. Grant Foundation
- **Laurie Garduque**, Program Director for Research, John D. and Catherine T. MacArthur Foundation
- **Barry Gold**, Program Officer, Conservation and Science, The David and Lucile Packard Foundation
- **Carmen Charette**, Senior Vice President, Canada Foundation for Innovation
- **Anthony Armstrong**, Director, Indiana 21st Century Research & Technology Fund

12:30 PM **Lunch**

1:30 **Interdisciplinary Researchers' Perspectives on Facilitating Interdisciplinary Research**

Moderator: **Stan Cohen**, Member, Cmte on Facilitating Interdisciplinary Research

- **F. Sherwood Rowland**, Bren Research Professor, Chemistry and Earth System Science, University of California at Irvine
- **Joel Cohen**, Abby Rockefeller Mauzé Professor, Laboratory of Populations, Rockefeller University and Columbia University
- **Lee Magid**, Professor, Chemistry, University of Tennessee, and Acting Director, Joint Institute for Neutron Sciences, UT and Oak Ridge National Laboratory
- **Diana Rhoten**, Program Officer, Social Science Research Council
- **Feniosky Peña-Mora**, Associate Professor of Construction Management and Information Technology William E. O'Neil Faculty Scholar, Civil and Environmental Engineering Department, University of Illinois Urbana-Champaign
- **Victoria Interrante**, Assistant Professor, Computer Science and Engineering, University of Minnesota

3:00 **Break**

3:15 **Research Center Directors' Perspectives on Facilitating Interdisciplinary Research**
Moderator: **Mario Molina**, Member, Cmte on Facilitating Interdisciplinary Research

- **Harvey Cohen**, Professor, Pediatrics, Stanford School of Medicine, and Chair, The Interdisciplinary Initiatives Committee, Bio-X, Stanford University
- **Catherine Ross**, Director, Center for Quality Growth, Georgia Tech
- **Pierre Wiltzius**, Director, Beckman Institute for Advanced Science and Technology, and Professor, Materials Science and Engineering Department and Physics Department University of Illinois at Urbana-Champaign
- **Uma Chowdhry**, Vice President, Central Research and Development, DuPont
- **Jeffrey Wadsworth**, Director, Oak Ridge National Laboratory
- **Ruzena Bajcsy**, Director, Center for Information Technology Research in the Interest of Society, University of California, Berkeley

4:45 **Break**

5-6:00 PM **Plenary Discussion**
Moderator: **Nancy Andreasen**, Co-Chair, Cmte on Facilitating Interdisciplinary Research
Discussant: **Julie Thompson Klein**, Professor of Humanities, Wayne State University

6-7:00 PM **Poster Session**

Friday, January 30, 2004

9:00 AM **Welcome**
Theodore Brown, Co-Chair, Cmte on Facilitating Interdisciplinary Research

Perspectives on Education and Training: Creating a New Generation of Interdisciplinary Researchers
Moderator: **Jennifer Chayes**, Member, Cmte on Facilitating Interdisciplinary Research

- **Marye Anne Carroll**, Professor, Atmospheric, Oceanic, and Space Sciences; Professor, Chemistry; Director, Program for Research on Oxidants: Photochemistry, Emissions, and Transport (PROPHET); Director, Biosphere—Atmosphere Research and Training (BART), University of Michigan
- **Edward Miles**, Professor of Marine Studies and Public Affairs, University of Washington
- **Alice Gottlieb**, Professor of Medicine and Director of the Clinical Research Center, Robert Wood Johnson Medical School, University of Medicine and Dentistry New Jersey
- **James Collins**, Ullman Professor of Biology, Arizona State University
- **Julio de Paula**, Professor of Chemistry, Haverford College

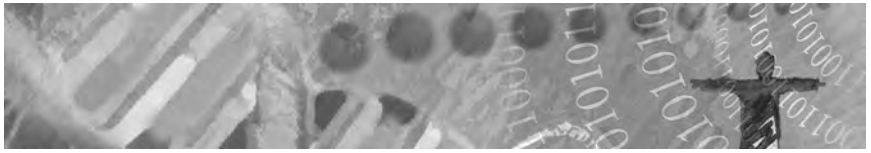
10:45 **Break**

11:00 **Plenary Discussion**
Moderator: **Theodore Brown**, Co-Chair, Cmte on Facilitating Interdisciplinary Research

11:45 **Closing Comments**

12:00 **Adjourn**

Copies of the PowerPoint presentations will be available shortly after the Convocation at http://www.nationalacademies.org/interdisciplinary



SPEAKERS BIOGRAPHICAL INFORMATION

ANTHONY ARMSTRONG is the Director of the Indiana 21st Century Research and Technology Fund. Prior to joining the Fund, Dr. Armstrong served in the Office of Technology Transfer with Indiana University's Advanced Research and Technology Institute (ARTI). Dr. Armstrong's focus was on the commercialization of innovations from the IU School of Medicine, and with corporate relations on behalf of IU. He was Director of Research with the IU School of Business Johnson Center for Entrepreneurship and Innovation prior to joining ARTI. Dr. Armstrong earned business and law degrees from Indiana University.

RUZENA BAJCSY was appointed Director CITRIS (Center for Information Technology Research in the Interest of Society) at the University of California, Berkeley in 2001, where she is also a faculty member in the EECS Department. Prior to coming to Berkeley, she was Assistant Director of the Computer Information Science and Engineering Directorate (CISE) at NSF from 1998 to 2001. Dr. Bajcsy is a pioneering researcher in machine perception, robotics and artificial intelligence. She is former Director of the University of Pennsylvania's General Robotics Automation Sensing Perception Laboratory, which she founded in 1978. She received her master's and Ph.D. degrees in electrical engineering from Slovak Technical University in 1957 and 1967, respectively. She received a Ph.D. in computer science in 1972 from Stanford University. Dr. Bajcsy holds membership in the National Academy of Engineering, the Neuroscience Institute, and the Institute of Medicine. In 2001 she became a recipient of the ACM A. Newell award. She was named to Discover Magazine's November 2002's list of the 50 most important women in science. In April of 2003 she received the CRA Distinguished Service Award and in May 2003 she was named to PITAC (the President's Information Technology Advisory Committee).

WILLIAM BERRY is the Director for Basic Research of the Military Services and Defense Agencies. He provides scientific leadership, management oversight, policy guidance and coordination of the $1.2 billion yearly basic research programs. Dr. Berry began his association with the Department of Defense as a National Research Council Postdoctoral Fellow at the Air Force Aerospace Medical Research Laboratory in 1976. Immediately prior

to his current position, Dr. Berry was Associate Deputy Assistant Secretary of the Air Force for Science Technology and Engineering and Director of the Washington Office of the Air Force Research Laboratory. His research publications are in the fields of environmental toxicology and neuroscience. Dr. Berry earned a B.S. in Biology from Lock Haven University, Lock Haven, PA, a M.A.T. in Zoology from Miami University, Oxford, OH, and a Ph.D. in Zoology/Biochemistry from the University of Vermont, Burlington, VT. He is a member of the American Association for the Advancement of Science and Sigma Xi, The Scientific Research Society.

MARY ANNE CARROLL is a professor of atmospheric science and chemistry and director of the Program for Research on Oxidants: Photochemistry, Emissions and Transport (PROPHET) at the University of Michigan. She is also Director of the NSF Research Experiences for Undergraduates in Atmospheric Chemistry, Meteorology, and Atmosphere–Forest Exchange and Principal Investigator for the Biosphere–Atmosphere Research and Training (BART) Program, a multi-institutional and multidisciplinary program for doctoral students (NSF IGERT). Dr. Carroll's research efforts include instrument development and field measurements focusing on the impacts of global change on atmospheric oxidant photochemistry and atmosphere–forest exchange. Dr. Carroll was a Research Chemist at the National Oceanic and Atmospheric Administration's Aeronomy Laboratory between 1984 and 1992, following a Postdoctoral Fellowship at the University of Colorado's Cooperative Institute for Research in Environmental Sciences. She also served as Associate Director of NSF's Atmospheric Chemistry Program from 1990 to1992 prior to joining the AOSS and Chemistry faculties at UM. During 1997–2000, Dr. Carroll served as Editor of the *Journal of Geophysical Research—Atmospheres*. Dr. Carroll holds a B.A. in Chemistry from the University of Massachusetts at Boston and a Sc.D. in Atmospheric Chemistry from the Massachusetts Institute of Technology.

CARMEN CHARETTE first joined the Canada Foundation for Innovation in July 1997 as vice president, programs. A year later, as the Foundation's scope and influence grew within Canada's science and innovation community, she was appointed to the position of senior ice president, program and operations. Today, Ms. Charette continues to play a significant role in carrying out the CFI's mandate and in keeping the Foundation focused on its increasing responsibility to Canada's research community. Before joining the CFI, Ms. Charette held a variety of Director positions during her 13 years at the Natural Sciences and Engineering Research Council (NSERC). She became the first Chair of the NSERC Operations Committee in 1997, and has continued as a member of the NSERC Senior Management com-

mittee to strategic planning. In addition, in 1996, she served as Presidenté de l'Association des administratrices et des administrateurs de recherche universitaire du Québec (ADARUQ). Ms Charette holds a B.S. in Biochemistry and a Bachelor of Business Administration, buth from the University of Ottawa.

UMA CHOWDHRY is vice president of Central Research & Development (CR&D) at DuPont, where she began in 1977 as a research scientist. For her contributions to the science of ceramics, Dr. Chowdhry was elected "Fellow" of the American Ceramics Society in 1989. For work ranging from catalysts to superconductors, she was elected to the National Academy of Engineering in 1996. Dr. Chowdhry has served on advisory boards of engineering schools at MIT, University of Pennsylvania, Princeton University and the University of Delaware as well as on the program advisory board and election subcommittee for the National Academy of Engineering. She has served on the National Research Council's study groups that generated assessment reports on various technology topics of national interest. She was recently elected to the board of directors for the Industrial Research Institute, the national Inventors' Hall of Fame and to a Laboratory Operations Board for the Department of Energy for the US Government. Dr. Chowdhry is a member of the National Committee on Women in Science and Engineering sponsored by both the National Academy of Science and the National Academy of Engineering since 1999. Born and raised in Mumbai, India, she came to the United States in 1968 with a B.S. in physics from Indian Institute of Science, Mumbai University, received an M.S. from Caltech in engineering science in 1970 and a Ph.D. in materials science from MIT in 1976.

HARVEY COHEN is a professor of pediatrics and chief of staff at Lucile Packard Children's Hospital, and has been named the first holder of the Arline and Pete Harman Professorship for the Chair of the Department of Pediatrics in the School of Medicine. Dr. Cohen received both his M.D. and his Ph.D. (biochemistry) in 1970 from Duke University School of Medicine. His postdoctoral work included a pediatrics residency at Children's Hospital in Boston and a pediatric hematology/oncology fellowship at Children's and the Dana Farber Cancer Institute. He held faculty posts at Harvard Medical School and at the University of Rochester School of Medicine, where he was James P. Wilmot Associate Professor of Pediatric Oncology and Associate Chair for Research and Development in the Department of Pediatrics. He was recruited to Stanford in 1993 as chair of the pediatrics department. His research interests include clinical trials in leukemia, mechanisms of drug resistance, immune killing of bacteria and tumor cells, free radical biochemistry and cell biology. He serves on the national Steering

Committee of the Pediatric Scientist Development Program and chairs the Interdisciplinary Initiative Program Committee for Bio-X, a new venture into scientific research, education and innovation at Stanford.

JOEL E. COHEN is Professor of Populations at the Rockefeller University and Columbia University, New York. Cohen's research deals with the demography, ecology, epidemiology and social organization of human and non-human populations and with mathematical concepts useful in these fields. Cohen earned two doctorates, a Ph.D. in Applied Mathematics (1970) and a DrPH in Population Science and Tropical Public Health (1973), from Harvard University. Cohen was elected to the American Academy of Arts and Sciences in 1989 (in evolutionary and population biology and ecology), the American Philosophical Society in 1994 (in the professions, arts, and affairs), and the U.S. National Academy of Sciences in 1997 (in applied mathematical sciences). Cohen serves on the Council of the National Academy of Sciences, the Governing Board of the National Research Council, the worldwide Board of Governors of The Nature Conservancy, and the Council of the American Academy of Arts and Sciences, among other boards. He is also a member of the Council on Foreign Relations, New York, and an Honorary Senior Fellow of the Foreign Policy Association, New York. In March 1999, Cohen was named co-winner of the Tyler Prize for Environmental Achievement, and in April 1998, co-winner of the Fred L. Soper Prize of the Pan American Health Organization, Washington, D.C., for work on Chagas' disease.

JAMES P. COLLINS is Virginia M. Ullman Professor of Natural History and the Environment in the School of Life Sciences at Arizona State University. From 1989 to 2002 he was Chairman of the Zoology, then Biology Department. Dr. Collins served as Director of the Population Biology and Physiological Ecology program at the National Science Foundation (NSF) in 1985-86. Dr. Collins's research centers on understanding the origin, maintenance, and reorganization of morphological variation within species. A special focus of the research is emerging wildlife diseases and their relationship to the global decline of amphibians; Collins heads an international team of 26 investigators studying this issue. Dr. Collins received his B.S. from Manhattan College and his M.S. and Ph.D. from The University of Michigan. He joined the faculty at Arizona State University in 1975. Dr. Collins is a Fellow of the American Association for the Advancement of Science. He is currently a member and chair of the Advisory Committee to NSF's Assistant Director for Biological Sciences and a member of the Advisory Committee for Environmental Research and Education reporting to NSF's Assistant Director for Geological Sciences.

RITA R. COLWELL is the Director of the National Science Foundation. Since taking office, Dr. Colwell has spearheaded the agency's emphases in K-12 science and mathematics education, graduate science and engineering education/training and the increased participation of women and minorities in science and engineering. In her capacity as NSF Director, she serves as Co-chair of the Committee on Science of the National Science and Technology Council. Before coming to NSF, Dr. Colwell was President of the University of Maryland Biotechnology Institute from 1991 to1998, and she remains Professor of Microbiology and Biotechnology (on leave) at the University Maryland. She was a member of the National Science Board from 1984 to 1990. Dr. Colwell previously served as Chairman of the Board of Governors of the American Academy of Microbiology and also as President of the American Association for the Advancement of Science, the Washington Academy of Sciences, the American Society for Microbiology, the Sigma Xi National Science Honorary Society, and the International Union of Microbiological Societies. Dr. Colwell is a member of the National Academy of Sciences, American Academy of Arts and Sciences, and The American Philosophical Society. Dr. Colwell was born in Beverly, Massachusetts, holds a B.S. in Bacteriology and an M.S. in Genetics, from Purdue University, and a Ph.D. in Oceanography from the University of Washington.

CLIFFORD GABRIEL is currently serving as Deputy to the Associate Director for Science in the Office of Science and Technology Policy (OSTP). In this position, he helps shape federal science policy in the physical, life, and social sciences. Dr. Gabriel handles issues for OSTP related to agricultural biotechnology, animal and plant health, animal welfare, food safety, plant genomics, pesticides, Gulf War veterans' illnesses, and dioxin. From 1993 to 1996, Dr. Gabriel was Executive Director of the American Institute of Biological Sciences. As Executive Director, he was responsible for all operations of the Institute including publications, contracts and grants, annual meetings, and public policy. Dr. Gabriel received his Ph.D. in plant pathology from the University of Wisconsin-Madison in 1983.

LAURIE R. GARDUQUE is the Director for Research in the MacArthur Foundation's Program on Human and Community Development. Her primary responsibilities focus on activities in mental health, juvenile justice, education, and child and youth development. Dr. Garduque joined the Foundation in 1991 after serving as Director of the National Forum on the Future of Children and Families, a joint project of the National Research Council and the Institute of Medicine. From 1984 to 1987, she was Director in charge of governmental affairs and professional liaison for the American Educational Research Association in Washington, D.C. This position

followed the year she spent, from 1983 to 1984, as a Congressional Science Fellow in the U.S. Senate. From 1980 to 1983, Garduque held a faculty position as an Assistant Professor in human development at Pennsylvania State University. She received her bachelor's degree in psychology and her M.A. and Ph.D. in educational psychology from the University of California at Los Angeles.

BARRY GOLD is Program Officer for Conservation and Science at the The David and Lucile Packard Foundation and in this role leads the Foundation's efforts to develop and implement two new strategies. The first is intended to foster the development of the emerging field of sustainability science, while the second will guide scientific activities in support of the Foundation's Oceans and Coasts program. Before joining the Foundation, Dr. Gold led an effort to understand and protect some of the most highly prized scenic and natural resources in the United States while balancing potentially conflicting social and political interests and demands upon the resource. Dr. Gold has dedicated his career to working at the environmental science and policy interface. In this role he has advised senior officials in Congress, federal and state agencies, the White House, non-governmental organizations and civic groups. Dr. Gold holds a D.Sc. from Washington University, an M.A. from George Washington University, an M.S. from the University of Connecticut, and a B.S. from the University of Miami. He is a member of AAAS, the Ecological Society of America, and Sigma Xi.

ALICE GOTTLIEB has spent the majority of her professional career treating and researching immunology and inflammatory diseases and disorders. Her own passion for research, coupled with a desperate need for clinical research into these conditions, prompted her to develop a research fellowship program for promising physicians. She is currently a Professor of Medicine, director of the Clinical Research Center at UMDNJ-Robert Wood Johnson Medical School and holds the W. H. Conzen Chair in Clinical Pharmacology at UMDNJ-Robert Wood Johnson Medical School. Dr. Gottlieb received her medical degree from Cornell University Medical College in 1980, her Ph.D. in Immunology from the Rockefeller University in 1977 and completed her residency at New York Hospital and was certified by the American Board of Dermatology in 1993. She is also board certified in Rheumatology (1984) having trained at the Hospital for Special Surgery and board certified in Internal Medicine (1982) having trained at the New York Hospital.

ROBERT GRANGER is President of the William T. Grant Foundation. Since joining the Foundation in 2000, Dr. Granger has been responsible for leading the Foundation's grantmaking, including refinements that would

improve its impact on youth policy and practice. He came to the Foundation from the Manpower Demonstration Research Corporation (MDRC), where he was senior vice president and director of MDRC's education, children, and youth department. Prior to that he was executive vice president at the Bank Street College of Education, and executive director of the Child Development Associate National Credentialing Program. Dr. Granger's research specialties include the study of social programs and policies that affect low-income children, youth, and families. He earned his doctorate in education from the University of Massachusetts, Amherst.

VICTORIA INTERRANTE is Assistant Professor in the Department of Computer Science and Engineering at the University of Minnesota. Her research focuses on the application of insights from visual perception, art and illustration to the design of more effective techniques for conveying data through images. Her research involves active collaborations with colleagues across the University from the Department of Aerospace Engineering and Mechanics to the Department of Architecture. Her present projects include: the study of texture's effect on shape perception and the design and synthesis of texture patterns to facilitate accurate shape representation; the study of texture perception and the development of methods for effectively using texture in visualizing multivariate data and representing data uncertainty; the development of algorithms for the effective detection, tracking and visualization of vortical structures in turbulent boundary layer flows; and the study of spatial perception in immersive virtual environments and the use of VR technology in the development of tools to enhance the process of conceptual design in architecture. She received her B.A. in computer science from the University of Massachusetts at Boston in 1984, her M.S. from UCLA in 1986, and her Ph.D. in 1996 from the University of North Carolina at Chapel Hill, where she studied under the joint direction of Dr. Henry Fuchs and Dr. Stephen Pizer. From 1996-1998 she worked as a staff scientist at ICASE, a non-profit research center operated by the Universities Space Research Association at NASA Langley. In 1999 she received a Presidential Early Career Award for Scientists and Engineers, and she was awarded a 2001-2003 McKnight Land-Grant Professorship from the University of Minnesota.

JULIE THOMPSON KLEIN is an internationally recognized scholar in the field of interdisciplinary history, theory, and methodology. Dr. Klein arrived at Wayne State in 1970 and has been with what is now the Department of Interdisciplinary Studies in the College of Lifelong Learning since 1976. A past president of the Association for Integrative Studies, she lectures and consults throughout the world for universities developing interdisciplinary programs. Professor Klein currently is a member of the Association of

American Colleges and Universities national task force on Integrative Learning.

LINDA J. (LEE) MAGID is a Professor of Chemistry at the University of Tennessee. Her research focuses on physiochemical investigations of micelles and polyelectrolytes in aqueous solutions; techniques used include light scattering, small-angle neutron scattering, neutron spin-echo spectroscopy and NMR spectroscopy. She has served as Vice-President for Research and Graduate Studies at the University of Kentucky and is currently UT's ORNL/SNS Liaison for Science & Technology and the Acting Director of the UT/ORNL Joint Institute for Neutron Sciences. She has a B.S. in chemistry from Rice University and a Ph.D. in chemistry from the University of Tennessee. She is a Fellow of AAAS. Currently she is a member of the NRC Board on Physics and Astronomy and serves as vice-chair of the Solid State Sciences Committee. In addition, she serves on the Board on Assessment of NIST Programs' subpanel on the NIST Center for Neutron Research, and on the U.S. National Committee to the IUPAC. She also served on the Committee on Developing a Federal Materials Strategy.

EDWARD L. MILES is the author of many studies on international organizations, international science and technology policy, and marine policy and ocean management. He has served as chairman of the Ocean Policy Committee, National Academy of Sciences/National Research Council (1974-79); member of the Executive Board, Law of the Sea Institute, 1972-81 and 1985-89 and President 1989-93; Chairman of the Legal and Institutional Task Group on the Implications of Disposal of High-Level Radioactive Waste into the Seabed and Advisor to the Executive Committee, Seabed Working Group, Nuclear Energy Agency, OCED, 1981-1987; and Chairman of the Advisory Committee on International Programs of the National Science Foundation, 1990-92. He has also served as consultant to the United Nations, Intergovernmental Oceanographic Commission of Unesco, Dept. of Fisheries of FAO, and the South Pacific Forum Fisheries Agency. In April 1993 he served as the UN-designated expert on GESAMP, the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection and in 1994 he was appointed Lead Author for Marine Policy in WG II-B (Oceans and Large Lakes) of the Intergovernmental Panel on Climate Change 1995, Re-assessment of the Global Climate Change Problem. Within the University of Washington, he has served as Director of the School of Marine Affairs (1982-1993), Chairman of the University Committee on Interdisciplinary Research and Graduate Education (1991-1992), and a member of the University's Steering Committee on Global Change (since 1992), and chairman of the President's Task Force on Environmental Education, 1995-1996. He was elected to membership in the NAS on April 29, 2003.

RAYMOND L. ORBACH is the Director of the Office of Science at the Department of Energy (DOE). As Director of the Office of Science (SC), Dr. Orbach manages an organization that is the third largest Federal sponsor of basic research in the United States which is viewed as one of the premier science organizations in the world. Prior to his appointment, Dr. Orbach served as Chancellor of the University of California at Riverside from April 1992 through March 2002; he now holds the title Chancellor Emeritus. Dr. Orbach began his academic career as a postdoctoral fellow at Oxford University in 1960 and became an assistant professor of applied physics at Harvard University in 1961. He joined the faculty of the University of California, Los Angeles (UCLA) two years later as an associate professor, and became a full professor in 1966. From 1982 to 1992, he served as the Provost of the College of Letters and Science at UCLA. Dr. Orbach has received numerous honors as a scholar including two Alfred P. Sloan Foundation Fellowships, a National Science Foundation Senior Postdoctoral Fellowship, a John Simon Guggenheim Memorial Foundation Fellowship, the Joliot Curie Professorship at the Ecole Superieure de Physique et Chimie Industrielle de la Ville de Paris, the Lorentz Professorship at the University of Leiden in the Netherlands, and the 1991-1992 Andrew Lawson Memorial Lecturer at UC Riverside. He is a fellow of the American Physical Society and the AAAS. Dr. Orbach received his B.S. degree in Physics from the California Institute of Technology in 1956. He received his Ph.D. degree in Physics from the University of California, Berkeley, in 1960 and was elected to Phi Beta Kappa.

JULIO DE PAULA is Professor of Chemistry and Director of the Marian E. Koshland Integrated Natural Sciences Center at Haverford. He is the recipient of the Henry Dreyfus Teacher-Scholar Award, a national honor bestowed on chemists who have excelled at both teaching and research. Funding for his research comes from the National Science Foundation. He has focused his years of research on the molecular interactions responsible for plant photosynthesis and on novel laser-based tumor treatments. He obtained his B.A. degree in Chemistry from Rutgers, The State University of New Jersey in 1982, and received a Ph.D. in Chemistry from Yale University in 1987. He was a recipient of an NIH Postdoctoral Fellowship in 1988 to conduct research at Michigan State University. He joined the Haverford faculty in 1989. Dr. Paula is the co-author of the Seventh Edition of "Physical Chemistry" with Peter Atkins, Oxford University.

MARIA PELLEGRINI joined the W. M. Keck Foundation as Program Director for Science, Engineering and Liberal Arts in February of 1998. She was Dean of Research in the College of Letters, Arts and Sciences at the University of Southern California from 1994 to 1998. Dr. Pellegrini was

Professor of Biological Sciences at USC from 1977 to 1998, serving as department chair from 1988 to 1993. She has taught a variety of courses in molecular biology and biochemistry at the undergraduate and graduate levels. Her research interests included studies of the structure-function relationships within ribosomes, the regulation of ribosomal gene expression, and, recently, work on genes that are important in human production. She has co-authored over 50 scientific journal articles and review chapters including an Institute for Scientific Information "citation classic." Dr. Pellegrini was the recipient of an Alfred P. Sloan Foundation Fellowship and a Dreyfus Foundation Teacher-Scholar Award. She has received numerous research and training grants from the National Institutes of Health. She has served on National Institutes of Health, California Breast Cancer Research Council and American Cancer Society grant review panels. She received her B.A. degree in chemistry from Connecticut College in 1969 and her Ph.D. in chemistry from Columbia University in 1974 followed by postdoctoral fellowships at Caltech and UC Irvine.

FENIOSKY PEÑA-MORA is currently an O'Neil Faculty Scholar and Associate Professor in the Department of Civil and Environmental Engineering at the University of Illinois at Urbana-Champaign. Peña-Mora was previously an Associate Professor of Information Technology and Project Management in the Civil and Environmental Engineering Department's Intelligent Engineering Systems Group at the Massachusetts Institute of Technology. His current research interests are in information technology support for collaboration, change management, conflict resolution, and process integration during design and development of large-scale civil engineering systems. He is the author of publications on computer-supported design, computer-supported engineering design and construction, project control and management of large-scale engineering systems. One of his publications received the 1995 award for best paper published in the ASCE Journal of Computing in Civil Engineering. Another of his publications is the textbook entitled "Introduction to Construction Dispute Resolution." He is also holder of a 1999 NSF CAREER Award and a 2000 White House PECASE (Presidential Early Career Award for Scientists and Engineers) Award. He is an Associate Editor for the ASCE Journal of Computing in Civil Engineering and the ASCE Journal of Construction Engineering and Management.

DIANA RHOTEN is a program office for the Social Science Research Council. She has a Ph.D. in Social Sciences, Policy, and Educational Practice and an M.A. in Organizational Sociology from Stanford University, as well as an M.Ed. in International Development Education from Harvard University. From 2001 to 2003, Dr. Rhoten served as an assistant professor

at the Stanford University School of Education where she taught courses in international education development and interdisciplinary research methods. At this time, Dr. Rhoten was also the research director of the Hybrid Vigor Institute and the principal investigator of the Institute's NSF-funded study on interdisciplinary research networks and methods. In addition to analyzing interdisciplinary research organizations, Dr. Rhoten also studies cross-programmatic strategies in philanthropy.

CATHERINE ROSS is the Georgia Tech College of Architecture's first endowed faculty member—the Harry West Chair for Quality Growth and Regional Development. In this role, Dr. Ross directs a center that examines key issues of land use, community design, transportation and air quality throughout the Atlanta region and beyond. She grew up in Ohio, graduated from Kent State University, and received her Ph.D. in Urban and Regional Planning at Cornell University. She did post-doctorate work at the University of California at Berkeley. In addition, Ross founded a consulting company that has conducted research for numerous government transportation agencies, and has been published extensively in the fields of urban planning, transportation planning and public participation. Dr. Ross has served as senior policy advisor at the National Academy of Sciences Transportation Research Board and vice provost for academic affairs at Georgia Tech. She is past president of the National Association of Collegiate Schools of Planning and was recently appointed to the national advisory board of the Women's Transportation Seminar. She also serves as vice chair of the Atlanta Development Authority.

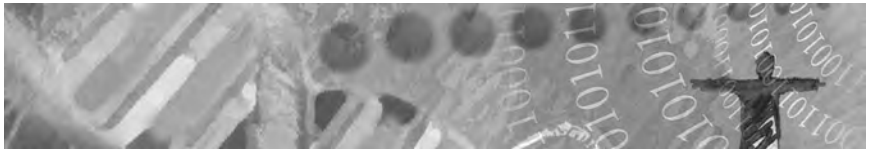
F. SHERWOOD ROWLAND is a specialist in atmospheric chemistry and radiochemistry, and was, with colleague Mario Molina, the first scientist to warn that chlorofluorocarbons (CFCs) released into the atmosphere were depleting the earth's critical ozone layer. Dr. Rowland arrived at the University of California, Irvine, in 1964 as the first chair of the Department of Chemistry. He previously held faculty positions at Princeton University and the University of Kansas. He holds a bachelor's degree from Ohio Wesleyan University, a master's and a doctorate from the University of Chicago, and a number of honorary degrees from universities in the United States and the United Kingdom. Rowland is a member of the National Academy of Sciences and the American Academy of Arts and Sciences. During 1991–1993, he served successive one-year terms as President-Elect, President, and Chairman of the Board of the American Association for the Advancement of Science. Dr. Rowland was awarded the American Chemical Society 1993 Peter Debye Medal in Physical Chemistry, and the 1994 Roger Revelle Medal from the American Geophysical Union. In 1995, he shared the Nobel Prize in Chemistry with Mario Molina and Paul Crutzen.

LAWRENCE A. TABAK is the director of the National Institute of Dental and Craniofacial Research (NIDCR). The former director of the Center for Oral Biology, Aab Institute, at the University of Rochester in New York, Dr. Tabak also served as senior associate dean for research at the School of Medicine and Dentistry. While at Rochester, he oversaw a number of interdisciplinary research groups studying the molecular and genetic aspects of craniofacial-oral-dental conditions. He also directed graduate research training programs at the university and held professorships in dentistry and biochemistry and biophysics. Dr. Tabak has also served in various official capacities in a number of professional organizations, including the International/American Association for Dental Research, the American Association for the Advancement of Science, and the Society for Glycobiology. He has received numerous honors and awards for his work, including being named a fellow of the AAAS and most recently, his election to the Institute of Medicine of the National Academies. A native of Brooklyn, New York, Dr. Tabak received his undergraduate degree from City College of the City University of New York, his D.D.S. from Columbia University, and both a Ph.D. and certificate of proficiency in endodontics from the State University of New York at Buffalo.

JEFFREY WADSWORTH is the director of Oak Ridge National Laboratory, the largest multipurpose laboratory of the U.S. Department of Energy (DOE), with 3,800 staff members and an annual budget of $1 billion. He is also a corporate officer of Battelle Memorial Institute, in Columbus, Ohio, where he is senior vice president for DOE Science Programs. He joined Battelle in August 2002 and was a member of the White House Transition Planning Office for the U.S. Department of Homeland Security. He previously served as Deputy Director for Science and Technology at DOE's Lawrence Livermore National Laboratory, as well as Associate Director for Chemistry and Materials Science at that laboratory. Dr. Wadsworth holds B.S., Ph.D., and D. Met. degrees in metallurgy from the University of Sheffield in England. He is a Fellow of the American Society for Metals and the Minerals, Metals, and Materials Society. In 2003, he was elected a Fellow of the American Association for the Advancement of Science in recognition of "distinguished contributions in developing advanced materials and superplasticity, and in determining the history and origins of Damascus and other steels, and for broad scientific leadership supporting national security."

PIERRE WILTZIUS is director of the Beckman Institute for Advanced Science and Technology; a professor in both the Department of Materials Science and Engineering and the Department of Physics; and a full-time Beckman Institute faculty member in the Nanoelectronics and Biophotonics

Group. His fields of professional interest are soft-condensed matter, colloidal self-assembly, photonic crystals and microphotonics. Pierre Wiltzius received his Ph.D. in physics from the Swiss Federal Institute of Technology (ETHZ), Zurich, Switzerland in 1981. He was at Bell Laboratories (Lucent Technologies, formerly AT&T) between 1984 and 2001, where he was most recently the Director of Semiconductor Physics Research. He is a Fellow of the American Physical Society; a Fellow of the American Association for the Advancement of Science; a Senior Member of the IEEE; and a recipient of a NATO Fellowship. Interdisciplinary research has been central to his professional career. His Ph.D. thesis was on aspects of blood coagulation and was the result of a collaboration between physicists and clinical physicians.



REPRESENTED ORGANIZATIONS

The following organizations are represented at the Convocation on Facilitating Interdisciplinary Research.

Aerospace Corporation
Abt Associates, Inc.
Alliance for Academic Internal Medicine
American Association of Colleges of Pharmacy
American Chemical Society
American College of Radiology
American Health Information Management Association
American Institute of Biological Sciences
American Institute of Physics
American Mathematical Society
American Museum of Natural History
American Psychological Association
American Psychological Society
American Society of Cell Biology
American Society of Plant Biologists
American Sociological Association
Arizona State University
Arnold & Porter
ASHP Research & Education Foundation
Association of American Geographers
Atlantic Philanthropies (USA)
Baltimore City Public Schools
Bar-Ilan University
BART IGERT: Biosphere-Atmosphere Research and Training Program
Biophysical Society
Brookhaven National Laboratory
Buffalo State College
Burroughs Wellcome Fund
California State University Program for Education and Research in Biotechnology
Canadian Institute for Advanced Research
Consortium for Oceanographic Research and Education

Contemporary Communications, Inc.
Cornell University
Council on Undergraduate Research
Des Moines University
Duke Center for Environmental Solutions
Duke University
Ecological Society of America
Embassy of France
Embassy of Switzerland
EnTech Strategies, LLC
Environment Canada
Experimental Program to Stimulate Experimental Research Foundation
Faculty Career and Diversity Consultant
Federation of American Societies for Experimental Biology
Flattau Associates, LLC
Florida A & M University
Food and Drug Administration
Fred Hutchinson Cancer Research Center
George Washington University
Georgia Institute of Technology
Graduate Partnerships Program
Graduate School of Public Health, University of Pittsburgh
Gulf Coast Consortia
Harvard University
Health Resources and Services Administration
House Resources Committee
Howard Hughes Medical Institute
Howard University
Independent Consultant
Industry-University Cooperative Research Program
Institute for Prevention Research
James Madison University
JMW Associates
John Templeton Foundation
Johns Hopkins University, Bloomberg School of Public Health
Land Information and Computer Graphics Facility
Lewis-Burke Associates
Lincoln University of Pennsylvania
Louisiana Tech University
Mathematical Association of America
McGeary and Smith
Medical College of Georgia
Michigan State University

Montclair State University
Mouvement Burkinabè d'Ecologie
National Aeronautics Space Administration Marshall Space Flight Center
National Cancer Institute
National Education Knowledge Industry Association
National Institute of Biomedical Imaging and Bioengineering
National Institute of Mental Health
National Institute of Standards and Technology
National Institute on Drug Abuse
National Institutes of Health
National Institute on Disability and Rehabilitation Research
Natural Sciences and Engineering Research Council of Canada
National Institute for Biomedical Imaging and Bioengineering/National Institutes of Health
National Institute of General Medical Sciences
National Institutes of Health/National Heart, Lung, & Blood Institute
National Institute of Mental Health
National Oceanic and Atmospheric Administration/OAR
Northern Arizona University
Northwestern University
National Science Foundation
Ohio Agricultural Research and Development Center/Ohio State University
Ohio State University
Office of Management and Budget
Office of Naval Research Global
Office of Science & Technology Policy
Office of the Director, NIH
Office of Translational Research & Scientific Technology
Oklahoma State University
Orthotic and Prosthetic Assistance Fund, Inc.
Paralyzed Veterans of America
Pennsylvania State University
Potomac College
Purdue University
Research for Better Schools
Rutgers University
Sandia National Laboratories
SETI Institute
Social Science Research Council
Society for Women's Health Research
Southern Illinois University Carbondale
Stony Brook University

Syracuse University
Technology Policy and Assessment Center
TechVision21
Texas Tech University
Thomas Jefferson University
University of Maryland—Baltimore Campus
UMDNJ-Robert Wood Johnson Medical School
Uniformed Services University
University of Nebraska Medical Center
University at Buffalo
University of California
University of California, Los Angeles
University of California, Davis
University of California, Irvine
University of Cincinnati
University of Colorado
University of Florida
University of Georgia
University of Kansas
University of Massachusetts, Lowell
University of Michigan
University of Nebraska, Lincoln
University of New Mexico
University of North Carolina at Chapel Hill
University of North Carolina at Greensboro
University of North Dakota
University of Oklahoma, Tulsa Graduate College
University of Oregon
University of Pittsburgh
University of the Philippines Baguio
University of Wisconsin, Milwaukee
U.S. Department of Agriculture—Cooperative State Research, Education, and Extension Service
U.S. Department of Commerce
U.S. Department of Energy
U.S. Environmental Protection Agency
U.S. State Department
Utah Addiction Center
University of Texas at Dallas
University of Texas Medical Branch
Vanderbilt University
Vanderbilt University Medical Center
Virginia Polytechnic Institute and State University

W. M. Keck Foundation
Washington State University
Washington University School of Medicine
Water Environment Research Foundation
Wind Hollow Foundation
Women in International Security
Yale University School of Medicine

D

From Interdiscipline to Discipline

The relationship between interdisciplinary and disciplinary research is dynamic. Researchers in one discipline may follow a question to the interface of another discipline and return "home" with new knowledge. If the journey is especially productive, it may cross one or more intellectual frontiers to produce a new discipline.

As discussed in Chapter 2, this process of interdisciplinarity has been propelled by a number of "drivers." For example, the driver of generative technologies may be said to have given rise to partnerships between biology and chemistry more than two centuries ago after Lavoisier's studies of combustion and Priestley's discovery of the presence of oxygen in the air. And the partnerships coalesced over the years in the new "interdiscipline" of biochemistry, which emerged with its own distinctive character and is now generally considered a discipline.

In most cases, emerging disciplines become mature when they attract a critical mass of participants whose increasing numbers and productivity warrant a new set of societies, journals, and academic departments. The founders of the distinct discipline, who were usually trained in one of its "parent" disciplines, may then take the logical, although often discomfiting step, of moving into a new professional identity and culture.

The purpose of this appendix is to illustrate, by example, how interdisciplinary partnerships have evolved into new disciplines and how these new disciplines have led to the creation of a new breed of interdisciplinary professional society since World War II. This issue is discussed further in Chapter 7 on the role of professional societies in interdisciplinary research.

GEOBIOLOGY

The recent emergence of geobiology into a mature field was preceded by a long gestation period, beginning with the pioneering studies of the earth's surface by James Hutton more than two centuries ago. By the beginning of the 20th century, the great Russian polymath Vladimir Vernadsky focused more explicitly on the influence of the biosphere (including human activities) on geological processes, and the term *geobiology* was first used soon afterward by the Dutch biologist Lourens Bass Becking in 1934. Most recently, the extensive writings of the independent scientist James Lovelock served to highlight the role of life in influencing the surface environment of the earth.[1]

Awareness of the importance of geobiology was widened by technologies that revealed new kinds of organisms that flourish in remote and extreme environments. Discoveries of how microbes contribute to geochemical reactions or react with the geosphere in novel ways have stirred the excitement of many who seek solutions to a wide array of environmental and resource challenges. Among the existing disciplines that have fed the growth of geobiology are geochemistry, geohydrology, oceanography, microbiology, environmental studies, biogeochemistry, ecology, molecular biology, genomics, paleobiology, and mineralogy.

The interaction of biological and geological thinking developed over many decades, but the formal birth of the new field happened quickly. It was stimulated in part by the report of a colloquium held in December 2000 by the American Academy of Microbiology, which formally described geobiology as "research that attempts to understand the interface between the biosphere and the geosphere." The report was followed by the decision of the Geological Society of America to create the new Geobiology and Geomicrobiology Division in May 2001 and then by the decisions of Elsevier Science to publish *Virtual Journal of Geobiology* in 2002 and of Blackwell Publishing to launch the new journal *Geobiology* in 2003. The University of Southern California Wrigley Institute for Environmental Studies held an "International Training Course in a Rapidly Evolving Field: Geobiology" in June 2004.[2]

[1]Lovelock's assertion that the "planet Gaia" is a "self-regulating" system has stirred controversy, but his elucidation of biosphere-geosphere interactions is nonetheless extensive.

[2]See the colloquium report "Geobiology: Exploring the Interface Between the Biosphere and the Geosphere, 2001, at *http://www.asm.org/Academy/index.asp?bid=2132*.

NEUROSCIENCE

Neuroscience has been defined as the interdisciplinary investigation of the nervous system and behavior.[3] Thomas Willis, an English anatomist, provided the first detailed description of brain structure in the middle 1600s, and 200 years later scientists began to correlate structures with functions. By the end of the 19th century, brain research institutes began to formalize research activity in the structure of universities.

Until a few decades ago, most scientists engaged in brain research identified themselves with anatomy, physiology, psychology, biochemistry, and other disciplines. Then, in the 1960s, a "critical mass" of brain researchers around the world felt the need to focus their activities on a single framework and to formalize neuroscience as a discipline. In response, the International Brain Research Organization was founded in 1960 to promote cooperation among the world's scientific resources for research on the brain. The British Brain Research Association was founded in 1968; it is now the British Neuroscience Association. In the United States, the Society for Neuroscience was founded in 1969, with its official organ, the *Journal of Neuroscience*. Membership in the US society grew from 1,000 in 1970 to about 34,000 in 2000.

In this new discipline, neuroscientists are integrating a variety of perspectives to gain insights into fundamental questions about the nervous system in health and disease. According to a recent study, "Neuroscience is a clear example of a discipline of today arising from interdisciplinary approaches of the past."[4] Like other emerging fields, it interacts with other disciplines and techniques as needed, including informatics and molecular biology. It has been invigorated by new technologies, such as the use of positron emission tomography to image blood flow and magnetic resonance imaging to look at neural structures. Its growth has been so rapid that some of its own subdisciplines, such as cognitive neuroscience, are now acquiring disciplinary status.

SUSTAINABILITY SCIENCE AND ENGINEERING

In contrast with the previous two examples, the concept behind sustainability science is relatively young, having evolved largely out of the environ-

[3]Frank, R. J., Marshall, L. H., and Magoun, H. W. "The Neurosciences," In Bowers, J. Z. and Purcell, E. F., *Advances in American Medicine: Essays at the Bicentennial, Vol. 2,* Josiah Macy Jr. Foundation, 1976.

[4]Institute of Medicine, *Bridging Disciplines in the Brain, Behavioral, and Clinical Sciences*, Washington, D.C.: National Academy Press, 2000.

mental movement of the 1960s and 1970s. That decade saw growth in the awareness of a linked series of environmental problems, including resource depletion, population growth, and pollution of air, water, and soil.

Initially, environmental studies focused on issues of waste management, especially on air, water, and soil pollution. The strategy for treating pollutants focused on "end-of-pipe" techniques and other local measures. As it became clear that end-of-pipe measures were merely palliative, they evolved toward the broader activities of pollution prevention, conservation, and social policies.

By 1987, a report from the UN-mandated Brundtland Commission could describe "sustainable development" as development "which meets the needs of the present without compromising the ability of the future to meet its needs."[5] That report served as a catalyst for the 1992 UN Conference on Environment and Development (the "Earth Summit") in Rio de Janeiro. The evidence delivered at the conference made it clear that it was necessary "to integrate the physical and social science disciplines with engineering to address the ecological, economic, social, and political processes that determine the sustainability of natural and human life cycles and activities."[6] Thus arose the need to develop an interdisciplinary infrastructure, termed *sustainability science and engineering*. The broad goals of this field are to define major threats to sustainability, find accurate indicators of change (from children's birth weights to atmospheric chemistry), and explore promising opportunities for circumventing or mitigating environmental threats.

Although it may be premature to define this field as a stand-alone discipline,[7] some researchers have articulated a vision of a "metadiscipline." For example, one paper defines sustainability as "the design of human and industrial systems to ensure that humankind's use of natural resources and cycles do not lead to diminished quality of life due either to losses in future economic opportunities or to adverse impacts on social conditions, human health, and the environment."[8] It remains to be seen whether an enterprise of such breadth is a discipline in the traditional sense or whether researchers are leading us toward a new concept of the discipline.

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[5]World Commission on Environment and Development, *Our Common Future*, New York: Oxford University Press, 1987.

[6]National Research Council, *Our Common Journey: A Transition Toward Sustainability*, 1999.

[7]Clark, W. C. and Dickson, N. M. "Sustainability science: The emerging research program," *Proceedings of the National Academy of Sciences*, 100(14):806, 2003.

[8]Mihelcic, J. R. et al., "Sustainability Science and Engineering: The Emergence of a New Metadiscipline," *Environmental Science and Technology* 37(23):5315, 2003.

CONCLUSION

Perhaps the most common driver of interdisciplinarity toward the emergence of new disciplines is the sheer complexity of nature, which draws researchers toward the next important question, moving toward interfaces with other disciplines and partnerships with colleagues in them. In the three examples above, the intellectual journey seems to be natural and even inevitable for those seeking answers to the questions of science and engineering. The more institutions and funding organizations can help these pioneer investigators along their way, the greater the intellectual and practical rewards of research are likely to be.

E

Survey of Institutions and Individuals Conducting Interdisciplinary Research

To enhance scholarship and collect quantitative data on the impediments, programs, and evaluation criteria related to interdisciplinary research (IDR), the committee developed survey instruments and disseminated them to provosts and others.[1] In this appendix, we analyze the results of the committee's surveys of those interested in IDR, including students, postdoctoral scholars, faculty, funders, policy makers, and disciplinary societies.

The first survey, referred to in the report as the "convocation survey," was given to the 150 persons who attended the Convocation on Facilitating Interdisciplinary Research, on January 29-30, 2004 (see Appendix C); 91 convocation participants responded to the survey—about a 75 percent return rate. The "individual survey," a slightly modified version of the convocation survey, was posted on the committee's Web site. An invitation to participate in the survey was sent to universities, professional societies, nongovernment organizations, and participants in federal and private interdisciplinary programs; 423 people responded to the solicitation. An invitation to participate in a third survey, the "provost survey," was distributed on line to provosts or vice-chancellors of institutions that conduct IDR; 57 institutions responded.

[1] *http://www7.nationalacademies.org/interdisciplinary/SurveyHome.html*. The survey instrument for individuals is appended. It differs from the provost survey in question #1.

It must be noted that the survey population does not represent a random sample. There was undoubtedly selection bias in those who attended the Convocation on Facilitating Interdisciplinary Research and in those who responded to the Web-based survey. The results are representative of a wide population of researchers, but cannot be extrapolated to the entire population of researchers involved in interdisciplinary projects and programs. That said, the findings corroborate and extend previous studies of IDR, and offer unique insights on joint appointments and differences between researchers and administrators, and provide suggestions for how to prioritize change efforts.

DISSEMINATION

The convocation survey was distributed at the convocation in Washington, D.C. and the individual survey was distributed by the following organizations. We made every attempt to distribute the survey as widely as possible. Our strategy was to request larger organizations and umbrella societies in a variety of fields to distribute the survey

- American Chemical Society (ACS)
- American Institute of Biological Sciences (AIBS)
- Association for Integrative Studies
- Association of American Medical Colleges (AAMC)
- Association of American Universities (AAU)
- Association of Independent Research Institutes
- Biophysical Society
- Council of Graduate Students (CGS)
- Federation of American Societies for Experimental Biology (FASEB)
- National Association of State Universities and Land-Grant Colleges (NASULGC)
- National Academy of Public Administration
- National Institutes of Health Bioengineering Consortium (NIH BECON)
- DOE National Laboratories
- National Science Foundation (NSF) Engineering Research Centers
- NSF Frontiers in Integrative Biological Research (FIBR) awardees
- NSF Integrative Graduate Education and Research Traineeships (IGERT) awardees
- NSF Science and Technology Centers
- Washington Science Policy Alliance

The following institutions participated in the provost survey. We received the assistance of NASULGC and AAU in distributing the survey to their member universities.

- Barnard College
- Boston University
- Carnegie Mellon University
- Cedars-Sinai Medical Center
- Clarkson University
- Columbia University
- Department of Energy Idaho Operations Office
- Florida State University
- Georgia State University
- Instituto Mexicano del Seguro Social
- Iowa State University
- Jackson Laboratory
- Johns Hopkins University
- Lewis & Clark College
- Massachusetts Institute of Technology
- Medical College of Georgia
- Miami University
- National Cancer Institute
- National Dairy Council
- New York University
- North Dakota State University
- Northwestern University
- Pennsylvania State University
- Purdue University
- Simon Fraser University
- Stanford University
- Syracuse University
- Texas A&M University
- Tulane University
- University at Buffalo
- University of Arizona
- University of California, Irvine
- University of California, Los Angeles
- University of California, Santa Barbara
- University of Chicago
- University of Cincinnati College of Medicine
- University of Houston
- University of Idaho
- University of Illinois, Chicago

- University of Maryland, Baltimore County
- University of Michigan
- University of Minnesota
- University of Missouri, Columbia
- University of North Carolina, Chapel Hill
- University of Tennessee
- University of Texas, Austin
- University of Utah
- University of Washington
- Vanderbilt University
- Virginia Polytechnic Institute and State University
- Wayne State University
- Wright State University

SURVEY DEMOGRAPHICS

The committee collected information on respondent position and rank, involvement in IDR, age, and institution type, size, and budget.

Position and Rank

Respondents were predominantly faculty researchers, administrators, or both.

	Convocation		Individual		Provost	
Position	n	%	n	%	n	%
Student	2	2.2	26	6.2	0	0
Postdoctoral scholar	0	0.0	18	4.3	0	0
Researcher/faculty	29	31.9	325	76.8	3	5.3
Administrator	26	28.6	5	1.2	12	21.1
Researcher/admin.	17	18.7	47	11.1	40	70.2
Funder	16	17.6	0	0	0	0
Other/not answered	1	1.1	2	0.5	2	3.5
Total	91	100.1	423	100	57	100.1

Respondents to the convocation and provost surveys predominantly held senior positions. The individual survey showed a wider array of ranks, but people holding senior-level positions outnumbered middle-level and junior positions by 2 to 1.

	Convocation		Individual		Provost	
Rank	n	%	n	%	n	%
Senior	64	70.3	194	45.9	52	91.2
Middle-level	17	18.7	113	26.7	1	1.8
Junior	6	6.6	105	24.8	2	3.5
Not answered	4	4.4	11	2.6	2	3.5
Total	91	100.0	423	100.0	57	100.0

Age Distribution

Overall, age distribution was fairly normal, with a mean of about 50 years.

	Convocation		Individual		Provost		Total	
Age	n	%	n	%	n	%	n	%
20-29	3	3.3	31	7.3	0		34	6.0
30-39	11	12.1	103	24.3	1	1.8	115	20.1
40-49	27	29.7	122	28.8	7	12.3	156	27.3
50-59	35	38.5	95	22.5	30	52.6	160	28.0
60-69	11	12.1	48	11.3	12	21.1	71	12.4
>70	3	3.3	6	1.4	0		9	1.6
Not answered	1	1.1	18	4.3	7	12.3	26	4.6
Total	91	100.1	423	99.9	57	100.1	571	100.0

Type of Institution

The majority of respondents were working at public academic institutions. About half as many worked at private academic institutions. (See Figure E-1.) Industry researchers, funders, and disciplinary-society representatives were targeted for participation only at the convocation and are not represented in the individual or provost survey populations.

	Convocation		Individual		Provost	
Type of Institution	n	%	n	%	n	%
Public academic	42	46.2	264	62.4	33	57.9
Private academic	15	16.5	122	28.8	17	29.8
Industrial R&D org.	2	2.2	3	0.7	0	
Government R&D org.	3	3.3	17	4.0	3	5.3
Indep. research inst.	3	3.3	9	2.1	1	1.8
Public funding inst.	9	9.9	8	1.9	0	
Private funding inst.	8	8.8	0		0	
Professional society	6	6.6	0		0	
Other/not answered	8	8.8	0		3	5.3
Total Surveys (Total[a])	91(96)	105.6	423	101.8	57	100.1

[a]Some respondents gave multiple answers to this question. Percent is calculated using the total number of surveys returned, and may add up to more than 100%.

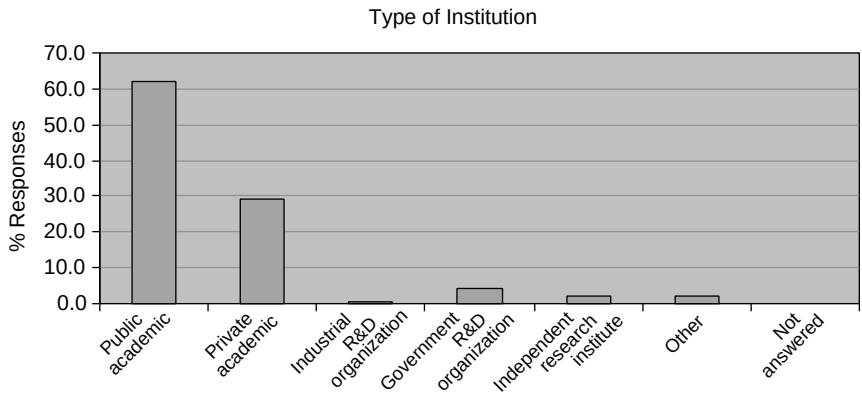

FIGURE E-1 Type of institutions responding.

Size, Budget, and Number of Researchers

Survey respondents were asked to indicate the annual budget of their institutions and the numbers of faculty, undergraduates, graduate students, and postdoctoral fellows (see Figure E-2). It appears that most respondents were working at large research institutions. Annual budgets showed a bimodal distribution, with peaks at $10 million–100 million and over $1 billion. At the same time, almost half the respondents indicated that they

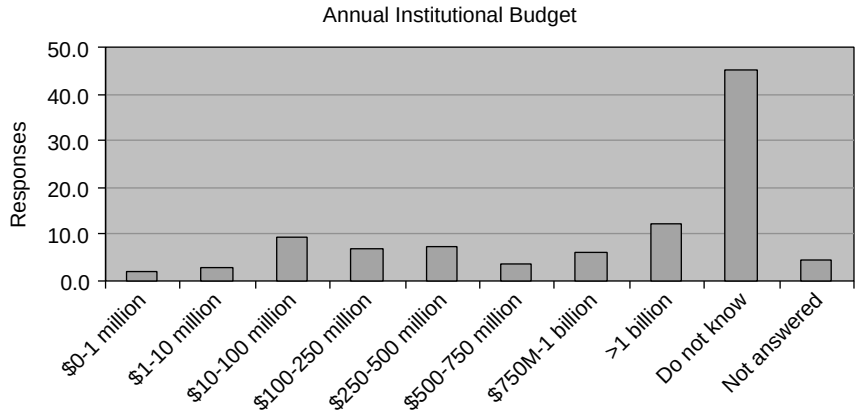

FIGURE E-2 Annual institutional budgets.

were not aware of their institutions' annual budget. Responses indicated that institutions tended to have over 500 faculty, 10,000 undergraduates, and over 2,500 graduate students (Figures E-3, E-4, and E-5). Most respondents did not know how many postdoctoral fellows were at their institutions (Figure E-6).

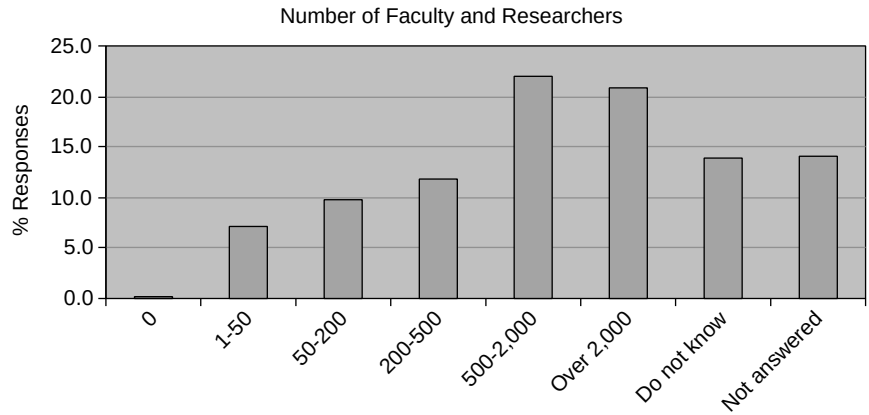

FIGURE E-3 Number of faculty and researchers at the respondents' institutions.

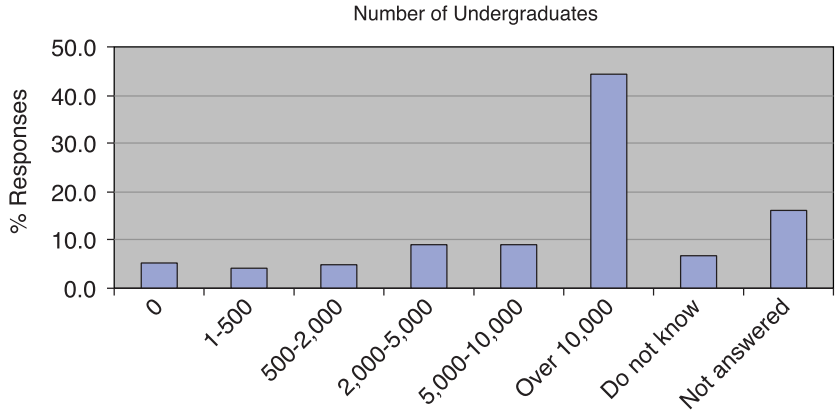

FIGURE E-4 Number of undergraduate students at the respondents' institutions.

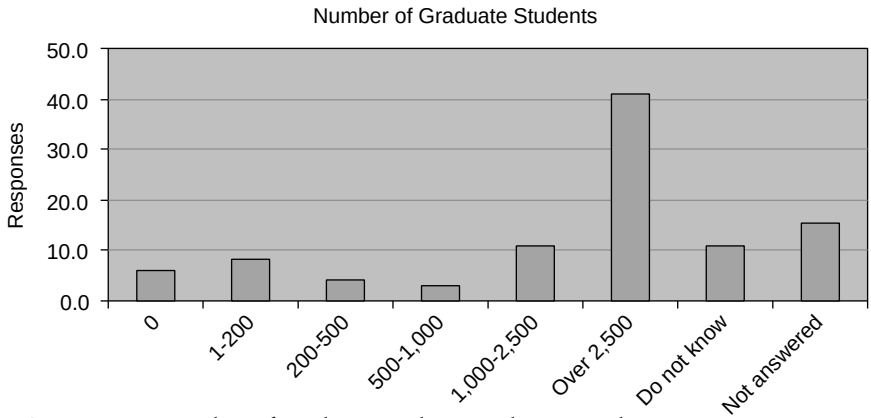

FIGURE E-5 Number of graduate students at the respondents' institutions.

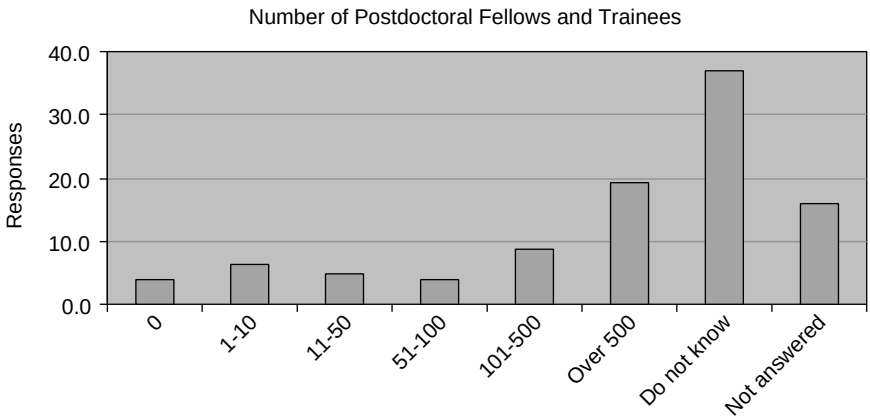

FIGURE E-6 Number of postdoctoral fellows and trainees at the respondents' institutions.

RELATIONSHIP TO INTERDISCIPLINARY RESEARCH

Participation in Interdisciplinary Research

In the combined surveys, 94 percent of respondents were at least partially involved in IDR.

	Convocation		Individual		Provost	
Participation	n	%	n	%	n	%
Primarily interdisciplinary	53	58.2	263	62.2	24	42.1
Partially interdisciplinary	28	30.8	147	34.8	22	38.6
Not interdisciplinary	0		12	2.8	4	7.0
Not answered	10	11.0	1	0.2	7	12.3
Total	100.0		433	102.4	57	100.0

Specific Roles

Respondents were asked to indicate how they were involved in IDR. This was a free-answer section; responses were analyzed and categorized by staff. Because more than one answer could have been provided, results may add up to more than 100 percent.

	Convocation		Individual		Provost	
Involvement in IDR	n	%	n	%	n	%
Oversee or support IDR programs	19	23.5	0	0	45	97.8
Fund IDR programs or grants	14	17.3	0	0		
Research is interdisciplinary	41	50.6	366	89.3	23	50.0
Collaborate with others in different disciplines	3	3.7	97	23.7	2	4.3
Head/director of IDR program	7	8.6	28	6.8	1	2.2
Involved with IDR training program or teach IDR classes	2	2.5	18	4.4	1	2.2
Editor of IDR journal	0	0.0	2	0.5	0	0
Other	8	9.9	8	2.0	0	0
Total involved in IDR	81		410		46	
Not interdisciplinary or not answered	10		13		11	

Ranking of Institutional Environment for IDR

Respondents were asked to rank the general supportiveness for IDR at their current institution and up to two previous institutions on a scale of 0 (IDR-hostile) to 10 (IDR-supportive). There appears to be a trend toward more supportive environments for IDR. It is possible that respondents moved to institutions that were more supportive during the course of their careers. Rankings are reported as mean +/– standard deviation. Not all respondents provided an answer. The total number of responses to this question was n = 480.

Environment for IDR	Convocation	Individual	Provost
Current institution	7.74 +/– 2.07	7.25 +/– 2.31	7.24 +/– 1.70
Previous institutions	5.95 +/– 2.17	6.35 +/– 2.57	5.67 +/– 2.04

To determine whether rank was associated with institution size or budget, we sorted the rankings by annual budget, number of faculty, and number of undergraduates (see Figures E-7 and E-8). There was no relationship between number of undergraduates and ranking, but there are some interesting trends for budget and number of faculty. It appears that smaller or larger institutions have a better environment for IDR than those with intermediate budget and faculty numbers.

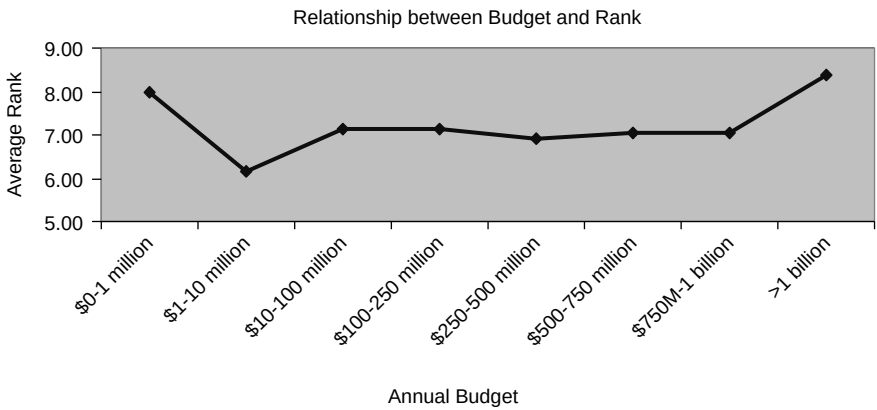

FIGURE E-7 Relationship between institutional budget and rank.

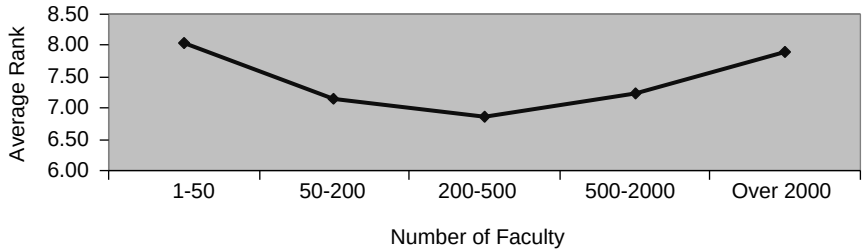

FIGURE E-8 Relationship between number of faculty and rank.

INTERDISCIPLINARY RESEARCH AT INSTITUTIONS

When asked whether there were impediments to IDR at their current institutions, 70.7 percent of the respondents answered yes, 23.2 percent answered no, and 6.2 percent did not know or did not answer (see Figure E-9).

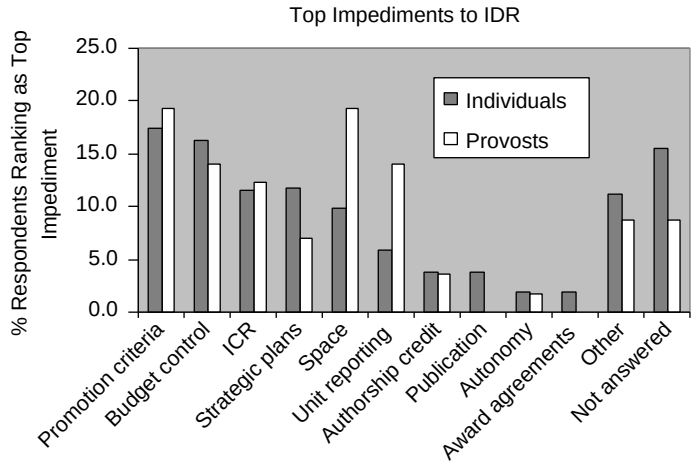

FIGURE E-9 Top impediments to interdisciplinary research at various institutions.

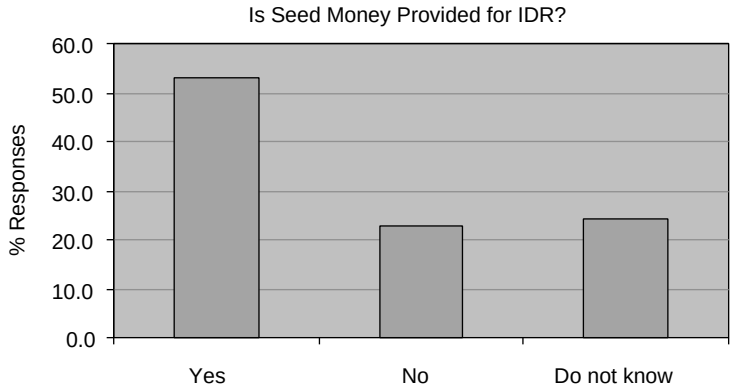

FIGURE E-10 Survey results as to whether seed money was provided for IDR.

Respondents were provided a list and asked to rank the top five impediments to IDR at their institutions (see Figure 4-5). The list[2] included budget control, indirect-cost recovery (ICR), publication in disciplinary and interdisciplinary journals, compatibility with college or department strategic plans, promotion and tenure criteria, credit for joint authorship, unit reporting relationships, space allocation, honoring award agreements, restrictions on faculty autonomy, and other. The chart indicates the percentage of respondents who gave an impediment top ranking. It is interesting to note that "individuals" and provosts ranked impediments differently. Furthermore, impediments often mentioned in research literature–authorship credit and publication–were among the lowest ranked by both respondent groups. The impediments that were most often ranked first by "individuals" were promotion criteria, budget control, ICR, and compatibility with strategic plans. For provosts, the top impediments were promotion criteria, space allocation, budget, and ICR.

Seed Money

Respondents were asked whether their institution provided seed money to help start up interdisciplinary programs and were asked to briefly describe the amounts available and the major criteria used in making awards. Over half the institutions provided such "venture capital" for interdisciplinary work. Amounts provided ranged from $1,000 to $1 million. Duration of awards also varied but tended to be short: 1- to 2-year grants (see Figures E-10, E-11, and E-12).

[2]Feller, I. "New Organizations, old culture. Strategy and Implementation of Interdisciplinary Programs." AAAS Annual Meeting Presentation. February 16, 2002.

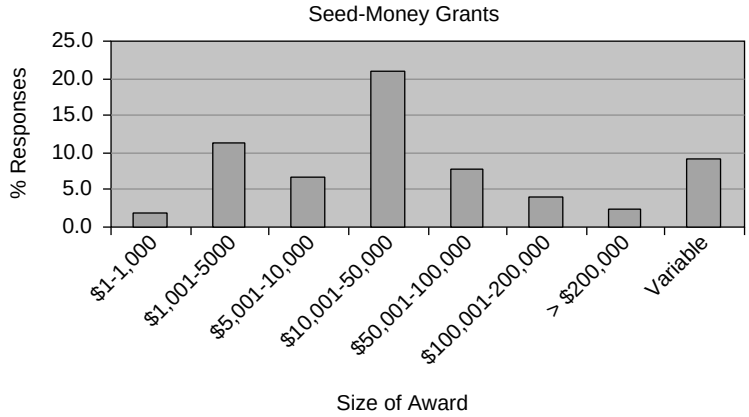

FIGURE E-11 Seed money grants and the size of the award.

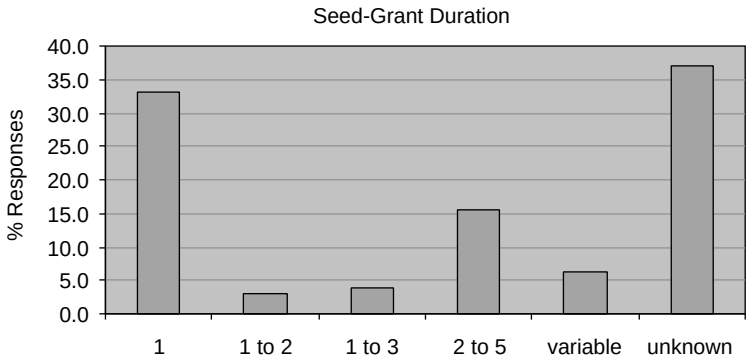

FIGURE E-12 Duration of the seed grant.

Three main criteria were cited by survey respondents for evaluating proposals for seed money:

1. What is the likelihood that this project or program, once developed, would generate outside funding? (21 percent)
2. What is the scientific merit of the work? (20 percent)
3. Is the work truly interdisciplinary? (20 percent)

"Other" responses (19.8 percent) ranged from selection-committee biases to university or department long-term strategic goals. Respondents often cited more than one criterion for determining seed-money allocation; therefore, the percentage of responses (based on the number of respondents) exceeds 100 percent (see Figure E-13).

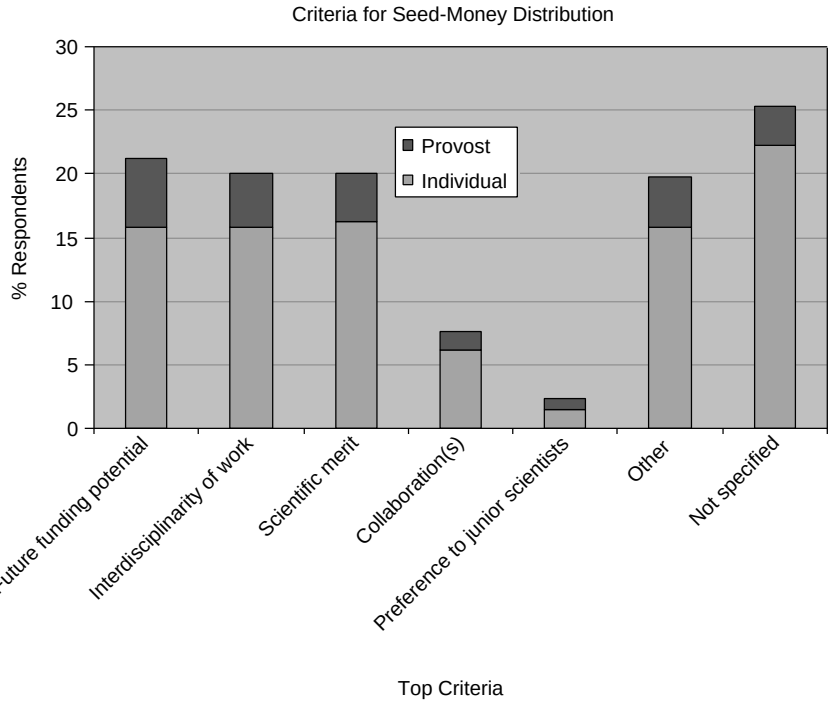

FIGURE E-13 Criteria for seed-money distribution.

Joint Appointments

When asked whether their institutions made joint appointments for interdisciplinary faculty or staff in which salary is shared, most respondents answered yes. However, in most cases, fewer than 10 percent of the faculty at the respondents' institutions held such joint positions.

	Individual		Provost	
Shared Salary for Joint Appointments?	n	%	n	%
Yes	249	58.9	42	73.7
No	85	20.1	12	21.0
Do not know	88	20.8	2	3.5
Not answered	1	0.2	1	1.8
Total	423	100.0	57	100.0

	Individual		Provost	
Proportion of Such Joint Appointments	n	%	n	%
0-10%	190	76.3	33	78.6
10-25%	24	9.6	7	16.7
Over 25%	6	2.4	1	2.4
Did not answer	29	11.6	1	2.4
Total (based on those who answered yes above)	249	100	42	100.1

Interdisciplinary Programs and Characteristics

Respondents were asked to list and describe up to three interdisciplinary programs at their institutions with which they were currently involved, including centers and teaching programs. They were asked to indicate the number and name of each involved department, whether extra-institutional groups were involved, the number of researchers, whether there were associated faculty lines or training slots, the sources of funding, whether there was a central facility for the program, and how space was allocated. Over 800 programs were described, and this yielded rich data for anyone interested in examining the current organizational structure of IDR programs and centers. Among the findings, respondents indicated that 29.5 percent of the centers and programs did have faculty lines, whereas 33.3 percent did not; 12.3 percent stated that faculty lines did not apply to the program listed, and 24.7 did not know or did not provide an answer. The percentage of associated training slots was higher: 40.9 percent of programs listed had such slots, 23.1 percent did not.

EVALUATION OF INTERDISCIPLINARY RESEARCH PROGRAMS

Respondents were asked to describe dominant forms of evaluation used by their institutions to evaluate interdisciplinary programs. The predominant methods of evaluation were internal and external visiting committees and informal feedback. Percentages add up to more than 100 because respondents could choose more than one answer.

	Individual		Provost	
Institutional Evaluation Methods	n	%	n	%
Internal committee	148	35.0	38	66.7
Visiting committee	130	30.7	46	80.7
Informal feedback	122	28.8	30	52.6
Principal-investigator assessment	113	26.7	24	42.1
Interviews	25	5.9	7	12.3
Benchmarking surveys	20	4.7	10	17.5
Do not know	155	36.6	1	1.8
Other	24	5.7	6	10.5
Not answered	35	8.3	3	5.3
Total answers	423		57	

Respondents were also asked to report the top three methods that they used to evaluate the success of interdisciplinary programs. Respondents were provided a list and the opportunity to enter other options. The predominant IDR evaluation methods varied between individual researchers and provosts. For both groups, the top two choices were potential for innovation and increasing institutional funding. Provosts ranked enhancing the reputation of their institutions third, and individual researchers ranked enhancing student experiences third.

	Individual		Provost	
Personal Evaluation Methods	n	%	n	%
Level of (or potential for) scientific discovery or innovation	239	56.5	46	80.7
Increasing institution's research funding	156	36.9	33	57.9
Enhancing richness of undergraduate or graduate experience	150	35.5	22	38.6
Enhancing institution's reputation	132	31.2	25	43.9
Increasing ability to attract outstanding faculty or postdoctoral scholars	123	29.1	28	49.1
Societal relevance of problem being addressed	97	22.9	15	26.3
Quality of leadership	95	22.5	25	43.9
Attracting greater number or mix or caliber of undergraduates into science	87	20.6	7	12.3
Do not know	59	13.9	2	3.5
Other	26	6.1	7	12.3
Not answered	32	7.6	1	1.8
Total number of surveys	423		57	

PROPOSED RECOMMENDATIONS

Finally, respondents were asked to list one action that each stakeholder group could take to best facilitate IDR. Responses were categorized and are illustrated below in graphs for institutions, units and departments, funders, journal editors, principal investigators and team leaders, educators, postdoctoral scholars, and students. These were free-response questions; staff analyzed and categorized the responses. Percentages are based on the numbers of responses provided for each category.

The top three recommendations for institutions (n = 341) were to foster a collaborative environment (26.5 percent), to provide faculty incentives (including hiring and tenure policies) that reflect and reward involvement in IDR (18.4 percent), and to provide seed money for IDR projects (11.1 percent). See Figure E-14.

The top three recommendations for departments (n = 294) were to adopt new organizational approaches to IDR (32.1 percent), to recognize and reward faculty and other researchers for interdisciplinary work (20.8 percent), and to adapt or increase departmental resources to support IDR (12.3 percent). See Figure E-15.

The top three recommendations for funding agencies (n = 266) were to provide more support for IDR (39.1 percent), to develop and implement a more effective review process for IDR proposals (17.7 percent), and to rethink funding allocation strategies (11.3 percent). See Figure E-16.

The top two recommendations for journal editors (n = 196) were to adjust the expertise of editorial and review panels and incorporate more reviewers with IDR experience (38.8 percent) and to feature novel innovations and initiatives (36.2 percent); 17.3 percent of respondents reported that they were satisfied with the current situation. See Figure E-17.

The top three recommendations for principal investigators (n = 186) were to increase leadership and team-forming activities (44.1 percent), to develop and clearly state their research goals and their overall vision (34.4 percent), and to build networks with researchers in other disciplines (20.4 percent). See Figure E-18.

Respondents (n = 190) recommended that educators develop curricula that incorporate interdisciplinary concepts (64.7 percent), take part in teacher-development courses on interdisciplinary topics (40 percent), and provide student opportunities in IDR (23.7 percent). See Figure E-19.

Respondents (n = 157) encouraged postdoctoral scholars to get a broad background and learn new skills (14.0 percent), to find a postdoctoral fellowship in a field different from their own graduate work (12.7 percent), and to develop collaborations and seek additional mentors (12.1 percent). See Figure E-20.

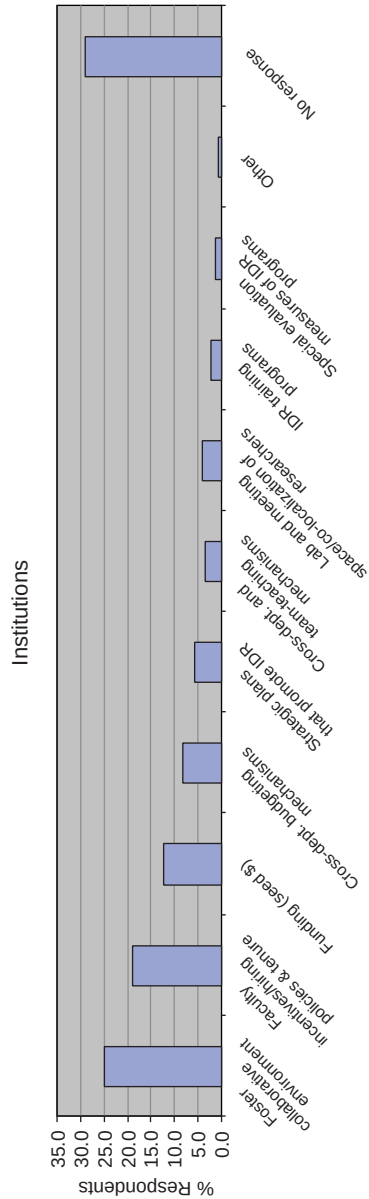

FIGURE E-14 Institutional recommendations to best facilitate IDR.

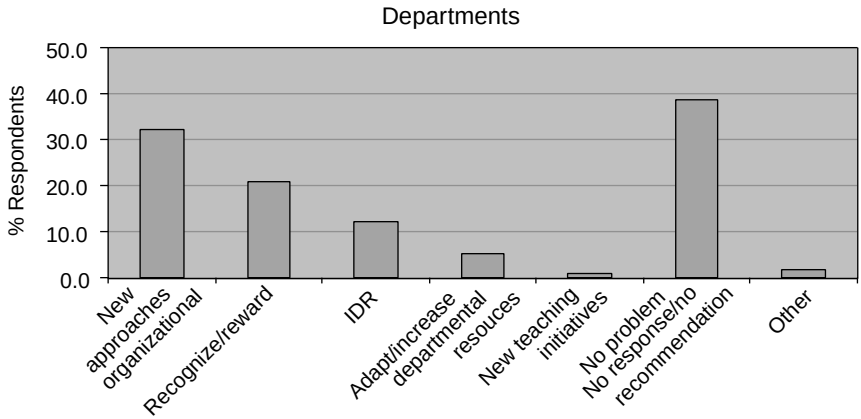

FIGURE E-15 Departmental recommendations for adapting approaches to IDR.

Finally, respondents (n = 171) recommended that students cross boundaries between disciplines (25.1 percent), take a broad range of courses (23.4 percent), but also develop a solid background in one discipline (12.3 percent). See Figure E-21.

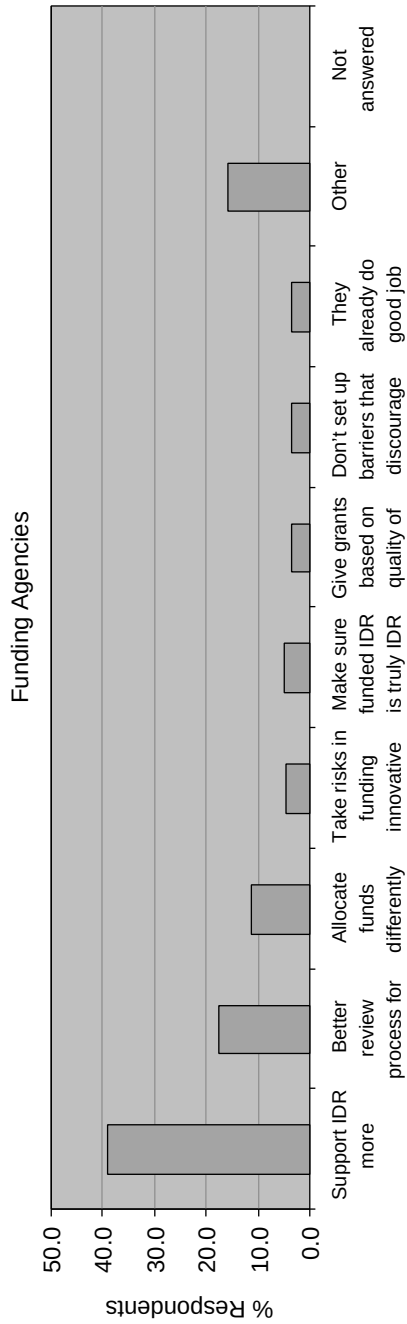

FIGURE E-16 Recommendations for funding agencies to provide more support to IDR.

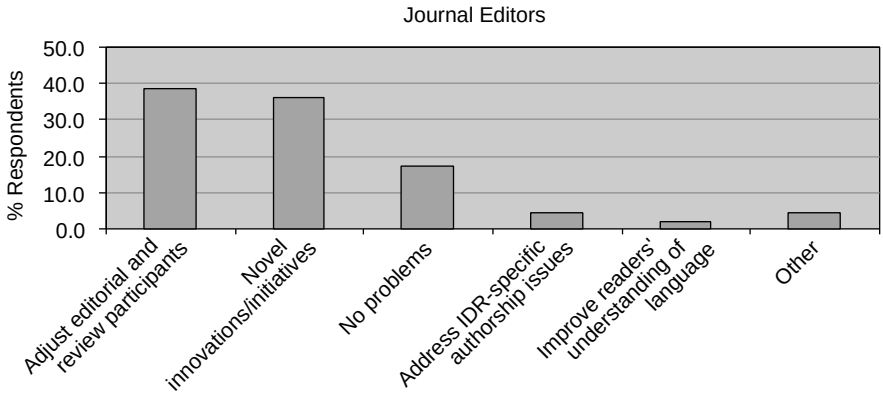

FIGURE E-17 Recommendations for journal editors.

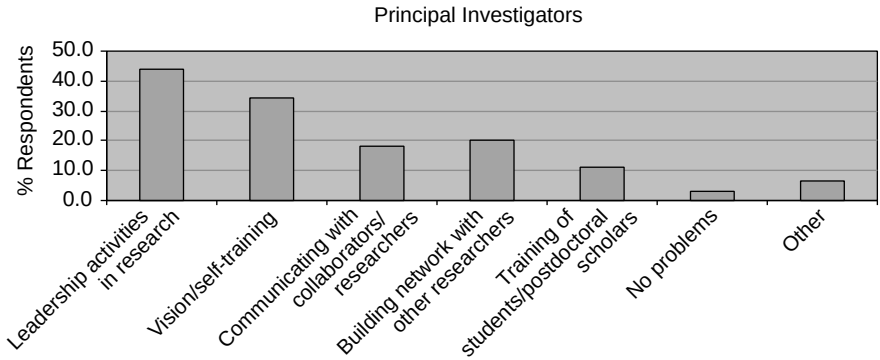

FIGURE E-18 Recommendations for principal investigators.

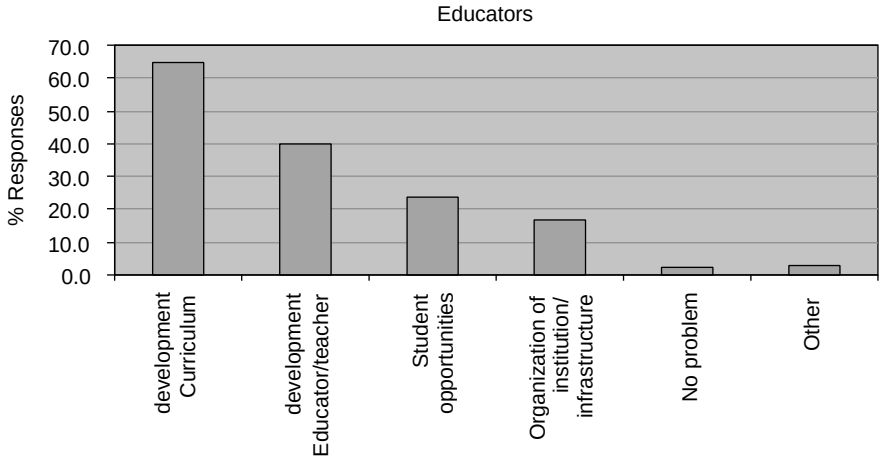

FIGURE E-19 Recommendations for educators.

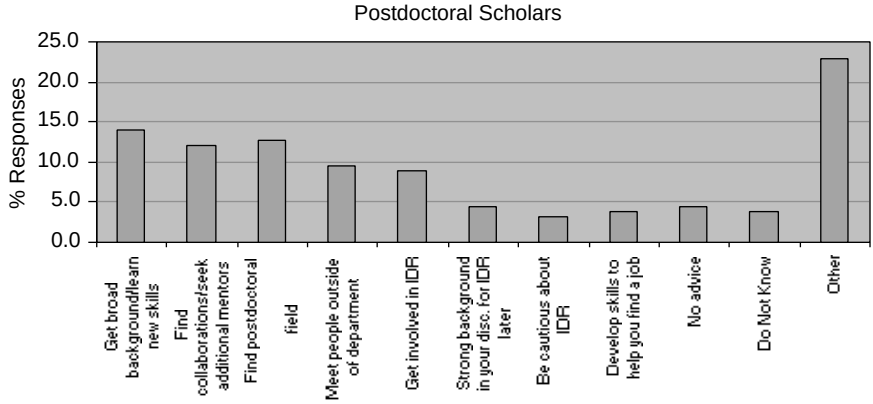

FIGURE E-20 Recommendations for postdoctoral scholars.

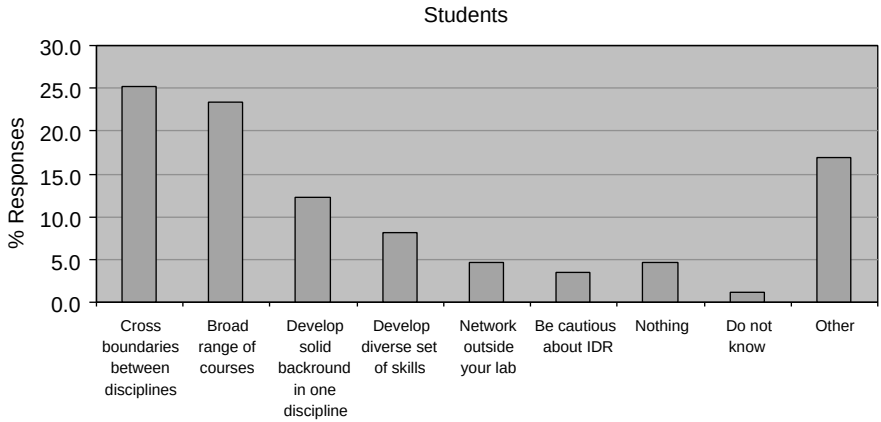

FIGURE E-21 Recommendations for students.

THE "INDIVIDUAL" IDR SURVEY

Demographics

1. Please tell us about yourself:
   - __ Researcher/faculty member
   - __ Administrator
   - __ Student
   - __ Postdoc

   Rank:
   - __ Senior
   - __ Mid-level
   - __ Junior

   Age: _____

   Describe your research:
   - __ Primarily interdisciplinary
   - __ Partially interdisciplinary
   - __ Not interdisciplinary

2. Which of these best describes your institution?
   - a. __ Public Academic
   - b. __ Private Academic
   - c. __ Industrial R&D organization
   - d. __ Government R&D organization
   - e. __ Independent research institute
   - f. __ Other (Please describe): _____

3. What is the size of your institution?

   a. Annual budget:

__ $0-1 Million	__ $100-250 M	__ $750 M-1 Billion
__ $1-10 M	__ $250-500 M	__ >$1 B
__$10-100 M	__$500-750 M	__Do Not Know

   b. If research institution, number of:

Faculty/ Researchers	0	1-50	50-200	200-500	500-2000	Over 2000	Do Not Know
Undergraduates	0	1-500	500-2000	2000-5000	5000-10,000	Over 10,000	Do Not Know
Graduate Students	0	1-200	200-500	500-1000	1000-2500	Over 2500	Do Not Know
Postdoctoral Researchers, Fellows, and Trainees	0	1-10	11-50	51-100	101-500	Over 500	Do Not Know

Relationship to Interdisciplinary Research

4. How are you involved with interdisciplinary research?

5. Based on your personal experiences, rate your present institution and prior institutions (that you feel able to judge) on general supportiveness of interdisciplinary research (IDR) using a scale from 0 (IDR-hostile) to 10 (IDR-friendly):

Current institution
name: _____
rating: 0 1 2 3 4 5 6 7 8 9 10
(hostile) (very supportive)

Previous institution
name: _____
rating: 0 1 2 3 4 5 6 7 8 9 10
(hostile) (very supportive)

Previous institution
name: _____
rating: 0 1 2 3 4 5 6 7 8 9 10
(hostile) (very supportive)

Interdisciplinary Research at Your Institution

6. Are there impediments to interdisciplinary research at your institution?

Yes _____ No _____ Do Not Know _____

If yes, please indicate the top 5 impediments in order of importance.

__ Budget control
__ Indirect cost recovery distribution
__ Publication in disciplinary/interdisciplinary journals
__ Compatibility with college/dept strategic plans
__ Promotion and tenure criteria
__ Credit for joint authorship
__ Unit reporting relationships
__ Space
__ Honoring award agreements
__ Restrictions on faculty autonomy
__ Other_____

7. Does your institution provide seed money to help start up interdisciplinary programs? If yes, please briefly describe the amounts available and major criteria employed in making awards.

Yes _____ No _____ Do Not Know _____

If yes, please indicate:
Amount:
Duration:
Award Criteria:

8. Does your institution make joint appointments for interdisciplinary faculty/staff members in which salary support is shared between departments, units, and/or schools?

Yes _____ No _____ Do Not Know _____

If yes, what proportion of the faculty/staff have such joint appointments?

__0-10% __10-25% __Over 25%

9. Using the table below, please list and describe up to three interdisciplinary program(s) at your institution with which you are currently involved. These programs could be centers, organized research units (ORUs), teaching programs, etc.

	A	B	C
Program/Center Name:			
URL:			
Contact person:			
Phone #/e-mail:			
i. Number of involved depts/ schools/colleges	__ 1 __Don't know __ 2-4 __ 5-10 __ Over 10	__ 1 __Don't know __ 2-4 __ 5-10 __ Over 10	__ 1 __Don't know __ 2-4 __ 5-10 __ Over 10
ii. List the primary depts. involved			
iii. Extra-institutional groups involved?	__ Yes __ No __ Don't know	__ Yes __ No __ Don't know	__ Yes __ No __ Don't know
iv. Number of Researchers	__1-5 __5-10 __10-20 __Over 20 __Don't know	__1-5 __5-10 __10-20 __Over 20 __Don't know	__1-5 __5-10 __10-20 __Over 20 __Don't know

	A	B	C
v. Faculty Lines?	__Yes __No __Don't know __Not applicable	__Yes __No __Don't know __Not applicable	__Yes __No __Don't know __Not applicable
vi. Source of Funding?	__ DoD __ DoE __ NASA __ NIH __ NSF __ Foundation: __ Institutional: __ Don't know __ Other:	__ DoD __ DoE __ NASA __ NIH __ NSF __ Foundation: __ Institutional: __ Don't know __ Other:	__ DoD __ DoE __ NASA __ NIH __ NSF __ Foundation: __ Institutional: __ Don't know __ Other:
vii. Central Facility?	__ Yes __ No __ Don't know	__ Yes __ No __ Don't know	__ Yes __ No __ Don't know
viii. Space Allocation	__ Project-driven __ Researcher-specific __ Don't know	__ Project-driven __ Researcher-specific __ Don't know	__ Project-driven __ Researcher-specific __ Don't know
ix. Training Slots?	__ Yes __ No __ Don't know	__ Yes __ No __ Don't know	__ Yes __ No __ Don't know

Evaluation of Interdisciplinary Research Programs

10. What are the dominant methods of evaluation employed by your institution to evaluate interdisciplinary programs? (check all that apply)

__ Visiting Committee
__ Internal Committee
__ Benchmarking Surveys
__ Interviews
__ Informal Feedback
__ Principal Investigator Assessment
__ Do not know
__ Other (Please describe):

11. What are the dominant methods you use to evaluate the success of interdisciplinary programs? (select up to three or add your own).

__ Level of (or potential for) scientific discovery or innovation
__ Quality of leadership
__ Attracting a greater number/mix/caliber of undergraduates into science
__ Enhancing the richness of the undergraduate/graduate experience
__ Increasing the ability to attract outstanding faculty/postdocs
__ Societal relevance of problem being addressed
__ Enhancing institution's reputation
__ Increasing institution's research funding levels
__ Do not know
__ Other (Please describe):

Proposed Recommendations

12. If you could recommend one action each of the following could take that would best facilitate interdisciplinary research, what action would that be?

a) Institutions:
b) Units/Departments:
c) Funding Agencies:
d) Journal Editors:
e) Principal Investigators/Team Leaders:
f) Educators:
g) Postdocs:
h) Students:

F

Committee Interviews with Administrators, Scholars, and Center Directors

Over the course of the study, staff supplemented available scholarship with interviews to gain information on the history of interdisciplinary research (IDR) and related scholarship. A primary goal was to collect information on policies, procedures, and effective practices for education programs, research management, and evaluation. Interviewees' names are listed in the order in which they were reached. In most cases, interviews were conducted by teleconference. The symbol * indicates an e-mail interview; the symbol # indicates an in-person meeting.

IDR HISTORY AND SCHOLARSHIP

Scholars and historians were queried for information on available literature resources and quantitative studies. There is a rich qualitative and philosophical literature on interdisciplinarity,[1] but quantitative studies are few. Much of the research on structural models of interdisciplinarity is based on case studies published in the late 1970s and early 1980s. It was during that period that the National Science Foundation, through its Office

[1]For a review of the literature see for example: Klein, J. T. *Interdisciplinarity: History, Theory, and Practice*. Detroit: Wayne State University Press. 1990; Lattuca, L. *Creativity Interdisciplinarity: Interdisciplinary Research and Teaching Among College and University Faculty*. Nashville: Vanderbilt University Press. 2001. Klein, J. T. "Prospectus for Transdisciplinarity." *Futures* 2004, 36:515-526; Rhoten, D. 2004. "Interdisciplinary Research: Trend or Transition." *Items and Issues* 5(1-2):6-11.

of Interdisciplinary Research, provided funding for international meetings on the organization of IDR.[2] Most quantitative research to date has examined interdisciplinarity by using citation-database analysis.[3]

We contacted

- *Margaret Somerville, Samuel Gale Professor of Law and Professor of Medicine, McGill Center for Medicine, Ethics, and Law, McGill University
- *Julie Thompson Klein, professor of humanities, Wayne State University

IDR PROGRAMS AND CENTERS

IDR program and center directors were asked to discuss their experience in IDR, evaluating prospective researchers, accessing funding, facilitating IDR, determining research goals and duration, evaluating the success of the research team, and publishing research results. We also asked for examples of models and effective practices.

From those discussions, a few themes emerged: leadership, institutional support, and departmental buy-in. To create a successful academic interdisciplinary center or program required a visionary leader. In addition to being persistent and persuasive, the leader had to have sufficient stature in the institution and in a research field and the support of the university president or provost. The leader had to coordinate her/his vision with relevant institutional departments; in effect, the leader needed to develop partnerships and sell participation in the program or center. The leader had to successfully negotiate shared costs, faculty hires, space allocation, and funding. Finally, the leader had to recruit and sustain faculty and student participation.

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[2]See *Managing High Technology: An Interdisciplinary Perspective*. Eds. Mar, B.W., Newell, W.T., and Saxberg, B.O. Elsevier: New York. 1985. This volume is based on papers from the Third International Conference on Interdisciplinary Research, Seattle, Washington, U.S.A., 1-3 August, 1984.

[3]Baumann, H. 2003. Publish and Perish? The impact of citation indexing on the development of new fields of environmental research. *Journal of Industrial Ecology* 6, 3-4:13-26; Chubin, D. E., Porter, A. L., and Rossini, F. A. 1984. "Citation Classics" Analysis: An Approach to Characterizing Interdisciplinary Research. *Journal of the American Society for Information Science* 35, 6:360-368; McCain, K. W. and Whitney, P. J. 1994. Contrasting Assessments of Interdisciplinarity in Emerging Specialties: The Case of Neural Networks Research. *Knowledge: Creation, Diffusion, Utilization* 15, 3:285-306; Steele, T. W. and Stier, J. C. 2000. The Impact of Interdisciplinary Research in the Environmental Sciences: A Forestry Case Study. *Journal of the American Society for Information Science* 51, 5:476-84.

We contacted

- James McClelland, director, Center for the Neural Basis of Cognition, Carnegie Mellon University, *http://www.cnbc.cmu.edu/*
- Frances Leslie, director, Transdisciplinary Tobacco Use Research Center, University of California, Irvine, *http://www.tturc.uci.edu/*
- Jim LeBaugh, Water Resources Division, United States Geological Survey, and participant, Shingobee Headwaters Aquatic Ecosystems Project (SHAEP), *http://wwwbrr.cr.usgs.gov/projects/IRI/*
- C. Channa Reddy, director, Huck Institute for Life Sciences, Pennsylvania State University, *http://www.lsc.psu.edu/*
- Michael Merson, director, Center for International Research on AIDS, Yale University, *http://cira.med.yale.edu*
- *John Ballato, director, Center for Optical Materials and Science and Engineering Technologies (COMSET), Clemson University, Carolinas Optics Center, *http://www.ces.clemson.edu/comset/*

INTERDISCIPLINARY EDUCATION PROGRAMS

Education-program directors were asked to provide an overview of their interdisciplinary programs, the impetus for establishing them, their goals and duration, evaluation criteria for the competition, and information on where the programs have been implemented. We asked how an education program encouraged the development of interdisciplinary curricula and pedagogic tools. Finally, we asked for examples of models and effective practices and for suggestions of additional contacts.

Among the themes that emerged were a concern that science and engineering programs were in general not appealing to undergraduates and that undergraduate and graduate programs do not sufficiently prepare students for careers in industry. Interdisciplinary problem-based approaches to learning were seen as a way to encourage more students to take science classes and to prepare students for a variety of careers.

We contacted

- Gerry Wheeler, executive director, National Science Teachers Association, Re: ExploraVision, *http://www.exploravision.org/*
- #Wyn Jennings, director, IGERT Program, Division of Graduate Education, National Science Foundation, *http://www.nsf.gov/home/crssprgm/igert/start.htm*
- Ed Miles, former chair, Task Force on Environmental Education, and professor, School of Marine Affairs, Graduate School of Public Affairs, University of Washington, *http://depts.washington.edu/poeweb/*

IDR EVALUATION

Evaluation scholars were asked to share IDR evaluation tools and case studies with the committee relevant to IDR and program evaluation, promotion and tenure, budget models, and education and career development. In most cases, IDR evaluation tools were in development and unavailable. Social-networks analysis was often cited as an evaluation concept that had been used successfully to evaluate IDR. But scholars were quick to point out that this analysis, while providing a measure of interconnectedness and interdisciplinarity, did not necessarily measure research quality and impact. There was agreement that more work was needed to develop specific criteria and measures for IDR.

We contacted

- #Irwin Feller, professor emeritus of economics, Pennsylvania State University
- Diana Rhoten, Helen Doyle, and Denise Caruso, Hybrid Vigor Institute, *http://www.hybridvigor.org/*
- Barry Bozeman, Regents' Professor of Public Policy, Georgia Institute of Technology
- Ed Hackett, professor, Department of Sociology, Arizona State University
- Marye Anne Carroll, director, Biosphere-Atmosphere Research and Training (BART), University of Michigan; and Kristin Kusmierek, BART IGERT program evaluator, *http://www.bart-wmich.org/*

IDR POLICIES

Policy makers and research administrators were asked for information on policies and procedures to facilitate IDR. We asked those at academic institutions to discuss their experience in promoting interdisciplinary initiatives. We asked research administrators to share their experiences and policies for evaluating prospective interdisciplinary researchers, accessing funding to support interdisciplinary projects, hiring interdisciplinary faculty, and facilitating IDR. For example, we asked whether faculty teaching time was shared between departments, how space for projects involving faculty from multiple departments was allocated, and whether faculty hires were made collaboratively between departments. We also inquired about how research project and program goals and duration were determined. For example, we asked how the success of interdisciplinary projects was evaluated and whether publication of research results was a key component in that evaluation. Finally, we asked for examples of models and best practices.

In this category, a general theme was flexibility. Specific solutions need to be tailor-made to fit institutional context, but there are examples of effective policies and organizational structures. Administrators suggested meshing vertical departmental structures with horizontal, cross-cutting programmatic themes. A discretionary fund, or seed money, controlled by the provost was critical for promoting and supporting cross-cutting initiatives. Specific guidelines for promotion and tenure that accounted for interdisciplinary scholarship had been enacted. Team teaching was encouraged, and in many cases credit hours were counted by all the involved departments. Still, administrators concurred that more needed to be done to provide for cost-sharing between departments and between institutions, especially at the grant level. Some concern was expressed about national evaluation of IDR programs and centers, many of which exist outside standard institutional structures.

We contacted

- National Science and Technology Council Subcommittee on Research Business Models, Committee on Science, Office of Science and Technology Policy
- June Howard, associate dean for interdisciplinary initiatives, University of Michigan
- Cornelius Sullivan, vice provost for research, University of Southern California
- Maria Pallavicini, professor and dean, School of Natural Sciences, University of California, Merced

IDR IN INDUSTRY AND NATIONAL LABORATORIES

Directors and researchers were asked about the importance of IDR in industry and national labs. Specifically, what actions were taken to facilitate IDR? How were people organized to work together on IDR problems? What are examples of where IDR worked and where it did not work? Has the role of IDR teams evolved? And finally, what lessons can national labs provide to academia as to how to best facilitate IDR? The results of these interviews are summarized and presented in Chapter 3.

We contacted:

- #John Armstrong, vice president, Science and Technology, IBM (ret.)
- *Norm Burkhard, division leader, Energy and Environment Directorate, Lawrence Livermore National Laboratory
- *Michael Crow, president, Arizona State University

- Bernard S. Meyerson, IBM Fellow, VP and Chief Technologist, IBM Systems and Technology Group
- Edward C. Stone, David Morrisroe Professor of Physics; Vice Provost for Special Projects; former Vice President and Director of the Jet Propulsion Laboratory (1991-2001).
- *Tom Wilbanks, chair, Corporate Fellows Council, Oak Ridge National Laboratory

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Focus Groups on Facilitating Interdisciplinary Research

NATIONAL ACADEMIES
KECK FUTURES INITIATIVE CONFERENCE

Signals, Decision, and Meaning in Biology, Chemistry, Physics, and Engineering

Irvine, California
November 15, 2003

The National Academies Keck *Futures Initiative* Conference brings together over 100 of the nation's best and brightest researchers from academic, industrial, and government laboratories to ask questions about—and to discover interdisciplinary connections between—important areas of cutting-edge research.

At the first Keck *Futures* meeting in November 2003, the Committee on Facilitating Interdisciplinary Research hosted three focus groups to brainstorm policies and practices that funding organizations, educators, academic administrators, researchers, and students could implement to overcome barriers to interdisciplinary research (IDR). The focus was on the role that policies and practices related to training, education, evaluation, teambuilding, funding, hiring, and employment could play in facilitating IDR. The committee was especially interested in learning about effective programs and policies; to this end, the moderator was encouraged to steer

discussion from that of barriers to one of suggestions and solutions. The data gathered from the focus groups were used to help the committee to develop findings and recommendations. It is important to keep in mind in reviewing these comments that this group is made up entirely of those interested in IDR.

FOCUS-GROUP QUESTIONS

The following discussion questions were provided to each moderator for discussion.

Training and Education

Should undergraduate students be encouraged to pursue an interdisciplinary degree? What policies can institutions adopt that would facilitate team teaching, curricular development, and cross-departmental course offerings? What programs and/or policies would be most effective at facilitating interdisciplinary training of graduate students and postdoctoral scholars?

Hiring and Employment

What can institutions do to facilitate hiring and review of interdisciplinary faculty? Are joint appointments a good idea? Are multi-departmental review panels effective? Should outside experts be appointed to review panels for interdisciplinary tenure candidates? What strategies can an interdisciplinary tenure-track researcher employ to enhance the review process? What can faculty and departments do to enhance the process?

Evaluation

What are effective criteria for evaluating interdisciplinary papers? Interdisciplinary researchers? Interdisciplinary programs? What can investigators, institutions, and funding agencies do to enhance the review/evaluation procedure? Does interdisciplinary research require different or additional criteria for evaluation than disciplinary research?

Establishing a Team

What programs and policies can institutions and funding agencies adopt to facilitate collaboration between disciplines? Are seed grants effective? Are meetings effective? What are the critical aspects of team formation?

Funding

What are the most effective funding strategies for facilitating IDR? Should funders focus on research grants in emerging areas, seed grants for teams, infrastructure development, training and education, and/or internal polices and procedures to facilitate submission and review of interdisciplinary proposals (e.g., panel review, site visits, etc.)? Are there polices that federal agencies or institutions could adopt that would facilitate IDR, such as budgeting structures, cost-sharing, allowing for co-PIs, etc.?

FOCUS-GROUP FORMAT

The moderators were Bruce Alberts, Bill Wulf, and Harvey Fineberg, presidents of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine, respectively. Each focus group consisted of about 20 researchers in many fields. The results of those discussions follow this summary. Each used a different discussion technique, and the results reflect that.

SUMMARY OF FOCUS GROUP A DISCUSSION

(MODERATOR, HARVEY FINEBERG,
PRESIDENT, INSTITUTE OF MEDICINE)

Definition

Scale and scope: A researcher in biomolecular systems at Pacific Northwest National Laboratory suggested that "what drives IDR is the scale and scope of the problem." He said that a truly interdisciplinary problem would require five to 10 investigators; for biologic systems, it would involve not only biologists, but also mathematicians, instrument builders, and others. "As long as funding agencies say they want to solve large problems, we'll see communities come together" to do so.

Models

Promoting collaboration: A professor of chemistry and neurosciences at the University of Illinois Beckman Institute noted that "it's a physical space, with no funding, and people from many labs." They share space and equipment. Each participant does not do disciplinary work but builds on it and is encouraged to ask for collaboration. The Institute "formalizes the idea that you'll work with someone else." Faculty can apply for a semester's training in another discipline, as long as their faculty head signs off on it.

Beyond departments: In 2005, when the University of California, Merced, opens its campus, its School of Natural Sciences will have no departments and will integrate science and engineering. The dean of the new school said that it had made a commitment to hire faculty with excellence in a particular discipline to avoid the "risk of being shallow across whatever you do". One challenge she noted was that the 15 faculty who had already been recruited tended to interview faculty applicants according to criteria of excellence that differed between disciplines. "Until we get that it will be hard to be successful, especially at the junior level."

Crossing theoretical disciplines: A scientist at the Salk Institute praised the Sloan Foundation's program in theoretical neurobiology, which brings young theoreticians from the physical, mathematical, and computer sciences into neurobiology at five university-based research centers. Some have gone on to start their own laboratories he said, although faculties sometimes blocked cross-disciplinary hiring recommended by "visionary" search committees.

Policies and Procedures

Tenure as an obstacle: A professor in the Massachusetts Institute of Technology Program in Science, Technology, and Society said that the largest obstacle to IDR in universities has been tenure. When one is a postdoctoral scholar or an assistant professor, she said, it is risky to work outside one's own department. She applauded the initiative of the Harvard Medical School in founding its new Department of Systems Biology, which is inherently interdisciplinary.

Beyond departments: A professor in the Harvard Medical School Department of Biological Chemistry and Molecular Pharmacology said, "I think universities could get rid of departments." She admitted that her view came out of her work in cancer research, which is highly interdisciplinary.

Three effective procedures: A professor in the Harvard Department of Physics and Applied Physics recommended three procedures that he had found effective in promoting interdisciplinary work:

- 24-hour retreats on campus for groups of faculty. He described a successful retreat on neurosciences, in which faculty established personal connections and talked about long-term interests in ways that they could not easily do in the midst of busy schedules.
- Working in other departments and experiencing related or relevant fields.
- Getting some seed money from the university (for example, the dean's fund) for a postdoctoral or graduate student who would like to work in different fields.

Teaching in mixed groups: A biology professor who works in biomedical research in a Canadian Organized Research Unit noted the risk of teaching biology to computer-science students because of the difficulty of communication. He had found that a computer scientist might say he was going to do one thing and a biologist something else, and it could turn out that they intended to do the same thing. For a biologist, however, the risk was necessary to model biologic systems. "Certainly, computer-science students are fascinated by questions in biology. You need to take that step and go out and teach in mixed groups and learn their language."

Policies at state universities: The Texas A&M Department of Chemical Engineering and Chemistry had found it possible to share National Institute of Health (NIH) grants "so that everyone gets something." When the university budgets were cut by the state, however, principal investigators (PIs) had to show the revenue generated by their own research to maintain their share of state funding, and the sharing mechanism was in jeopardy.

Promoting communication: A Salk Institute investigator saw communication as a key, especially better communication between funding committee members of different backgrounds and better communication of the intellectual content of one's own work.

Training and Education

Following one's curiosity: Entelos,[1] a private firm working in computer modeling of diseases, needs both mathematicians and engineers for its interdisciplinary work. It prefers to hire "a great person rather than someone who's already been trained in two disciplines." The chief scientist referred to her own experience as a graduate student, when she and her colleagues first attained a solid grounding in their field and then benefited by following their curiosity to work on problems in other departments.

"Excellence at the interface": In training young IDR investigators, a member of the Pharmacology Department of the University of Texas argued in favor of "finding individuals who have more than one discipline in one brain, to make that creative stuff happen." People who are excellent in one discipline, he said, may not make good collaborators. The ideal scenario is to "create that depth in individuals at the interface. Students brought up in that ethic and studying at the interface learn how to be good in more than one thing."

[1]Entelos is a firm that develops large-scale computer models of human disease using a patented PhysioLab technology. In partnership with biotechnology and pharmaceutical companies, it seeks to speed development of new treatments for such diseases as asthma, obesity, and diabetes.

Planning IDR from scratch: In planning of curricula for the new School of Natural Sciences of the University of California, Merced, two challenges had arisen: (1) faculty did not want to "give up any content in their courses" and (2) planning an interdisciplinary undergraduate curriculum turned out to be harder than planning an interdisciplinary graduate curriculum because faculty felt a need to cover the basics first.

Inviting students to initiate research: The norm is for a PI to recruit graduate students on the basis of a project whose goals have been determined. In that system, students often feel like hired hands working for someone else. A Harvard professor argued for the reverse: Challenge graduate students, who may be more up to date than their professors, to design their own research projects and win the support of PIs and laboratories.

Flinging graduate students through the "gates of Hell": A professor at Thomas Jefferson University argued in favor of exposing engineers to biologic problems by putting them through biology courses at the same level as medical students. They would collect their own data and gain a realistic view of gathering data. "Then they become the 'glue people' that you need in multidisciplinary groups." Several people voiced strong agreement with that proposal.

SUMMARY OF FOCUS GROUP B DISCUSSION

(MODERATOR, BILL WULF, PRESIDENT,
NATIONAL ACADEMY OF ENGINEERING)

The focus group started with the premise that there are six targets for which specific short- and long-range goals could be set to foster IDR: education, culture, hiring and employment, publication, evaluation, and funding. The goals are listed below by target.

Some of the proposed goals are seemingly straightforward and could be implemented at the individual, department, or institution level with little financial or logistical difficulty. For example, cross listing graduate-school classes across departments or writing abstracts for a more general scientific audience would take little effort and may reap large rewards. Others would require more long-range strategic planning, such as adjusting the National Science Foundation (NSF) Research Experience for Undergraduates (REU) program to contain more mentors so that the undergraduate students would have a broader exposure to cross-discipline projects.

Education

- Cross-list all graduate-school courses in all departments.
- Allow greater freedom with respect to electives in graduate school.

- Offer more classes that have no prerequisites.
- Foster joint-degree programs.
- Create a buddy system—for example, with a graduate student in biology matched with one in mathematics. Promote informal lunch meetings between them. Make them explain their work to each other.
- The summer NSF REU program should require two mentors, not just one.
- Mandate industrial internships before granting the PhD. Industry is intrinsically more interdisciplinary than academe.

Culture

- The only thing that will really foster change is years of lunches shared by disparate groups.
- It is not the faculty who are in the best position to spur IDR, but rather the "lab rat" who is actually doing experiments.
- Mimic the 1993 "Grand Challenge" by having a central entity define long-term unresolved problems and issue them as challenges.
- Co-locate departments; don't allow physical space to constitute a barrier between departments (for example, biochemistry on one floor, microbiology on the next, comparative biology on the next).
- Establish postdoctoral salary parity across fields (physical-science postdoctoral scholars are paid much more than biology postdoctoral scholars).
- Encourage graduate students to switch departments when doing postdoctoral work.

Hiring and Employment

- Create incentives for departments to create and fill interdisciplinary positions (along the lines of affirmative action).
- Highlight the availability of people with interdisciplinary skills (such as people who run core facilities).

Publication

- Do not promote new journals that are classified as being in single disciplines. Submit papers only to interdisciplinary journals.
- Promote and fund databases that cover multiple journals in many fields. (For example, the National Library of Medicine searches almost no mathematical fields.) We are in an article-based, not a journal-based, publication environment.
- Require that abstracts be written for a more general audience.

Evaluation (for promotion and in peer review)

- Reward at the institutional level.
- Make sure that departments do not hold up promotion of cross-department faculty. (Sometimes an institution has to intervene or simply make promotion and tenure decisions only at the institution level.)
- Document evaluation norms by discipline. For example, in physics, conference proceedings are much more prestigious than publications; in biology it is the opposite.
- Reward people for publishing in a variety of journals, as opposed to only journals with high impact factors—for example, two articles in journals sponsored by very different professional societies (such as the Society for Neuroscience and the American Physical Society).

Funding

- Promote streamlined procedures for interdisciplinary signoff at universities. Getting a joint grant is too laborious, and the deans want to know only who is subject to the direct costs and overhead.
- Promote a mechanism for 5-6 years of support based solely on the drive to learn another discipline or to learn core new skills not normally attributed to the "home" department.
- Students need to know that some places, such as publishing and industry, financially reward people who have multidisciplinary backgrounds.

SUMMARY OF FOCUS GROUP C DISCUSSION

(MODERATOR, BRUCE ALBERTS, PRESIDENT, NATIONAL ACADEMY OF SCIENCES)

The discussion focused primarily on evaluation and funding mechanisms. The following is a compilation of the participants' top recommendations for facilitating IDR.

Evaluation

- Go beyond research issues in evaluating IDR; education is a key factor as well.
- Focus on the quality of the people who are submitting grant proposals.

Funding Mechanisms

- The next generation is the key to IDR, so look at the experience of the NIH Alliance for Cellular Signaling in working with junior scholars.

- Effective programs that have a large impact on the potential impact of a beginning researcher to hire people and obtain computers and other necessary equipment need not be high-cost. For example, the NIH FIRST (R29) award provides a research support for newly independent, biomedical and behavioral science investigators to initiate their own research and demonstrate the merit of their own research ideas.[2]
- Focus more on middle-level people who have tenure, because they are able to take the risks entailed in IDR.
- Focus funding on fellows and on travel grants that provide them with the necessary independence.
- Create independent IDR institutions where people can come together on equal footing.

Institutional Mechanisms

- Focus attention on institutional roles—the leadership of an organization is critical.
- Create universitywide interdisciplinary research positions.

Other issues:

- When disciplines come together, they need to do so on an equal basis
- Treat postdoctoral fellows as the glue between researchers who should be joint advisers.
- Study history.
- Make medical schools more hospitable to IDR.

[2]Guidelines for FIRST awards Web page *http://grants2.nih.gov/grants/policy/r29.htm.*

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Bibliography

1. "Advanced Photon Source Home page." Web page, [accessed 6 May 2004]. Available at http://epics.aps.anl.gov/aps.php.
2. "Association for Integrative Studies (AIS)." Web page, [accessed 8 August 2003]. Available at http://www.units.muohio.edu/aisorg/intro.html.
3. "Budgeting with the UB Model at the University of Michigan." Web page, [accessed 24 July 2003]. Available at http://www.umich.edu/~provost/budgeting/ubmodel.html.
4. "Department of Defense Strategic Plan." Web page, [accessed 22 July 2003]. Available at http://www.conginst.org/resultsact/PLANS/plans_dod.html.
5. "Department of Energy Strategic Plan." Web page, [accessed 15 July 2003]. Available at http://www.cfo.doe.gov/stratmgt/plan/DOEsplan.htm.
6. "Environmental Protection Agency/OCFO—Strategic Plan." Web page, [accessed 15 July 2003]. Available at http://www.epa.gov/ocfo/plan/plan.htm.
7. "Fund for the Advancement of the Discipline." Web page, [accessed 23 February 2004]. Available at http://www.asanet.org/members/fad.html.
8. "Good Work Project." Web page, [accessed 18 July 2003]. Available at http://www.goodworkproject.org.
9. "History of X-ray Crystallography and Associated Topics." Web page, [accessed 8 March 2004]. Available at http://www.d1.ac.uk/SRS/PX/history/history.html.
10. "Human Frontier Science Program." Web page, [accessed 30 July 2003]. Available at http://www.hfsp.org/home.php.
11. "Institute for Operations Research and the Management Sciences (INFORMS)." Web page, [accessed 8 August 2003]. Available at http://www.informs.org/.
12. "Integrative Graduate Education and Research Traineeship (IGERT)." Web page, [accessed 10 March 2004]. Available at http://www.nsf.gov/pubs/2004/nsf04550/nsf04550.pdf.
13. "Keck Futures Conferences." Web page, [accessed 3 March 2004]. Available at http://www7.nationalacademies.org/keck/Keck_Futures_Conferences.html.

14. "Marine Biological Laboratory Home page." Web page, [accessed 6 May 2004]. Available at http://www.mbl.edu/research/summer/index.html.
15. "Mathematical Sciences Research Institute." Web page, [accessed 6 May 2004]. Available at http://www.msri.org/.
16. "Microsoft Research Home page." Web page, [accessed 6 May 2004]. Available at http://research.microsoft.com/aboutmsr/jobs/internships/.
17. "National Academies Keck Futures Initiative." Web page, [accessed 3 March 2004]. Available at http://www7.nationalacademies.org/keck/index.html.
18. "National Institute of Standards and Technology 2010 Strategic Plan." Web page, [accessed 16 July 2003]. Available at http://www.nist.gov/director/.
19. "National Science Foundation GPRA Strategic Plan FY 2001—2006." Web page, [accessed 15 July 2003]. Available at http://www.nsf.gov/pubs/2001/nsf0104/start.htm.
20. "The Shingobee Headwaters Aquatic Ecosystems Project (SHAEP) Home page." Web page, [accessed 6 May 2004]. Available at http://wwwbrr.cr.usgs.gov/projects/SHAEP/index.html
21. "Society for Social Studies of Science (4S)." Web page, [accessed 8 August 2003]. Available at http://www.lsu.edu/ssss/.
22. "Training for a New Interdisciplinary Research Workforce." Web page, [accessed 1 June 2004]. Available at http://grants1.nih.gov/grants/guide/rfa-files/RFA-RM-04-015.html.
23. "University of Minnesota Budget and Interdisciplinary Initiatives." Web page, [accessed 5 August 2003]. Available at http://www.evpp.umn.edu/evpp/init.htm.
24. "USGS Home page; Cottonwood Lake Study Area." Web page, [accessed 6 May 2004]. Available at http://www.npwrc.usgs.gov/clsa/index.htm.
25. "Vanderbilt Institute of Chemical Biology." Web page, [accessed 20 January 2004]. Available at http://www.vanderbilt.edu/vicb/home.html.
26. "What is Biogeochemistry?" Web page, [accessed 20 January 2004]. Available at http://calspace.ucsd.edu/virtualmuseum/climatechange1/05_1.shtml.
27. Advisory Council for Science and Technology Policy. 2003. *1 + 1 > 2 Promoting Interdisciplinary Research*, Report 54 of Series Advisory Reports. http://www.awt.nl/en/index.html.
28. Balsiger, P. W. 2004. Supradisciplinary research practices: history, objectives and rationale. *Futures* 36, no. 4:407-21.
29. Barth, R. T. and R. Steck. 1979. *Interdisciplinary Research Groups: Their Management and Organization*. Vancouver: International Group on Interdisciplinary Programs.
30. Baumann, H. 2003. Publish and Perish? The impact of citation indexing on the development of new fields of environmental research. *Journal of Industrial Ecology* 6, no. 3-4:13-26.
31. Bayer, P. S. and B. Steinheider. 2004. Working in interdisciplinary research teams: Why heterogeneity matters. Society for Industrial and Organizational Psychology.
32. Bechtel, W. 1986. *Integrating Scientific Disciplines: The Nature of Scientific Integration*. Dordrecht: Martinus Nijhoof.
33. Bell, N. 2003. Mapping Academic Disciplines to a Multi-Disciplinary World. *Proceedings of an NSF/CPST/Professional Societies Workshop* Washington, D.C.: Commission on Professionals in Science and Technology.
34. Birnbaum-More, P. H., F. Rossini, and D. Baldwin. 1990. *International Research Management*. New York: Oxford University Press.
35. Birnbaum, P. H. 1983. Predictors of Long-Term Research Performance. *Managing Interdisciplinary Research*. S. R. Epton, R. L. Payne, and A. W. Pearson, 47-59. New York: John Wiley and Sons.

36. Birnbaum, P.H. 1979. A Theory of Academic Interdisciplinary Research Performance: A Contingency and Path Analysis Approach. *Management Science* 25, no. 3:231-42.
37. Bourke, P. and L. Butler. 1998. Institutions and the map of science: Matching university departments and fields of research. *Research Policy* 26:711-18.
38. Bozeman, B. and E. Corley. 2004. Scientists' Collaboration Strategies: Implications for Scientific and Technical Human Capital. *Research Policy* 33, no. 4:599-616.
39. Brainard, Jeffrey. 2002. U.S. Agencies Look to Interdisciplinary Science. *The Chronicle of Higher Education*: A20.
40. Brandt, E.N. 1997. Research Administration in a Time of Change. *SRA Journal* 29, no. 1,2:233-36.
41. Bruce, A., C. Lyall, J. Tait, and R. Williams. 2004. Interdisciplinary integration in Europe: the case of the Fifth Framework programme. *Futures* 36, no. 4:457-70.
42. Bruhn, J.G. 2000. Interdisciplinary Research: A Philosophy, Art Form, Artifact or Antidote? *Integrative Physiological and Behavioral Science* 35, no. 1:58-66.
43. Butler, D. 1998. Interdisciplinary research 'being stifled'. *Nature* 396, no. 6708:202.
44. Butler, D. 2000. Pasteur Institute to Abandon Departmental Structure? *Nature* 405, no. 6790:990.
45. Cairns, R. B., E. J. Costello, and Elder, G. H. 1996. The Making of Developmental Science. *Developmental Science*. R.B. Cairns, G.H. Elder, and E.J. Costello, 223-34. New York: Cambridge University Press.
46. Campbell, W. H., W. K. Anderson, and G. J. Burckart. 2003. "Institutional and faculty roles and responsibilities in the emerging environment of university-wide interdisciplinary research structures." *Report of the 2001-2002 Research and Graduate Affairs Committee*, American Association of Colleges of Pharmacy.
47. Caruso, D. and D. Rhoten. 2001. Lead, follow, get out of the way: sidestepping the barriers to effective practice on interdisciplinarity. *The Hybrid Vigor Institute* http://www.hybridvigor.net/interdis/pubs/hv_pub_interdis-2001.04.30.pdf.
48. Chase, A., J. Giancola, L. Horst, R. Jacob, A. Martinez, M. A. Millsap, W. C. Smith, S. Goldsmith, D. Haviland, and N. Tushnet. 2003. *IGERT Annual Cross-Site Report: 1998 and 1999 Cohorts*, Abt Associates Inc., Washington D.C.
49. Chase, A., J. Giancola, L. Litin, A. Martinez, and C. Weiland. 2003. *IGERT Implementation and Early Outcomes: 2002*, Abt Associates Inc., Washington D.C.
50. Chubin, D. E. 1986. "Interdisciplinary Analysis and Research: Theory and Practice of Problem-Focused Research and Development." *Interdisciplinary Analysis and Research: Theory and Practice of Problem-Focused Research and Development*. Mt. Airy: Lomond Publications.
51. Chubin, D. E., A. L. Porter, and F. A. Rossini. 1984. "Citation Classics" Analysis: An Approach to Characterizing Interdisciplinary Research. *Journal of the American Society for Information Science* 35, no. 6:360-368.
52. Chubin, D. E., A. L. Porter, F. A. Rossini, and T. Connolly. 1986. *Interdisciplinary Analysis and Research: Theory and Practice of Problem-Focused Research and Development*. Mt. Airy: Lomond Publications.
53. Cohen, L., M. J. Aboelata, T. Gantz, and J. Van Wert. 2003. "Collaboration Math: Enhancing the Effectiveness of Multidisciplinary Collaboration: Applying Collaboration Math to the U.C. Berkeley Traffic Safety Center." Prevention Institute, www.preventioninstitute.org.
54. Collins, J. P. 2002. May You Live in Interesting Times: Using Multidisciplinary and Interdisciplinary Programs To Cope with Change in the Life Sciences. *Bioscience* 52, no. 1:75-83.

55. Colwell, R. 2001. From Microscope to Kaleidoscope: Merging Fields of Vision. *Transdisciplinarity: Joint Probelm Solving among Science, Technology, and Society*. J. Thompson-Klein, W. Grossenbacher-Mansuy, R. Haberli, A. Bill, R.W. Scholz, and M. Welti, 59-66. Basel, Boston, Berlin: Birhauser-Verlag.
56. Committee on Building Bridges in Brain, Behavioral, and Clinical Sciences. 2000. "Bridging Disciplines in the Brain, Behavioral, and Clinical Sciences." National Academy Press, Washington, D.C.
57. Committee on Human Factors. 2003. "Dynamic Social Network Modeling and Analysis: Workshop Summary and Papers." National Academy Press, Washington, D.C.
58. Committee on Large-Scale Science and Cancer Research. 2003. *Large-Scale Biomedical Science: Exploring Strategies for Future Research*. Washington, D.C.: The National Academies Press.
59. Committee on Research in Mathematics, Science, and Technology. 1987. *Interdisciplinary research in mathematics, science, and technology education*. Washington, D.C.: National Academy Press.
60. Committee on Undergraduate Biology Education to Prepare Research Scientists for the 21st Century. 2003. "BIO 2010: Transforming Undergraduate Education for Future Research Biologists." Washington, D.C.: National Academy Press.
61. Committee to Examine the Methodology for the Assessment of Research-Doctorate Programs, Policy and Global Affairs Division. 2003. "Assessing Research-Doctorate Programs: A Methodology Study." Washington, D.C.: The National Academies Press.
62. Couzin, J. 2003. Congress Wants the Twain to Meet. *Science* 301:444.
63. Cummings, J. and S. Kiesler. 2003. *KDI Initiative: Multidisciplinary Scientific Collaborations*, NSF Award No. IIS-9872996. National Science Foundation.
64. Cutler, R. S. 1979. A Policy Perspective on Interdisciplinary Research in U.S. Universities. *Interdisciplinary Research Groups: Their Management and Organization*. R. T Barth, and R. Steck, 295-314. IGRIP.
65. Davis, J. R. 1995. *Interdisciplinary Courses and Team Teaching: New Arrangements for Learning*. Phoenix, AZ: Oryx Press.
66. de Paula, J. C. 2003. Integrating the Sciences at Haverford College. *Research Corporation Report* http://www.rescorp.org/report/rc_report.htm: 3.
67. Defila, R., and A. DiGiulio. 1999. Evaluating Transdisciplinary Research. *Panorama* 1.
68. Derry, S. J. C. D. Schunn, and M. A. Gernsbacher. 2004. *Problems and Promises of Interdisciplinary Collaboration: Perspectives from Cognitive Science*. Mahwah, NJ: Erlbaum.
69. Despres, C., N. Brais, and S. Avellan. 2004. Collaborative planning for retrofitting suburbs: transdisciplinarity and intersubjectivity in action. *Futures* 36, no. 4:471-86.
70. DeWachter, M. 1982. Interdisciplinary Bioethics: But Where Do We Start? A Reflection on Epoche as Method. *Journal of Medicine and Philosophy* 7, no. 3:275-87.
71. Dill, K. A. 1999. Strengthening biomedicine's roots. *Nature* 400:309-10.
72. Dressel, P. 1970. *The Confidence Crisis: An Analysis of University Departments*. San Francisco: Jossey-Bass.
73. Edwards, A. Jr. 1996. *Interdisciplinary Undergraduate Programs: A Directory*. Acton, MA: Copley Publishing Group.
74. Elder, G. H., J. Modell, and R. D. Parke. 1993. Epilogue: An emerging framework for dialogue between history and developmental psychology. *Children in time and place: Developmental and historical insights*. G. H. Elder, J. Modell, and R. D. Parke, 241-49. New York: Cambridge University Press.
75. Elgass, J. R. 1994. Clarke co-directs project at Argonne photon facility. *The University Record* March 28.

76. Epton, S. R., R. L. Payne, and A. W. Pearson. 1983. Contextual Issues in Managing Cross-Disciplinary Research. *Managing High Technology: An Interdisciplinary Perspective*, 209-29. New York: Elsevier.
77. Epton, S. R., R. L. Payne, and A. W. Pearson. 1984. Cross-Disciplinarity and Organizational Forms. Managing Interdisciplinary Research. Chichester: John Wiley and Sons.
78. Epton, S. R., R. L. Payne, and A. W. Pearson. 1983. *Managing Interdisciplinary Research*. Chichester: John Wiley and Sons.
79. European Commission. 2003. "CORDIS FP6: Guidelines on proposal evaluation and selection procedures [FP6]." Web page. Available at http://dbs.cordis.lu/.
80. European Commission. 2003. "CORDIS FP6: Provisions for implementing integrated projects: Background document. " Web page. Available at http://dbs.cordis.lu/.
81. Feder, T. 2000. Strasbourg Interdisciplinary Institute Gets Off the Ground. *Physics Today* April: 58.
82. Feist, G. J. and M. E. Gorman. 1998. The Psychology of Science: Review and Integration of a Nascent Discipline. *Review of General Psychology* 2, no. 1:3-47.
83. Feller, I. 2002. New Organizations, old cultures: stategy and implementation of interdisciplinary programs. *Research Evaluation* 11:109-16.
84. Feller, I. 2002. Performance Measurement Redux. *American Journal of Evaluation* 23:435-52.
85. Feller, I. 2004. Whither Interdisciplinarity (In an Era of Strategic Planning)? *Proceedings of 2004 Annual AAAS Meeting* Washington D.C.: AAAS.
86. Fiscella, J. and S. Kimmel. 1999. "Interdisciplinary Education: A Guide to Resources." *Interdisciplinary Education: A Guide to Resources*, The College Board, New York.
87. Flexner, H. 1979. The Curriculum, the Disciplines, and Interdisciplinarity in Higher Education: Historical Perspective. *Interdisciplinarity and Higher Education*. J. Kockelmans, 93-122. University Park: The Pennsylvania State University Press.
88. Fouke, J. and K. Brodie. 2003. *Symposium on catalyzing team science*. Bioengineering Consortium (BECON), National Institutes of Health.
89. Friedman, R. S., and R. C. Friedman. 1985. Organized Research Units of Academe Revisited. *Managing High Technology: An Interdisciplinary Perspective*. B. W. Mar, W. T. Newell, and B. O. Saxberg, 75-91.
90. Frost, Susan H. 2001. "Intellectual Initiatives: Working Across Disciplines, Schools and Institutions." *Emory: Provost Initiatives*, Emory University, Atlanta.
91. Garrett Russell, M. 1990. The Impact of Interdisciplinary Activities on Departmental Disciplines. *International Research Management*. P. H. Birnbaum-More, Frederick A. Rossini, and Donald R. Baldwin, 81-96. New York: Oxford University Press.
92. Gaughan, M., and S. Robin. 2004. National Science Training Policy and Early Scientific Careers in France and the United States. *Research Policy* 33:569-81.
93. Geneuth, J., I. Chompalov, and W. Shrum. 2000. How Experiments Begin: The Formation of Scientific Collaborations. *Minerva* 38, no. 3:311-48.
94. Gershon, D. 2000. Changing the Face of Training for Science at the Interface. *Nature* 404, no. 6775:315-6.
95. Gershon, D. 2000. Crossing the Divide Between Theory and Practice. *Nature* 404, no. 6775:316.
96. Gershon, D. 2000. Laying a Firm Foundation for Interdisciplinary Research Endeavours. *Nature* 406, no. 6791:107-8.
97. Gershon, D. 2000. Pushing the Frontiers of Interdisciplinary Research: an Idea Whose Time Has Come. *Nature* 404, no. 6775:313-5.
98. Goebel, G. "Microwave Radar and The MIT Rad Lab." Web page, [accessed 10 March 2004]. Available at http://www.vectorsite.net/ttwiz3.html.

99. Golde, C. M. and H. A. Gallagher. 1999. The Challenges of Conducting Interdisciplinary Research and Traditional Doctoral Programs. *Ecosystems* 2:281-85.
100. Gonzalez, C. 2003. The role of the graduate school in interdisciplinary programs: The University of California, Davis, Budget Model. *Communicator: Council of Graduate Schools* 26, no. 5:1-12.
101. Goulet, R. R. 1985. The National Science Foundation and High Tech Interdisciplinary Research. *Managing High Technology: An Interdisciplinary Approach*. W. T. Newell and B. O. Saxberg B.W. Mar, 179-83. New York: Elsevier.
102. Grace, D. J. and F. A. Rossini. 1990. Georgia Tech Research Institute: An Interdisciplinary Perspective. *International Research Management*. P. H. Birnbaum-More, Frederick A. Rossini, and Donald R. Baldwin, 105-13. New York: Oxford University Press.
103. Gregorian, V. 2004. Colleges Must Retain the Unity of Knowledge. *The Chronicle of Higher Education* 50, no. 39:1-5.
104. Guetzkow, J., and M. Lamont. 2002. Evaluating Creative Minds: The Assessment of Originality in Peer Review. *Creativity* July.
105. Gusdorf, G. 1977. Past, Present and Future in Interdisciplinary Research. *International Social Science Journal*. 29, no. 4:580-600.
106. Haberli, R., W. Grossenbacher-Mansuy, J. Thompson-Klein, A. Bill, R. Scholz, and M. Welti. 2001. Summary and Synthesis. *Transdisciplinarity: Joint Problem Solving among Science, Technology, and Society*. J. Thompson-Klein, W. Grossenbacher-Mansuy, R. Haberli, A. Bill, R.W. Scholz, and M. Welti, 3-23. Boston: Birkhauser Verlag.
107. Haggin, J. 1995. Illinois' Beckman Institute Targets Disciplinary Barriers to Collaboration. *Chemical and Engineering News* 73, no. 10:32-39.
108. Hagoel, L. 2002. Crossing Borders: Toward a Trans-Disciplinary Scientific Identity. *Studies in Higher Education* 27, no. 3:297-308.
109. Hansson, B. 1999. Interdisciplinarity: For what purpose? *Policy Sciences* 32:339-43.
110. Hattery, L. H. 1979. Interdisciplinary Research Management: Research Needs and Opportunities. *Interdisciplinary Research Groups: Their Management and Organization*. R. T Barth, and R. Steck, 9-25. IGRIP.
111. Hoag, H. 2003. Building Bridges. *Nature* 425:882-83.
112. Hollaender, K. 2001. Reflections on the Interactive Sessions: From Scepticism to Good Practices. *Transdisciplinarity: Joint Problem Solving among Science, Technology, and Society*. J. Thompson-Klein, W. Grossenbacher-Mansuy, R. Haberli, A. Bill, R.W. Scholz, and M. Welti Boston: Birkhauser-Verlag.
113. Hollingsworth, R., and E. J. Hollingsworth. 2000. Major Discoveries and Biomedical Research Organizations: Perspectives on Interdisciplinarity, Nurturing Leadership, and Integrated Structure and Cultures. *Practising Interdisciplinarity*. P. Weingart, and N. Stehr, 215-44. Toronto: University of Toronto Press.
114. Holton, G. 1998. *The Scientific Imagination*. Cambridge, MA: Harvard University Press.
115. Holton, G., and H. Jurkowitz E. Chang. 1996. How a Scientific Discovery is Made: A Case History. *American Scientist* 84, no. 4:364-75.
116. Hooper, J. W., and F. A. Rossini. 1990. The Development of an Interdisciplinary University-Based Microelectronics Research Center. *International Research Management*. Eds. P. H. Birnbaum, Frederick A. Rossini, and Donald R. Baldwin, 114-21. New York: Oxford University Press.
117. Horlick-Jones, T., and J. Sime. 2004. Living on the border: knowledge, risk and transdisciplinarity. *Futures* 36, no. 4:441-56.
118. Hursh, B., P. Haas, and M. Moore. 1983. An Interdisciplinary Model to Implement General Education. *Journal of Higher Education* 54:42-59.

119. Jeffrey, P. 2003. Smoothing the Waters: Observations on the Process of Cross-Disciplinary Research Collaboration. *Social Studies of Science* 33, no. 4:539-62.
120. Jewitt, G. P. W., and A. H. M. Görgens. 2000. Facilitation of interdisciplinary collaboration in research: lessons from a Kruger National Park Rivers Research Programme project. *South African Journal of Science* 96:411-14.
121. Kafatos, F. C., and T. Eisner. 2004. Unification in the Century of Biology. *Science* 303:1257.
122. Karlqvist, A. 1999. Going beyond disciplines: The meanings of interdisciplinarity. *Policy Sciences* 32:379-83.
123. Kates, R. W. 1989. The great questions of science and society do not fit neatly into single disciplines. *The Chronicle of Higher Education* 35:B2-B3.
124. Kessel, F., P. Rosenfield, and N. Anderson. 2003. "Expanding the Boundaries of Health and Social Science: Case Studies in Interdisciplinary Innovation." Oxford University Press, Oxford.
125. Klein, J. T. 1996. *Crossing Boundaries: Knowledge, Disciplinarities, and Interdisciplinarities.* Charlottesville: University Press of Virginia.
126. Klein, J. T. 1990. *Interdisciplinarity: History, Theory, & Practice.* Detroit: Wayne State University Press.
127. Klein, J. T. 2004. Prospects for Transdisciplinarity. *Futures* 36:515-26.
128. Klein, J. T., and W. H. Newell. 1997. Handbook of the Undergraduate Curriculum: A Comprehensive Guide to Purposes, Structures, Practices, and Change. *Advancing Interdisciplinary Studies.*, 393-415. San Francisco: Jossey-Bass.
129. Klein, J. T. Porter A. L. 1990. Preconditions for Interdisciplinary Research. *International Research Management: Studies in Interdisciplinary Methods from Business, Government, and Academia.* P. H. Birnbaum-More, F. A. Rossini, and D. R. Baldwin, 11-19. New York: Oxford University Press.
130. Kostoff, R. N. 2002. Overcoming Specialization. *BioScience* 52, no. 10:937-41.
131. Kostoff, R. N. 1997. Peer review: The appropriate GPRA metric for research. *Science* 277:651-52.
132. Kreeger, K. 2003. The Learning Curve. *Nature* 424:234-35.
133. Kusmierek, K. N. and M. Piontek. 2002. Content, Consciousness, and Colleagues: Emerging Themes from a Program Evaluation of Graduate Student Progress Toward Multidisciplinary Science. *42nd Annual Association for Institutional Research Forum.*
134. Landa, J. T. and M. T. Ghiselin. 1999. The emerging disciplines of bioeconomics: aims and scope of the Journal of Bioeconomics. *Journal of Bioeconomics* 1, no. 1:5-12.
135. Lattuca, L. R. 2001. *Creating Interdisciplinarity: Interdisciplinary Research and Teaching among College and University Faculty.* Nashville: Vanderbilt University Press.
136. Lawrence, R. J. 2004. Housing and health: from interdisciplinary principles to transdisciplinary research and practice. *Futures* 36, no. 4:487-502.
137. Lawrence, R. J. and C. Despres. 2004. Futures of Transdisciplinarity. *Futures* 36, no. 4:397-405.
138. Lind, I. 1999. Organizing for interdisciplinarity in Sweden: The case of *tema* at Linköping University. *Policy Sciences* 32:415-20.
139. Lindas, N. 1979. Conclusions from the American Society for Public Administration's Assessment of Four Interdisciplinary Research Management Projects. *Interdisciplinary Research Groups: Their Management and Organization.* R. T. Barth, and R. Steck, 278-94. IGRIP.
140. Lindbeck, A. "The Sveriges Riksbank (Bank of Sweden) Prize in Economic Sciences in Memory of Alfred Nobel 1969-2000." Web page, [accessed 27 February 2004]. Available at http://www.nobel.se/economics/articles/lindbeck/index.html.

141. Mansilla, V. B. and H. Gardner. 2003. Assessing Interdisciplinary Work at the Frontier. An Empirical Exploration of 'Symptoms of Quality." *Interdisciplines* http://www.interdisciplines.org/interdisciplinarity/papers/6.
142. Mar, B., W. T. Newell, and B. O. Saxberg. 1985. *Managing High Technology: An Interdisciplinary Perspective*, North Holland-Elsevier, Amsterdam.
143. Marshall, L. H., W. A. Rosenblith, P. Gloor, G. Krauthamer, C. Blakemore, and S. Cozzens. 1996. Early History of IBRO: The Birth of Organized Neuroscience. *Neuroscience* 72, no. 1:283-306.
144. McCain, K. W., and P. J. Whitney. 1994. Contrasting Assessments of Interdisciplinarity in Emerging Specialties: The Case of Neural Networks Research. *Knowledge: Creation, Diffusion, Utilization* 15, no. 3:285-306.
145. McCorcle, M. 1982. Critical Issues in the Functioning of Interdisciplinary Groups. *Small Group Behavior* 13:291-310.
146. McNeill, D. 1999. On Interdisciplinary Research: with particular reference to the field of environment and development. *Higher Education Quarterly* 53, no. 4:312-32.
147. Metzger, N. and R. N. Zare. 1999. Interdisciplinary Research: From Belief to Reality. *Science* 283, no. 5402:642.
148. Mey, H. 2001. Impact on Science Management and Science Policy. *Transdisciplinarity: Joint Probelm Solving among Science, Technology, and Society*. J. Thompson-Klein, W. Grossenbacher-Mansuy, R. Haberli, A. Bill, R.W. Scholz, and M. Welti, 253-59. Basel, Boston, Berlin: Birkhauser-Verlag.
149. Montgomery, S. 2004. Of Towers, Walls, and Fields: Perspectives on Language in Science. *Science* 303:1333-35.
150. Morgan, G. D., K. Kobus, K. K. Gerlach, C. Neighbors, C. Lerman, D. B. Abrams, and B. K. Rimer. 2003. Facilitating transdisciplinary research: The experience of the transdisciplinary tobacco use research centers. *Nicotine and Tobacco Research* 6, no. Suppl. 1:S11-S19.
151. Myers, G. 1993. Centering: Proposals for an Interdisciplinary Research center. *Science, Technology, & Human Values* 18, no. 4:433-59.
152. National Academy of Public Administration. 2004. "National Science Foundation: Governance and Management for the Future." 2015-001. Washington, D.C.
153. National Research Council. 1990. *Interdisciplinary Research: Promoting Collaboration Between the Life Sciences and Medicine and the Physical Sciences and Engineering*. Washington, D.C.: National Academy Press.
154. Nealson, K. and W. A. Ghiorse. 2000. Geobiology: Exploring the Interface between the Biosphere and the Geosphere. American Academy of Microbiology.
155. Nilles, J. M. 1975. Interdisciplinary Research Management in the University Environment. *Journal of the Society of Research Administrators* VI, no. 4:9-16.
156. O'Toole, J. C., G. H. Toenniessen, T. Murashige, R. R. Harris, and R. W. Herdt. The Rockefeller Foundation's International Program on Rice Biotechnology. *Proceedings of the Fouth International Rice Genetics Symposium* G. S. Khush, D. S. Brar, and B. Hardy.
157. Pain, E. 2003. Multidisciplinary Resources. *Science's Next Wave* http://nextwave.sciencemag.org/cgi/content/full/s002/12/30/16.
158. Palmer, C. 2001. "Work at the Boundaries of Science." *Work at the Boundaries of Science*, Dordrecht: Kluwer.
159. Palmer, C. L. 1999. Structures and Strategies of Interdisciplinary Science. *Journal of the American Society for Information Science*.
160. Palmer, C. L. and L. J. Neumann. 2002. The Information Work of Interdisciplinary Humanities Scholars: Exploration and Translation. *Library Quarterly* 72, no. 1:85-117.

161. Payne, S. L. 2001. Applying More Integrative Potenital for IDS Program Planning and Developemnt. *Issues in Integrative Studies* 19:149-69.
162. Pfirman, S. L., J. P. Collins, S. Lowes, and A. F. Michaels. in press. To Thrive and Prosper: Hiring, Supporting, and Tenuring Interdisciplinary Scholars.
163. Pinson, D. 2004. Urban planning: an 'undisciplined' discipline? *Futures* 36, no. 4:503-13.
164. Plater, W. M. 1995. Future work: Faculty time in the 21st century. *Change* 27, no. 3:23-33.
165. Porter, A. L. 1983. Interdisciplinary Research: Current Experience in Policy and Performance. *Interdisciplinary Science Reviews* 8, no. 2:158-67.
166. Porter, A. L. and D. E. Chubin. 1985. An Indicator of Cross-Disciplinary Research. *Scientometrics* 8, no. 3-4:161-76.
167. Porter, A. L., and F. A. Rossini. 1985. Forty Interdisciplinary Research Projects: Multiple Skills and Peer Review. *Managing High Technology: An Interdisciplinary Perspective*. B. W. Mar, W. T. Newell, and B. O. Saxberg, 103-12. New York: Elsevier.
168. Porter, A. L., and F. A. Rossini. 1984. Interdisciplinary research redefined: multi-skill problem-focussed research in the STRAP framework. *R&D Management* 14, no. 2:105-11.
169. Porter, A. L., and F. A. Rossini. 1986. Multiskill Research. *Knowledge: Creating, Diffusion, Utilization* 7, no. 3:219-46.
170. Porter, A. L., and F. A. Rossini. 1985. Peer Review of Interdisciplinary Research Proposals. *Science Technology & Human Values* 10, no. 3:33-38.
171. Pray, L. A. 2003. Interdisciplinarity in science and engineering: Academia in transition. *Science's Next Wave* http://nextwave.sciencemag.org/cgi/content/full/2003/01/15/5?
172. Qin, J., F. W Lancaster, and B. Allen. 1997. Types and Levels of Collaboration in Interdisciplinary Research in the Sciences. *Journal of the American Society for Information Science* 48, no. 10:893-916.
173. Ramadier, T. 2004. Transdisciplinarity and its challenges: the case of urban studies. *Futures* 36, no. 4:423-39.
174. Rhoten, D. 2004. Interdisciplinary Research: Trend or Transition. *Items and Issues* 5, no. (1-2):6-11.
175. Rhoten, D. Final Report, National Science Foundation BCS-0129573: A Multi-Method Analysis of the Social and Technical Conditions for Interdisciplinary Collaboration. September 29, 2003. Available at: http://www.hybridvigor.net/interdis/pubs/hv_pub_interdis-2003.09.29.pdf.
176. Rhoten, D. 2002. Organizing change from the inside out: Emerging models of intra-organizational collabotation in philanthoropy. *The Hybrid Vigor Institute* http://www.hybridvigor.net/interdis/pubs/hv_pub_interdis-2002.10.30.pdf.
177. Rinia, E. J, Th. N. Van Leeuwen, H. G. van Vuren, and A. F. J van Raan. 2001. Influence of interdisciplinarity on peer-review ad bibliometric evaluations in physics research. *Research Policy* 30:357-61.
178. Roberston, D. W., D. K. Martin, and P. A. Singer. 2003. Interdisciplinary Reseach: Putting the methods under the microscope. *Medical Research Methodology* 3, no. 20.
179. Roberts, J. A., and R. E. Barnhill. 2001. Engineering Togetherness: An Incentive System for Interdisciplinary Research. *ASEE/IEEE Frontiers in Education Conference*.
180. Rogers, J. 2000. The intellectual consequences of the research assessment exercise: A Response. *History of the Human Sciences* 13, no. 2:101-6.
181. Rogers, J. D. and B. Bozeman. 2002. A churn model of scientific knowledge value: Internet researchers as a knowledge value collective. *Research Policy* 31, no. 5:769-94.

182. Rossini, F., A. L. Porter, D. E. Chubin, and T. Connolly. 1984. Cross-Disciplinarity in the Biomedical Sciences: A Preliminary Analysis of Anatomy. *Managing Interdisciplinary Research*. S. R. Epton, R. L. Payne, and A. W. Pearson, 176-84. Chichester: Wiley.
183. Rossini, F. A. and A. L. Porter. 1979. Frameworks for integrating interdisciplinary research. *Research Policy* 8:70-79.
184. Russell, M. G. 1982. *Enabling Interdisciplinary Research: Perspectives from Agriculture, Forestry, and Home Economics*, Miscellaneous Publication #19. Agricultural Experiment Station, University of Minnesota, St. Paul, MN.
185. Russell, M. G. 1985. Peer Review and Interdisciplinary Research: Flexibility and Responsiveness. *Managing Interdisciplinary Research*. S. R. Epton, R. L. Payne, and A. W. Pearson, 184-202. New York: John Wiley and Sons.
186. Russell, M. G. and R. J. Sauer. 1983. Creating Administrative Environments for Interdisciplinary Research. *Journal of the Society of Research Administrators* 14, no. 4:21-31.
187. Sackett, W. T. 1990. Interdisciplinary Research in a High-Technology Company. *International Research Management*. P. H. Birnbaum-More, Frederick A. Rossini, and Donald R. Baldwin, 60-72. New York: Oxford University Press.
188. Sanders, C. 2003. Breaking Down the Borders of Science. *New York Times* 1570:8.
189. Saxberg, B. O., W. T. Newell, and B. W. Mar. 1981. Interdisciplinary Research: A Dilemma for University Central Administration. *Journal of the Society of Research Administrators* 13:25-43.
190. Schneidewind, U. 2001. Mobilizing the Intellectual Capital of Universities. *Transdisciplinarity: Joint Problem Solving among Science, Technology, and Society*. J. Thompson-Klein, W. Grossenbacher-Mansuy, R. Haberli, A. Bill, R.W. Scholz, and M. Welti, 94-100. Boston: Birkhauser-Verlag.
191. Sewell, W. H. 1989. Some Reflections on the Golden Age of Interdisciplinary Social Psychology. *Social Psychology Quarterly* 52, no. 2:88-97.
192. Shanken, E. A. "Bibliography of Interdisciplinary Collaboration." Web page, [accessed 17 March 2004]. Available at *http://www.artexetra.com/biblio_interdisciplinary.html*.
193. Simonton, D. K. 2004. *Creativity in Science: Chance, Logic, Genius, and Zeitgeist*. New York: Cambridge University Press.
194. Simonton, D. K. 2003. Scientific Creativity as Constrained Stochastic Behavior: The Integration of Product, Person, and Process Perspectives. *Psychological Bulletin* 129, no. 4:475-94.
195. Sjolander, S. 1985. "Long-term and Short-term Interdisciplinarity." *Inter-Disciplinarity Revisited*, L. Levin, and I. Eds. Stockholm: Lind.
196. Smith, R., M. T. Spina, J. Grayson, and M. L. Zuzolo. 1997. Research Administration Through a Decade of Change. *SRA Journal* 29, no. 1,2:37-44.
197. Smoliner, C., R. Haberli, and M. Welti. 2001. Mainstreaming Transdisiplinarity: A Research-Political Campaign. *Transdisciplinarity: Joint Problem Solving among Science, Technology, and Society*. J. Thompson-Klein, W. Grossenbacher-Mansuy, R. Haberli, A. Bill, R.W. Scholz, and M. Welti, 263-71. Boston: Birkhauser-Verlag.
198. Spiegel-Rosing, I. and D. de Solla Price. 1977. *Science, Technology, and Society: A Cross-Disciplinary Perspective*. Beverly Hills: Sage Publications.
199. Sproull, R., and H. Hall. 1987. " Multidisciplinary Research and Education Programs in Universities." Washington, D.C.: National Academy Press.
200. Steele, T. W. and J. C. Stier. 2000. The Impact of Interdisciplinary Research in the Environmental Sciences: A Forestry Case Study. *Journal of the American Society for Information Science* 51, no. 5:476-84.

201. Steinheider, B. and G. Legrady. 2004. Interdisciplinary Collaboration in Digital Media Arts: A Psychological Perspective on the Production Process. *Leonardo* 37, no. 4: http://mitpress2.mit.edu/e-journals/Leonardo/isast/journal/toc374.html.
202. Stember, Marilyn. 1991. Advancing the social sciences through the interdisciplinary enterprise. *Social Science Journal* 28, no. 1:1, 14.
203. Stokols, D., J. Fuqua, J. Gress, R. Harvey, K. Phillips, L. Baezconde-Garbanati, J. Unger, P. Palmer, M. A. Clark, S. M. Colby, G. Morgan, and W. Trochim. 2003. Evaluating transdisciplinary science. *Nicotine and Tobacco Research* 6, no. Suppl. 1:S21-S39.
204. Stone, A. R. 1969. The Interdisciplinary Research Team. *Journal of Applied Behavioral Sciences* 5, no. 3:351-65.
205. Straus, R. 1973. Departments and Disciplines: Stasis and Change. *Science* 182, no. 4115:895-98.
206. Submcommittee on Research Business Models. 2003. Alignment of Funding Mechanisms with Scientific Opportunities. *Regional Forum on Research Business Models* White House Office of Science and Technology Policy (OSTP) National Science and Technology Council (NSTC).
207. Suh, N. P. 1987. The ERCs: What Have We Learned. *Engineering Education* October: 16-18.
208. Suk, W. A., B. E. Anderson, C. L. Thompson, D. A. Bennett, and D. C. Vandermeer. 1999. Creating Multidisciplinary Research Opportunities. *Environmental Science & Technology* 33, no. 11:241A-4A.
209. Swoboda, W. W. 1979. Disciplines and Interdisciplinarity: A Historical Perspectives. *Interdisciplinarity and Higher Education*. Joseph Kockelmans, 49-84. University Park: The Pennsylvania State University Press.
210. Teagarden, M. B. 1998. Unbundling the intellectual joint venture process. The case of multinational, multifunctional interdisciplinary research consortia. *Journal of Managerial Psychology* 13, no. 3,4:178-87.
211. Trouillot, M-R. 1996. Open the Social Sciences. *Crosscurrents* 3, no. 2.
212. University of Michigan. 2001. *New Openings for the Research University: Advancing Collaborative, Integrative, and Interdisciplinary Research and Learning: University of Michigan Special Emphasis Self Study*, University of Michigan.
213. University of Washington. 2002. *Self-Study: Program on the Environment*, University of Washington.
214. Van Dusseldorp, S. and D. Wigboldus. 1994. Interdisciplinary Research for Integrated Rural Development in Developing Countries. *Issues in Integrative Studies* 12:93-138.
215. Waintraub, J. L. 1997. Institution wide reform through NSF supported projects. *ASEE Annual Conference Proceedings*.
216. Walsh, S., and T. Bartlett. 2003. U. of California-Merced Takes Interdisciplinary Approach; Virginia Tech Sends a Mixed Message. *The Chronicle of Higher Education* 49, no. 28:A10.
217. Weingart, P., and N. Stehr. 2000. *Practising Interdisciplinarity*. Toronto: University of Toronto Press.
218. Whitley, R. 1982. The rise and decline of university disciplines in the sciences. *Issues in Interdisciplinarity*. J. H. P. Paelinck, 17-43. Rotterdam: Erasmus University Press.