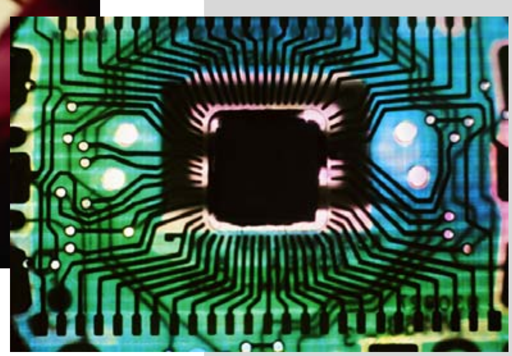
Workshop on Key Challenges in the Implementation of Convergence

September 16-17, 2013
Lecture Room
National Academy of Sciences



NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

Workshop on Key Challenges in the Implementation of Convergence

September 16-17, 2013

Organized by:
Committee on Key Challenge Areas for Convergence and Health
Board on Life Sciences
National Research Council

Lecture Room
The National Academy of Sciences
2101 Constitution Avenue, NW
Washington, DC 20418

Contents

ABOUT THE WORKSHOP: GOALS AND OBJECTIVES

Background

"Convergence" of the life sciences with fields including physical, chemical, mathematical, computational, and engineering sciences is a key strategy to tackle complex challenges and achieve new and innovative solutions. For example, researchers draw on contributions across these disciplines to advance our understanding of health and disease at genetic, cellular and systems levels and to develop and deliver novel therapeutics designed to treat diseases earlier, more successfully, and with fewer side effects.

Numerous reports have explored advances that are enabled when multiple disciplines come together in integrated partnerships. As a result, institutions have increasingly moved to implement programs that foster such convergence or are interested in how they can better facilitate convergent research. However, institutions face a lack of guidance on how to establish effective programs, what challenges they are likely to encounter, and what strategies other organizations have used to address the issues that arise.

The National Research Council has appointed a committee to investigate examples of organizations that have established mechanisms to support convergent research. By convening a workshop that gathers leaders from these organizations and programs along with additional academic and industry leaders, scientists, and foundations and agencies interested in advancing the implementation of convergence, the committee will explore details of the programs created and what has worked and not worked in varied settings. The committee's report will summarize the lessons learned and provide organizations with strategies to tackle practical needs and implementation challenges in areas such as infrastructure, student education and training, faculty development, and inter-institutional partnerships. This advice will help harness the excitement generated by the concept of convergence and channel it into the policies, structures, and networks that will enable it to realize its goals.

Workshop Goals

- Through presentations and discussion sessions, learn about how different organizations have approached the question of how to effectively enable the convergence of multiple disciplines, particularly:
    - What structures or policies they have established to enable convergence?
    - What barriers have they faced?
    - What strategies have they tried to implement to overcome these barriers?
    - What lessons have they learned about what works or doesn't work?
- Gather experiences and input from a range of stakeholders including:
    - Institutions/Universities, both large research institutions and primarily undergraduate institutions
    - Departments/Programs
    - Principal Investigators/Team Leaders, both senior and younger
    - Educators
    - Postdoctoral Fellows and Students
    - Funding Agencies and Foundations
    - Journal Editors

Desired Outcomes

- Identify key barriers to fostering an organizational culture that supports convergence
- Identify tactics or strategies to help overcome specific barriers, including whether certain strategies or tactics are most effective in certain types of situations or for certain types of organizations
- Identify key issues that still remain challenging obstacles
- Begin to distill the information gathered and lessons learned into a set of conclusions relevant to stakeholder groups such as the ones identified above.

THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

Board on Life Sciences

500 Fifth Street, NW
Washington, DC 20001
www.dels.nas.edu/bls

WORKSHOP ON KEY CHALLENGES IN THE IMPLEMENTATION OF CONVERGENCE

The National Academy of Sciences, Lecture Room
2101 Constitution Avenue NW
Washington, DC 20418

September 16-17, 2013

AGENDA

September 16
Light continental breakfast available

8:00 **Welcome**
Chair: Joseph DeSimone (NAS, NAE), Committee Chair, Frank Hawkins Kenan Institute of Private Enterprise, University of North Carolina, and North Carolina State University

- Overview of the background and goals of the meeting: *Joseph DeSimone*
- Welcome on behalf of the National Academies:
  - *Ralph Cicerone (NAS), President, National Academy of Sciences*
  - *C. D. Mote, Jr. (NAE), President, National Academy of Engineering*
  - *Harvey Fineberg (IOM), President, Institute of Medicine (by video)*
- How the goals of convergence complement OSTP priorities and activities: *White House Office of Science and Technology Policy (OSTP)*

8:30 **Recognizing Emerging Areas of Science at the Convergence Interface**
Chair: Nicholas Peppas (NAE, IOM), University of Texas at Austin
Session goal: What can convergence achieve and what are selected examples of science with exciting implications that cannot be achieved without a convergence mindset and approach?

- *Phillip Sharp (NAS, IOM), Massachusetts Institute of Technology*

9:00 **Establishing Background and Introduction to the Examples of Convergent and Transdisciplinary Science**
Chair: Hannah Valantine, Stanford University
Session goal: What is the existing research base on how to foster and measure the success of convergent, transdisciplinary, and/or team-science-based research?

- Review of the committee's definition of convergence: *Julie Thompson Klein, Wayne State University and David Roessner, SRI International*
- What does the social science research base tell us about effective teams: *Stephen Fiore, University of Central Florida*
- Evaluating the success of convergent and transdisciplinary research – factors and strategies to consider: *Kara Hall, National Cancer Institute, National Institutes of Health*

9:30 Break

Fostering Convergence in the Real World

How can the goals of convergence translate into practical results, i.e., what have groups and organizations specifically done to support and foster convergence-enabled science? What has worked well and what has not worked as well? Speakers representing several different perspectives will provide brief snapshots of what they did, what challenges they faced, and what they learned.

9:45 The ecosystem of convergent research and innovation in the life sciences: *Cherry Murray (NAS, NAE), Harvard University*

10:00 **Key Organizational Structures and Needs**

Chair: Timothy Galitski, EMD Millipore Corporation and Institute for Systems Biology

Session goal: Speakers in this session will particularly highlight factors in the successful implementation of convergent research such as organizational policies and support structures, strategies to address differences in research practices from bringing diverse communities together, and physical and technical components.

- *Carla Shatz (NAS, IOM), BioX, Stanford University*
- *Anna Barker, Transformative Healthcare Networks and Complex Adaptive Systems Network, Arizona State University*
- *Susan Singer, Carleton College and National Science Foundation*

11:00 **Faculty Issues**

Chair: Cato Laurencin (NAE, IOM), University of Connecticut

Session goal: Speakers in this session will particularly focus on issues such as institutional rewards systems for convergence research and hiring, retention, promotion, and professional development of faculty

- *Fernando Martinez, Bio5, University of Arizona*
- *Donald Ingber (IOM), Wyss Institute, Harvard University*
- *Gerald Rubin, (NAS, IOM) Janelia Farm Research Campus, Howard Hughes Medical Institute*

12:00 Working Lunch and Activity

If you could recommend one action each of the following actors could take that would best facilitate convergent research, what action would that be? Please try to identify a recommended action for at least two of the following categories. Write your answers on the provided post-it notes and affix them to the space beneath the name of the actor:

a) Institutions (e.g., universities, professional associations, non-profits)
b) Units/Departments
c) Principal Investigators/Team Leaders
d) Educators
e) Postdoctoral Fellows and Students
f) Funding Agencies
g) Journal Editors

1:00 **Challenges of Convergent Thinking and Innovation**

Chair: Carol Folt, University of North Carolina, Chapel Hill

- *Arunava Majumdar (NAE), Google, Inc.*

Fostering Convergence in the Real World, *continued*

1:30 **Education and Training**
Chair: Lynne Regan, Yale University
Session goal: Speakers in this session will highlight issues surrounding the education and training of students. Issues might include assuring students get the breadth of training and experience to work in a multidisciplinary setting but sufficient subject expertise for a major; how to issue degrees that span multiple departments or institutions; or other areas.

- *Katerina V. Thompson, University of Maryland College Park*
- *Simon Mochrie, Yale University*
- *Andrea Stith, BioFrontiers Institute, University of Colorado*

2:30 **Inter-Institutional Arrangements and Partnerships**
Chair: Sharon Glotzer, University of Michigan
Session goal: Speakers in this session will particularly discuss arrangements that span institutions.

- *Bruce Walker (IOM), Ragon Institute, Massachusetts General Hospital, Massachusetts Institute of Technology, and Harvard University*
- *David Canter, North Campus Research Complex, University of Michigan*
- *Regis Kelly, California Institute for Quantitative Biosciences (QB3), University of California*

3:30 Brief Break and Move to Small-Group Discussion Sections

3:45 **Discussion Sessions**
Session goal: Participants will be asked to think about the examples and models presented in the workshop as well as their own experiences, and start drawing out lessons on what works in different circumstances. Are there common themes? Are there factors that affect which model(s) appear to work best in different settings or for different goals? Participants will be assigned to a group based on their preferences and in order to get a balanced distribution. Discussion sessions will be given questions to use as starting points.

- GROUP A: Key Organizational Structures and Needs
  Chair: Robert Nerem (NAE, IOM), Georgia Institute of Technology
  Rapporteur: Adah Almutairi, University of California San Diego

- GROUP B: Faculty Issues
  Chair: Carl Simon, University of Michigan
  Rapporteur: Joshua Kritzer, Tufts University

- GROUP C: Education and Training
  Chair: Emery Brown (IOM), Massachusetts Institute of Technology
  Rapporteur: Jasmine Foo, University of Minnesota-Twin Cities

- GROUP D: Inter-institutional Arrangements and Partnerships
  Chair: Matthew Tirrell (NAE), University of Chicago
  Rapporteur: Manu Platt, Georgia Institute of Technology and Emory University

5:15 **Plenary:** Brief Recap of Day 1 and Plan for Day 2

5:30 Adjourn for Day
Reception to follow

September 17
Light continental breakfast available

8:15 **Introduction to Day 2**: *Joseph DeSimone, Committee Chair*

8:30 **Feedback from the Breakout Groups**
Chair: Monica Olvera de la Cruz, Northwestern University
Session goal: Breakout session rapporteurs will provide brief recaps of the key points from their group, followed by discussion.

9:30 **Funding Models**
Chair: James Gentile, Hope College
Session goal: provide an opportunity for agencies and foundations to share how they think about this issue and what issues or challenges they face.

- *Jon Lorsch, National Institute of General Medical Sciences, National Institutes of Health*
- *Dinah Singer, National Cancer Institute, National Institutes of Health*
- *Joann Roskoski, Directorate for Biological Sciences, National Science Foundation*
- *Maria Pellegrini, W.M. Keck Foundation*

10:30 Break

10:45 **Plenary: Roadmap for the Future**
Discussion Leaders: Susan Hockfield, Massachusetts Institute of Technology and Joseph DeSimone, Frank Hawkins Kenan Institute of Private Enterprise, University of North Carolina, and North Carolina State University
Session goal: A facilitated discussion to draw out key messages and lessons learned from the workshop.

12:15 Concluding Remarks: *Joseph DeSimone, Committee Chair*

12:30 **Workshop Adjourns**

BREAKOUT SESSION ASSIGNMENTS

Group A: Key Organizational Structures and Needs

Room: 120
Chair: R. Nerem
Rapporteur: A. Almutairi

A. Arvin
R. Barbero
A. Barker
A. Beheler
L.A. Clements
J. Collins
C. Cooper
J. Elisseeff
T. Galitski
J. Gentile
L. Hull
R. Kelley
J. Lahann
M. McNutt
G. Magombedze
S. Mueller
C. Murray
E. Nawrocki
M. Pellegrini
B. Seto
A. Sharei
P. Sharp
C. Shatz
D. Singer
S. Singer
U. Thakkar
G. von Maltzen
D. Zolandz

Group B: Faculty Issues

Room: 250 (2nd Floor)
Chair: C. Simon
Rapporteur: J. Kritzer

M. Ackerman
A. Arnold
R. Bizios
P. Favi
S. Fiore
M. Fisher
R. Germain
P. Grodzinski
X. Han
W. Harris
D. Ingber
C. Laurencin
F. Martinez
W. Miller
A. Minerick
L. Nagahara
C. O'Hern
M. Olvera de la Cruz
N. Peppas
R. Pieper
G. Rubin
N. Spruston
S. Steichen
H. Valantine
T. Winters
J. Yellin

Group C: Education and Training
Room: 118
Chair: Brown
Rapporteur: Foo

A. Arkin
C. Bauerle
K. Blagoev
R. Carbonell
V.C. Carter
C. Fromen
J.Z. Hilt
M. Hilton
K. Hughes
M. Kinney
S. Mochrie
K. Moynihan
J. Petersson
L. Regan
G. Reiness
S. Robinson
K. Shukla
D. Solomon
A. Stith
K. Thompson
J. Thompson Klein
A. Vollmer
E. Vosburgh
V. Wadhwa

Group D: Inter-Institutional Arrangements and Partnerships
Room: Lecture Room
Chair: Tirrell
Rapporteur: Platt

D. Ausiello
R. Avent
D. Canter
M. Chun
R. DuBois
C. Folt
S. Glotzer
S. Hockfield
R. Iyengar
R. Johnson
L. Kavraki
R. Kelly
J. Lee
J. Lorsch
M. Mitchell
K. Nelson
R. Pettigrew
M. Prakash
P. Reid
D. Roessner
J. Roskoski
P. Schofield
L. Sharpe
R. Tjian
B. Walker

BREAKOUT SESSION DISCUSSION QUESTIONS

The questions below are intended to help provide a starting point to stimulate group discussion and generate ideas for strategies that programs and institutions can use to effectively foster convergence. Your group does not need to limit itself to only these questions.

Group A: Key Organizational Structures and Needs

1. What do you see as the key aspects of organizational policies, structures and resources that are required to facilitate convergent / transdisciplinary research?
2. What are the primary advantages and limitations of different models for providing these policies and infrastructure – can any common themes or successful strategies be identified?
3. Are there key pitfalls to be aware of?
4. Are there specific actions that institutions and departments could take to most effectively facilitate convergence?

Group B: Faculty Issues

1. What do you see as the key factors needed by faculty in order to be able to successfully engage in convergent/ transdisciplinary research?
2. What are the advantages and limitations of different models for providing this type of faculty support and development – can any common themes or successful strategies be identified?
3. Are there key pitfalls to be aware of?
4. Are there specific actions that institutions, departments, and investigators could take to most effectively enable convergence?

Group C: Education and Training

1. What do you see as the key factors needed for the success of education and training programs designed to foster convergent/ transdisciplinary knowledge and research?
2. What are the advantages and limitations of different models for providing these programs – can any common themes or successful strategies be identified?
3. Are there key pitfalls to be aware of?
4. Are there specific actions that institutions, departments, investigators, and students could take to most effectively enable convergent education and training programs?

Group D: Inter-Institutional Arrangements and Partnerships

1. When and for what key issues are arrangements that span organizations needed in order to facilitate convergent/ transdisciplinary research?
2. What are the advantages and limitations of different models for providing these types of inter-institutional arrangements and partnerships – can any common themes or successful strategies be identified?
3. Are there key pitfalls to be aware of?
4. Are there specific actions that organizations, institutes, and other partners could take to most effectively facilitate convergence?

SPEAKER AND CHAIR BIOGRAPHIES

Anna Barker is Professor and Director of the Transformative Healthcare Networks initiative and Co-Director of the Complex Adaptive Systems initiative at Arizona State University. Prior to joining ASU, Dr. Barker served as the Deputy Director of the National Cancer Institute (NCI) and as Deputy Director for Strategic Scientific Initiatives for eight years – retiring in 2010. While Deputy, she developed and implemented multi/trans-disciplinary programs in strategic areas of cancer research and advanced technologies including: the Nanotechnology Alliance for Cancer; The Cancer Genome Atlas (TCGA) – in collaboration with the National Human Genome Research Institute; and the Clinical Proteomics Technologies Initiative for Cancer. Dr. Barker also led the development of a network of trans-disciplinary centers (Physical Sciences-Oncology Centers – PS-OCs) that integrate the physical and biological sciences to better understand cancer across scales. All of these programs emphasize innovation, transdisciplinary teams and convergence of scientific disciplines to enable progress against cancer. They also stress the synergy of large scale and individual initiated research, precompetitive research, public databases and clinical to more effectively detect prevent and treat cancer. Dr. Barker also led and collaborated on NCI's development efforts in biospecimens and bioinformatics (the Cancer Human Biobank (caHUB) and the Cancer Bioinformatics Grid (caBIG, respectively) to support molecularly based personalized medicine. She was the founding co-Chair of the NCI-FDA Interagency Task Force; founding co-Chair of the Cancer Steering Committee of the FNIH Biomarker Consortium; and oversaw the NCI's international cancer research programs, including pilot programs in Latin America and China. Dr. Barker has a long history in research and the leadership and management of research and development in the academic, non-profit and private sectors. She served as a senior scientist and subsequently as a senior executive at Battelle Memorial Institute for 18 years; and cofounded and served as the CEO of a public biotechnology drug development company. She has received a number of awards for her work in support of cancer research, cancer patients, professional and advocacy organizations and the ongoing national effort to prevent and cure cancer. Most recently she received the 2009 AACR Margaret Foti Award for Leadership and Extraordinary Achievements in Cancer Research, AACR 100th Anniversary Meeting; and in 2009 Dr. Barker was named to the list of "The 100 People Changing America" by Rolling Stone Magazine.

Emery N. Brown is the Edward Hood Taplin Professor of Medical Engineering, Professor of Computational Neuroscience, Associate Director of the Institute of Medical Engineering and Science at MIT and the Warren M. Zapol Professor of Anaesthesia at Harvard Medical School and Massachusetts General Hospital (MGH), and an Anesthesiologist at MGH.

Professor Brown received his B.A. (*magna cum laude*) in Applied Mathematics from Harvard College, his M.A. in Statistics from Harvard University, his M.D. (*magna cum laude*) from Harvard Medical School and a Ph.D. in Statistics from Harvard University. He is an anesthesiologist-statistician whose methodology research develops signal processing algorithms to characterize how the brain represents and transmits information. His experimental research is characterizing how anesthetic drugs act in the brain to create the state of general anesthesia.

Professor Brown is currently a member of the NIH BRAIN Initiative Working Group, NIH Council of Councils, the NSF Mathematical and Physical Sciences Advisory Committee, the Board of Directors of the International Anesthesia Research Society and Board of Directors of the Burroughs-Wellcome Fund.

Professor Brown is a fellow of the IEEE, the American Statistical Association, the American Association for the Advancement of Science, the American Academy of Arts and Sciences, and a member of the

Institute of Medicine. He is a recipient of a 2007 NIH Director's Pioneer Award, the 2011 Sacks Award from the National Institute of Statistical Sciences, and a 2012 NIH Director's Transformative Research Award.

David Canter is Senior Associate Vice President and Executive Director of the University of Michigan North Campus Research Complex (NCRC). In his role, Dr. Canter has the responsibility for mapping, developing and implementing the university's strategy to make the most of the site's 28 buildings and dozens of acres of open land. After nearly 25 years in pharmaceutical research and leadership at Pfizer as a Senior Vice President of Global Research and Development, Dr. Canter became Director of the Healthcare Research Initiative at the William Davidson Institute, a non-profit research and educational institute at the University of Michigan. Since 2008, he has led an effort to test business-based approaches to improving health care delivery in developing nations. A native of England, Dr. Canter received his undergraduate degree from Cambridge University and his medical degree from the Liverpool University Medical School. He is a Fellow of the Royal College of Surgeons. He has served on the boards of many local and regional organizations, from the Michigan Life Sciences Corridor Committee to the University Musical Society, and is well connected to the region's business and academic community. These connections are vital to his role as executive director of NCRC, which has stakeholders across the University and in the city, region and state.

Ralph J. Cicerone is the President of the National Academy of Sciences and Chair of the National Research Council. His research in atmospheric chemistry, climate change and energy has involved him in shaping science and environmental policy at the highest levels nationally and internationally.

Dr. Cicerone has received a number of honorary degrees and many awards for his scientific work. Among the latter, the Franklin Institute recognized his fundamental contributions to the understanding of greenhouse gases and ozone depletion by selecting Dr. Cicerone as the 1999 laureate for the Bower Award and Prize for Achievement in Science. In 2001, he led a National Academy of Sciences study of the current state of climate change and its impact on the environment and human health, requested by President Bush. The American Geophysical Union awarded Dr. Cicerone its James B. Macelwane Award in 1979 for outstanding contributions to geophysics by a young scientist and its 2002 Roger Revelle Medal for outstanding research contributions to the understanding of Earth's atmospheric processes, biogeochemical cycles, and other key elements of the climate system. In 2004, the World Cultural Council honored him with the Albert Einstein World Award in Science. In addition to the National Academy of Sciences, Dr. Cicerone is a member of the American Academy of Arts and Sciences, the American Philosophical Society, the Accademia Nazionale dei Lincei, the Russian Academy of Sciences, and the Korean Academy of Science and Technology. He has served as President of the American Geophysical Union, the world's largest society of earth scientists.

Dr. Cicerone was educated at the Massachusetts Institute of Technology (B.S. in electrical engineering) and the University of Illinois at Champaign-Urbana (M.S., Ph.D. in electrical engineering, with a minor in physics). In his early career, he was a research scientist and held faculty positions in electrical and computer engineering at the University of Michigan. The Ralph J. Cicerone Distinguished University Professorship of Atmospheric Science was established there in his honor in 2007. In 1978 he joined the Scripps Institution of Oceanography at the University of California, San Diego as a Research Chemist. From 1980 to 1989, he was a Senior Scientist and Director of the Atmospheric Chemistry Division at the National Center for Atmospheric Research in Boulder, Colorado. In 1989 he joined the University of California, Irvine, where he was Founding Chair of the Department of Earth System Science and was appointed the Daniel G. Aldrich Professor of Earth System Science. As Dean of the School of Physical

Sciences from 1994 to 1998, he recruited outstanding faculty and strengthened the school's curriculum and outreach programs. Immediately prior to his election as Academy President, Dr. Cicerone served as Chancellor of UC Irvine from 1998 to 2005, a period marked by a rapid rise in the academic capabilities of the campus. His research has focused on atmospheric chemistry, the radiative forcing of climate change due to trace gases, and the sources of atmospheric methane, nitrous oxide and methyl halide gases.

Joseph M. DeSimone is Chancellor's Eminent Professor of Chemistry at the University of North Carolina at Chapel Hill (UNC) and William R. Kenan Jr. Professor of Chemical Engineering at North Carolina State University. He is also the Director of the Frank Hawkins Kenan Institute of Private Enterprise at UNC and is an Adjunct Member at Memorial Sloan-Kettering Cancer Center in New York. His interests include applying lithographic techniques from the computer industry to the design of new medicines & vaccines; colloid, surfactant and surface chemistry; the role of diversity in innovation; and entrepreneurship from research-intensive universities. Dr. DeSimone has published over 290 scientific articles and has more than 130 issued patents in his name. In 2004 Dr. DeSimone launched Liquidia Technologies, which now employs roughly 50 people and has raised over $60 million in venture financing, including the first ever equity investment by the Bill and Melinda Gates Foundation in a for-profit biotech company. Liquidia has converted a soft lithography method, PRINT, into a GMP-compliant process and has recently brought its first product, a seasonal influenza vaccine based on PRINT particles, into its first clinical trial. Dr. DeSimone received his B.S. in Chemistry in 1986 from Ursinus College in Collegeville, PA and his Ph.D. in Chemistry in 1990 from Virginia Tech. He is a member of the National Academy of Sciences and the National Academy of Engineering.

Harvey V. Fineberg is President of the Institute of Medicine. He served as Provost of Harvard University from 1997 to 2001, following thirteen years as Dean of the Harvard School of Public Health. He has devoted most of his academic career to the fields of health policy and medical decision making. His past research has focused on the process of policy development and implementation, assessment of medical technology, evaluation and use of vaccines, and dissemination of medical innovations. Dr. Fineberg helped found and served as President of the Society for Medical Decision Making and has been a consultant to the World Health Organization. At the Institute of Medicine, he has chaired and served on a number of panels dealing with health policy issues, ranging from AIDS to new medical technology. He also served as a member of the Public Health Council of Massachusetts (1976-1979), as Chairman of the Health Care Technology Study Section of the National Center for Health Services Research (1982-1985), and as president of the Association of Schools of Public Health (1995-1996). Dr. Fineberg is co-author of the books *Clinical Decision Analysis*, *Innovators in Physician Education*, and *The Epidemic that Never Was*, an analysis of the controversial federal immunization program against swine flu in 1976. He has co-edited several books on such diverse topics as AIDS prevention, vaccine safety, and understanding risk in society. He has also authored numerous articles published in professional journals. Dr. Fineberg is the recipient of several honorary degrees and the Stephen Smith Medal for Distinguished Contributions in Public Health from the New York Academy of Medicine. He earned his bachelor's and doctoral degrees from Harvard University.

Stephen M. Fiore is an Associate Professor of Cognitive Sciences in the University of Central Florida's Department of Philosophy and director of the Cognitive Sciences Laboratory at UCF's Institute for Simulation and Training. He also serves as the current President of the Interdisciplinary Network for Group Research and is a founding program committee member for the annual Science of Team Science conference. Dr. Fiore's primary area of research is the interdisciplinary study of complex collaborative problem solving. He has taken a leadership role in the development of the field of team cognition, a melding of cognition with understanding how humans interact socially and with technology. He maintains a multidisciplinary research interest that incorporates aspects of the cognitive, social, and computational sciences in the investigation of learning and performance in individuals and teams. He is co-editor of recent volumes on *Shared Cognition*, (2012), *Macrocognition in Teams* (2008), *Distributed Learning* (2007), *Team Cognition* (2004), and he has co-authored over 150 scholarly publications in the area of learning, memory, and problem solving at the individual and the group level. His prior National Research Council service includes co-authoring and presenting a paper on “Assessment of Interpersonal Skills” for the Board on Testing and Assessment’s workshop on “Assessment of 21st Century Skills”. Dr. Fiore provided intellectual and practical assistance to the National Research Council staff in developing the project on the Science of Team Science. He has a Ph.D. in cognitive psychology from the University of Pittsburgh, Learning Research and Development Center.

Carol L. Folt is the 11th Chancellor, and the 29th Chief Executive, of the University of North Carolina at Chapel Hill. An environmental scientist and teacher, Dr. Folt previously served as Professor of Biological Sciences at Dartmouth College and as interim President of Dartmouth (2012-2013). After joining the Dartmouth faculty in 1983, Dr. Folt was named Associate Director of Dartmouth’s Toxic Metals Research Program in 1998, and two years later became Associate Director of the Center for Environmental Health Sciences. She was appointed Dean of Graduate Studies and Associate Dean of the Faculty for Interdisciplinary Programs in 2001, Dean of the Faculty in 2004, Acting Provost in 2009, and Provost in 2010. As interim President, she helped identify opportunities for greater collaboration across schools to enhance academic quality and competitiveness, oversaw growth in global partnerships, and augmented support for faculty, student and community entrepreneurship and technological innovation. Dr. Folt’s research has focused on the effects of dietary mercury and arsenic on human and ecosystem health, salmonid fisheries management and restoration, and global climate change. She and colleagues developed new technologies to assess mercury exposure and formed regional, national and international partnerships to shape public policy for safer waters. She worked her way through the University of California at Santa Barbara as a waitress, earning a bachelor’s degree in aquatic biology in 1976 and a master’s degree in biology two years later. She received her doctorate in ecology in 1982 from the University of California at Davis and did postdoctoral work at the W.K. Kellogg Biological Station of Michigan State University. She is a Fellow of the American Association for the Advancement of Science.

Timothy Galitski is the Head of Science & Technology in the Bioscience Business Unit of EMD Millipore Corporation, and an Affiliate Professor at the Institute for Systems Biology (ISB) in Seattle. Previously at the ISB for ten years, he was a Professor and a member of the leadership team that grew the institution from a handful of employees to a transformational organization with global scientific impact. His education, training, and research span the fields of genetics, microbiology, molecular and cell biology, functional genomics, proteomics, microfluidics technology development, and computational biology. Dr. Galitski earned his Ph.D. in the University of Utah's Department of Biology where he identified mechanisms of chromosome rearrangement and studied the origin of genetic variation. His research earned him the 1996 James W. Prahl Memorial Award for the Outstanding Graduate Student at the University of Utah Medical Center. With a fellowship from the Helen Hay Whitney Foundation, Dr. Galitski went on to a postdoctoral position at the Whitehead Institute for Biomedical Research and the Whitehead/MIT Center for Genome Research in Cambridge, Massachusetts. There he combined functional genomics, genetics, and computational methods to reveal global patterns of gene expression specifying cell type and developmental potential in yeast. For this work, Dr. Galitski was awarded the 2001 Burroughs Wellcome Fund Career Award in the Biomedical Sciences.

James M. Gentile is Dean for the Natural & Applied Sciences at Hope College in Holland, MI. He is the former President of Research Corporation for Science Advancement, a foundation dedicated to science since 1912 and the second-oldest foundation in the United States (after the Carnegie Corporation). A geneticist by training, Dr. Gentile has conducted extensive research on the role of metabolism in the conversion of natural and xenobiotic agents into mutagens and carcinogens, with funding from the National Institutes of Health, the National Science Foundation, the U.S. Environmental Protection Agency, and the World Health Organization, among many other institutions. He received his doctorate from Illinois State University and spent two years in postdoctoral studies in the Department of Human Genetics at the Yale University School of Medicine. He is the author of more than 150 research articles, book chapters, book reviews and special reports in areas of scientific research and higher education, and he is a frequent speaker on issues involving the integration of scientific research and higher education.

Sharon C. Glotzer is the Stuart W. Churchill Collegiate Professor of Chemical Engineering and Professor of Materials Science and Engineering, at the University of Michigan, Ann Arbor. She also holds faculty appointments in Physics, Applied Physics, and Macromolecular Science and Engineering. Dr. Glotzer's research focuses on computational nanoscience and simulation of soft matter, self-assembly and materials design, and is sponsored by the U.S. Department of Defense, U.S. Department of Energy, U.S. National Science Foundation, the J.S. McDonnell Foundation, and the Simons Foundation. Sharon C. Glotzer is an internationally recognized scientist, with over 170 publications and over 260 invited, keynote and plenary talks on five continents. In addition to numerous awards and honors, Dr. Glotzer was elected in 2011 to the American Academy of Arts and Sciences, is a Fellow of the American Physical Society (APS) and a National Security Science and Engineering Faculty Fellow, and was named a Simons Investigator in 2012, the inaugural year of that program. Dr. Glotzer serves on many editorial and advisory boards, and has provided leadership and input on roadmapping for federal granting agencies on many topics, including high performance computing, materials design, technology warning, and simulation-based engineering and science.

Kara Hall is a Health Scientist, Director of the Science of Team Science Team, and co-Director of the Theories Project in the Science of Research and Technology Branch of the Behavioral Research Program, Division of Cancer Control and Population Sciences at the National Cancer Institute. During her career, Dr. Hall has participated in a variety of interdisciplinary clinical and research endeavors. Her research has focused on the development of behavioral science methodologies such as the design of survey protocols, meta-analytic techniques for health behavior theory testing, as well as on applications of health behavior theory to multiple content areas and the development of computerized tailored interventions to foster health promotion and disease prevention behaviors. Since arriving at NCI, Dr. Hall has focused on advancing dissemination and implementation research and the science of team science as well as promoting the use, testing, and development of health behavior theory in cancer control research. Furthermore, Dr. Hall works to champion areas including systems science approaches and teams/groups in health and healthcare. Notably, Dr. Hall helped launch the field of the Science of Team Science by serving as a co-Chair for the 2006 conference "The Science of Team Science: Assessing the Value of Trans-disciplinary Research" and co-editor for the recent American Journal of Preventive Medicine Special Supplement on the Science of Team Science. Dr. Hall earned her master's and doctoral degrees in psychology with specializations in clinical psychology, neuropsychology, and behavioral science at the University of Rhode Island.

Susan Hockfield is Professor of Neuroscience at the Massachusetts Institute of Technology (MIT) and served as the sixteenth President of MIT from December 2004 through June 2012. After earning a B.A. in biology from the University of Rochester and a Ph.D. from the Georgetown University School of

Medicine, Dr. Hockfield was an NIH postdoctoral fellow at the University of California, San Francisco. She then joined the scientific staff at the Cold Spring Harbor Laboratory in New York. Joining the faculty of Yale University in 1985, Dr. Hockfield focused her research on the development of the brain and on glioma, a deadly form of brain cancer, and pioneered the use of monoclonal antibody technology in brain research. She gained tenure in 1994 and was later named the William Edward Gilbert Professor of Neurobiology. She served as Dean of Yale's Graduate School of Arts and Sciences and then as Provost. Dr. Hockfield holds honorary degrees from institutions including Brown University, Mt. Sinai School of Medicine, Tsinghua University (Beijing), University of Edinburgh, Université Pierre et Marie Curie, University of Massachusetts Medical School, University of Rochester, and the Watson School of Biological Sciences at the Cold Spring Harbor Laboratory. Her accomplishments have been recognized by the Charles Judson Herrick Award from the American Association of Anatomists, the Wilbur Lucius Cross Award from the Yale University Graduate School, the Meliora Citation from the University of Rochester, the Golden Plate Award from the Academy of Achievement, the Amelia Earhart Award from the Women's Union, the Edison Award, and the Pinnacle Award for Lifetime Achievement from the Greater Boston Chamber of Commerce.

Donald E. Ingber is the Founding Director of the Wyss Institute for Biologically Inspired Engineering at Harvard University, the Judah Folkman Professor of Vascular Biology at Harvard Medical School and Boston Children's Hospital, and Professor of Bioengineering at the Harvard School of Engineering and Applied Sciences. Dr. Ingber is a founder of the emerging field of biologically inspired engineering, and at the Wyss Institute, he oversees a multifaceted effort to identify the mechanisms that living organisms use to self-assemble from molecules and cells, and to apply these design principles to develop advanced materials and devices. He also leads the Biomimetic Microsystems platform in which microfabrication techniques from the computer industry are used to build functional circuits with living cells as components. His most recent innovation is a technology for building tiny, complex, three-dimensional models of living human organs, or "organs on chips", that mimic complicated human functions as a way to replace traditional animal-based methods for testing of drugs and toxins. Dr. Ingber has made major contributions to mechanobiology, tissue engineering, tumor angiogenesis, systems biology, and nanobiotechnology. He was the first to recognize that tensegrity architecture (in which a system stabilizes itself mechanically by balancing local compression with continuous tension) is a fundamental principle that governs how living cells are structured to respond biochemically to mechanical forces. In addition, Dr. Ingber has authored more than 375 publications and 85 patents and has received numerous honors including the Holst Medal, Pritzker Award from the Biomedical Engineering Society, Rous-Whipple Award from the American Society for Investigative Pathology, Lifetime Achievement Award from the Society of In Vitro Biology, and the Department of Defense Breast Cancer Innovator Award. He also serves on the Board of Directors of the National Space Biomedical Research Institute, and is a member of both the American Institute for Medical and Biological Engineering, and the Institute of Medicine of the National Academies.

Tom Kalil is the Deputy Director for Technology and Innovation for the White House Office of Science and Technology Policy and Senior Advisor for Science, Technology and Innovation for the National Economic Council. In this role, he serves as a senior White House staffer charged with coordinating the government's technology and innovation agenda. Prior to serving in the Obama Administration, Dr. Kalil was Special Assistant to the Chancellor for Science and Technology at the University of California, Berkeley. In 2007 and 2008, he was Chair of the Global Health Working Group for the Clinton Global Initiative. Previously, Dr. Kalil served for 8 years in the Clinton White House, ultimately as the Deputy Assistant to the President for Technology and Economic Policy, and the Deputy Director of the National

Economic Council. He received a B.A. from the University of Wisconsin at Madison, and completed graduate work at Tufts University's Fletcher School.

Regis B. Kelly is Director of the QB3 Institute, an innovation center made up of over 200 quantitative biologists at three northern California campuses (UCB, UCSC & UCSF) working at the interface of the physical and biological sciences and a team of professionals converting its discoveries into practical benefits for society. Prior to joining QB3 in 2004, Dr. Kelly served as Executive Vice-Chancellor at UCSF; he oversaw the UCSF research enterprise and was also responsible for construction of the new Mission Bay campus. He was Chairman of the Bay Area Scientific Innovation Consortium and has served on the boards of the Malaysian Biotechnology Industry Advisory Board, the Scleroderma Foundation, and Bridge Pharmaceuticals. He is an advisor to the Thailand Bionanotechnology Institute, Ho Chi Minh City Biotechnology Department Corp., University of Oxford Systems Biology Program, and the San Francisco Mayor's Biotechnology Advisory Group. He joined the UCSF Department of Biochemistry in 1971 and has served as Director of the Cell Biology Graduate Program, Director of the Hormone Research Institute, and Chair of the Department of Biochemistry and Biophysics. He earned an undergraduate degree in physics from the University of Edinburgh and a Ph.D. in biophysics from the California Institute of Technology.

Cato T. Laurencin is the Albert and Wilda Van Dusen Distinguished Endowed Professor of Orthopaedic Surgery and Professor of Chemical, Materials and Biomolecular Engineering at the University of Connecticut. An internationally prominent orthopaedic surgeon, engineer, and administrator, Dr. Laurencin is also the Founder and Director of both the Institute for Regenerative Engineering and the Sackler Center for Biomedical, Biological, Physical and Engineering Sciences at the University of Connecticut Health Center. In addition, he serves as the Chief Executive Officer of the Connecticut Institute for Clinical and Translational Science at the University of Connecticut. Dr. Laurencin has been a member of the National Science Foundation's Advisory Committee for Engineering (ADCOM), and has served both on the National Science Board of the FDA and the National Advisory Council for Arthritis, Musculoskeletal and Skin Diseases at the National Institutes of Health (NIH). He is currently a member of the National Advisory Council for Biomedical Imaging and Bioengineering and the Advisory Committee to the NIH Director. Dr. Laurencin earned his undergraduate degree in chemical engineering from Princeton University and his medical degree *magna cum laude* from Harvard Medical School. During medical school, he also earned his Ph.D. in biochemical engineering/biotechnology from the Massachusetts Institute of Technology. He is a member of the Institute of Medicine and the National Academy of Engineering.

Jon R. Lorsch is Director of the National Institute of General Medical Sciences (NIGMS) at the National Institutes of Health. He came to NIGMS from the Johns Hopkins University School of Medicine, where he was a Professor in the Department of Biophysics and Biophysical Chemistry. A leader in RNA biology, Dr. Lorsch studies the initiation of translation, a major step in controlling how genes are expressed. To dissect the mechanics of translation initiation, Dr. Lorsch and collaborators developed a yeast-based system and a wide variety of biochemical and biophysical methods. The work also has led to efforts to control translation initiation through chemical reagents, such as drugs. During his tenure at Johns Hopkins, he worked to reform the curricula for graduate and medical education, spearheaded the development of the Center for Innovation in Graduate Biomedical Education, and launched a program offering summer research experiences to local high school students, many from groups that are underrepresented in the biomedical and behavioral sciences. In addition, he advised dozens of undergraduate and graduate students and postdoctoral fellows. Dr. Lorsch received a B.A. in chemistry from Swarthmore College in 1990 and a Ph.D. in biochemistry from Harvard University in 1995, where he worked in the laboratory of Jack Szostak, Ph.D. He conducted postdoctoral research at Stanford University in the laboratory of Daniel Herschlag, Ph.D. He is the author of more than 60 peer-reviewed research articles, book chapters and other papers. He has also been the editor of three volumes of *Methods in Enzymology* and a reviewer for numerous scientific journals. He has one patent and one patent application related to his translation research. His honors include six teaching awards from Johns Hopkins.

Arunava Majumdar recently joined Google as Vice President of Energy. Until June 2012, he served as the Founding Director of the Advanced Research Projects Agency - Energy (ARPA-E) as well as the Acting Under Secretary of Energy in the Department of Energy. Before that, he was a Professor of Mechanical Engineering and Materials Science and Engineering at the University of California, Berkeley, as well as the Associate Laboratory Director for Energy and Environment at Lawrence Berkeley National Laboratory. Dr. Majumdar received his Ph.D. in Mechanical Engineering in 1989 from UC Berkeley, and bachelors in 1985 from the Indian Institute of Technology, Bombay. Among his recognitions, he was elected to the National Academy of Engineering in 2005.

Fernando Martinez is Director of the BIO5 Institute at the University of Arizona, which is a hub for collaborative, interdisciplinary research. BIO5 faculty currently represents over 22 different academic colleges and disciplines – including the original "5": Agriculture, Engineering, Medicine, Pharmacy, and Science. In addition to his role as Director of the BIO5 Institute, Dr. Martinez is a Regents' Professor, Swift-McNear Professor of Pediatrics in the College of Medicine, Director of the Arizona Respiratory Center, and Director of the Arizona Clinical Translational Science Institute at the University of Arizona. He is a researcher and clinician with major projects that study the natural history of childhood asthma, and the role of genetic, physiological, immunological and environmental factors as determinants of the risk for asthma in early life. Dr. Martinez received his medical degrees from the University of Chile, Santiago and the University of Rome, Italy. He completed his residency in pediatrics at the University of Rome, specializing in pediatric pulmonology. He has been at the University of Arizona since 1987. Dr. Martinez has been a member of the Board of Extramural Advisors of the National Heart, Lung and Blood Institute (NHLBI), and of the Pulmonary and Allergy Drug Advisory Committee of the U.S. Food and Drug Administration (FDA). He was also a member of the National Asthma Education and Prevention Program's Expert Panel, which developed the last two versions of the *NHLBI Guidelines for the Treatment of Asthma*. Dr. Martinez has written more than 200 journal articles, book chapters and editorials, and has lectured in over 50 countries across the world.

Simon Mochrie is Professor of Physics and Applied Physics at Yale University and serves as the Principal Investigator for the National Science Foundation Physics of Living Systems – Science Across Virtual Institutes Student Research Network at Yale. His research focuses on experimental studies of the properties, phase behavior, and phase transitions of soft matter using techniques such as high-resolution x-ray scattering, atomic force microscopy, and optical tweezers. He developed, and for the last four years has taught, a re-imagined version of Introductory Physics for the Life Sciences (IPLS) at Yale, which (1) Seeks to initiate a cultural shift away from the notion that quantitative, mathematical approaches are alien to the biological sciences; (2) Recognizes that the course will be taken by outstanding students, who, because they are fascinated by living things, have chosen to major in biology rather than the physical sciences or engineering; (2) Employs as examples meaningful and engaging quantitative and mathematical treatments of biologically-relevant topics; (3) Is taught at a level of mathematics and calculus that has been carefully calibrated to be well-suited to the students and the material without compromising sophistication; and (4) Incorporates a number of stimulating in-class activities, in which the students participate in “active learning”. He received his Ph.D. from the Massachusetts Institute of Technology in Experimental Condensed Matter Physics and Biophysics.

C. D. (Dan) Mote, Jr. is President of the National Academy of Engineering and Regents Professor, on leave, from the University of Maryland, College Park.

Dr. Mote is a native Californian who earned his B.S., M.S., and Ph.D. degrees at the University of California, Berkeley in mechanical engineering between 1959 and 1963. After a postdoctoral year in England and three years as an Assistant Professor at the Carnegie Institute of Technology in Pittsburgh, he returned to Berkeley to join the faculty in Mechanical Engineering for the next 31 years. He and his students investigated the dynamics, stability, and control of high-speed rotating and translating continua (e.g., disks, webs, tapes, and cables) as well as biomechanical problems emanating from snow skiing. He coined the area called “dynamics of axially moving materials” encompassing these systems. At Berkeley, he held an endowed Chair in Mechanical Systems and served as Chair of the Mechanical Engineering Department from 1987 to 1991. In 1991 he was appointed Vice Chancellor at Berkeley and in 1998 was recruited to the Presidency of the University of Maryland, College Park, a position he held until 2010 when he was appointed Regents Professor.

The NAE elected him to membership in 1988 and to the positions of Councillor (2002-2008), Treasurer (2009-2013), and President for six years beginning July 1, 2013. He has served on the NRC Governing Board Executive Committee since 2009. Dr. Mote’s recognitions include the NAE Founders Award, the American Society of Mechanical Engineers Medal, and the Humboldt Prize of the Federal Republic of Germany. At the University of California, Berkeley, he was honored with the Distinguished Teaching Award, Distinguished Engineering Alumnus Award, Berkeley Citation, and Excellence in Achievement Award. He is an Honorary Fellow of the American Society of Mechanical Engineers, and Fellow of the American Academy of Arts and Sciences, the American Academy of Mechanics, the Acoustical Society of America and the American Association for the Advancement of Science. He holds three honorary doctorates and two honorary professorships.

Cherry A. Murray is Dean of Harvard University’s School of Engineering and Applied Sciences, John A. and Elizabeth S. Armstrong Professor of Engineering and Applied Sciences, and Professor of Physics. Previously, Dr. Murray served as Principal Associate Director for Science and Technology at Lawrence Livermore National Laboratory from 2004-2009 and was President of the American Physical Society (APS) in 2009. Before joining Lawrence Livermore, she was Senior Vice President of Physical Sciences and Wireless Research after a 27 year long career at Bell Laboratories Research. As an experimentalist, Dr. Murray is known for her scientific accomplishments in condensed matter and surface physics. She has published more than 70 papers in peer-reviewed journals and holds two patents in near-field optical data storage and optical display technology. Dr. Murray was elected to the National Academy of Sciences in 1999, to the American Academy of Arts and Sciences in 2001, and to the National Academy of Engineering in 2002. She has served on more than 100 national and international scientific advisory committees, governing boards and National Research Council panels and as a member of the National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, and she is currently Chair of the National Research Council Division of Engineering and Physical Science. She received her B.S. in 1973 and her Ph.D. in physics in 1978 from the Massachusetts Institute of Technology.

Robert M. Nerem is the Parker H. Petit Distinguished Chair for Engineering in Medicine, Institute Professor Emeritus, and Former Director of the Parker H. Petit Institute for Bioengineering and Bioscience at the Georgia Institute of Technology. He received his Ph.D. in 1964 from Ohio State

University and joined the faculty there in the Department of Aeronautical and Astronautical Engineering, being promoted to Professor in 1972 and serving from 1975-1979 as Associate Dean for Research in the Graduate School. From 1979 to 1986 he was Professor and Chairman of the Department of Mechanical Engineering at the University of Houston. His research is in the field of cellular and tissue engineering as applied to the vascular system, including the development of a blood vessel substitute for use in bypass surgery, the investigation of hemodynamics as a regulator of vascular biology, and the mathematical modeling of the dynamic response of mammalian cells. Dr. Nerem has previously served as President of the International Federation for Medical and Biological Engineering (1988-91), the International Union for Physical and Engineering Sciences in Medicine (1991-94), the American Institute of Medical and Biological Engineering (1992-94), and the Tissue Engineering Society International (2002-2004). He is a Fellow of the American Institute for Medical and Biological Engineering, American Association for the Advancement of Science, American Physical Society, and American Society of Mechanical Engineers. Dr. Nerem is a member of the National Academy of Engineering (NAE) and the Institute of Medicine of the National Academy of Sciences. In addition, he served on the NAE Council for six years.

Monica Olvera de la Cruz is the Lawyer Taylor Professor of Materials Science & Engineering, Professor of Chemistry and of Chemical and Biological Engineering, and Director of the Materials Research Center at Northwestern University. Dr. Olvera de la Cruz obtained her B.A. in Physics from the Universidad Nacional Autónoma de México (UNAM) in 1981, and her Ph.D. in Physics from Cambridge University, U.K., in 1985. She was a Guest Scientist (1985-86) at the National Institute of Standards and Technology, Gaithersburg, MD. From 1995-97 she was a Staff Scientist in the Commissariat a l'Energie Atomique, Saclay, France, where she also held visiting scientist positions in 1993 and in 2003. She has developed theoretical models to determine the thermodynamics, statistics and dynamics of macromolecules in complex environments including multicomponent solutions of heterogeneous synthetic and biological molecules, and molecular electrolytes. She serves on the advisory boards of many national research centers and is a member of the editorial board of *Macromolecules*, *Journal of Polymer Science Polymer B: Polymer Physics*, *Current Opinion in Solid State and Materials Science*, *and Annual Review of Materials Research*. She is a member of the National Academy of Sciences and a Fellow of the American Academy of Arts and Sciences.

Maria Pellegrini is the Executive Director for Programs at the W.M. Keck Foundation in Los Angeles. She is the former Vice President for Research at Brandeis University and before that was the Program Director for Science and Engineering and the Liberal Arts at the Keck Foundation. Before joining the Keck Foundation Dr. Pellegrini served 20 years on the faculty of the University of Southern California as Professor of Biology. During that time, she served as department Chair for five years, and as Dean of Research in the College of Letters, Arts and Sciences. She was a Fellow of the Alfred P. Sloan Foundation and the recipient of the Camille and Henry Dreyfus Foundation Teacher Scholar Award. Dr. Pellegrini received her A.B. in Chemistry from Connecticut College, and her Ph.D. in Chemistry from Columbia University. She was a postdoctoral fellow at Caltech.

Nicholas A. Peppas is the Fletcher Stuckey Pratt Chair in Engineering, Chair of the Department of Biomedical Engineering, and Professor of Chemical Engineering, Biomedical Engineering and Pharmacy at the University of Texas at Austin. Dr. Peppas is a pioneer in the synthesis, characterization and dynamic behavior of polymer networks, particularly hydrogels. He is a leading researcher, inventor and pacesetter in the field of drug delivery and controlled release, a field that he helped develop into a mature area of scholarly and applied research. As an inventor of new biomaterials, he has contributed seminal work in the field of feedback controlled biomedical devices. The multidisciplinary approach of his research in biomolecular engineering blends modern molecular and cellular biology with engineering to generate next-generation systems and devices, including bioMEMS with enhanced applicability, reliability, functionality, and longevity. His contributions have been translated into more than twenty medical products. He has received numerous awards including the Founders Award of the National Academy of Engineering (2012); the Distinguished Achievement Award from the Biomedical Engineering Society (2010); the Founders Awards of the American Institute of Chemical Engineers (AIChE), the Society for Biomaterials (SFB) and the Controlled Release Society (CRS); and the Pierre Galletti Award of the American Institute of Medical and Biological Engineering (AIMBE). He is President of the International Union of Societies of Biomaterials Science and Engineering and President-elect of the Engineering Section of the American Association for the Advancement of Science (AAAS). He is a Fellow of AAAS, ACS, APS, MRS, AIChE, AIMBE, BMES, SFB, ASEE, CRS and AAPS. Dr. Peppas is an elected member of the National Academy of Engineering (NAE), the Institute of Medicine (IOM), the National Academy of France and the Royal National Academy of Spain. A native of Athens, Greece, he received his B.S. from the National Technical University of Athens in 1971 and his Sc.D. from MIT in 1973, both in chemical engineering. He holds honorary doctorates from the Universities of Ghent, Parma, Athens and Ljubljana.

Lynne J. Regan is Professor of Molecular Biophysics and Biochemistry, Professor of Chemistry, and Director of the Integrated Graduate Program in Physical and Engineering Biology (IGPPEB) at Yale University. The program is designed to train a new generation of scientists skilled in applying physics and engineering methods and reasoning to biological research, while remaining sufficiently sophisticated in their biological training that they will be able to readily identify and tackle cutting-edge problems in the life sciences. Dr. Regan's research focuses on protein structure, function, and design, particularly the question of how a protein's primary sequence specifies its three dimensional structure. Dr. Regan received a B.A. from Oxford University in 1981 and a Ph.D. from the Massachusetts Institute of Technology in 1987. She has been a Visiting Scientist at E.I. du Pont de Nemours & Company and a Visitor in the Structural Studies Division of the Medical Research Council Laboratory of Molecular Biology, Cambridge, U.K.

J. David Roessner is Senior Fellow with SRI International's Center for Science, Technology and Economic Development and Professor of Public Policy Emeritus at Georgia Institute of Technology. Dr. Roessner's research interests include national and regional technology policy, the evaluation of research programs, industry-university research collaboration, technology transfer, and assessment of interdisciplinary research. His recent projects include evaluations of NSF-funded U.S. Engineering Research Centers and State/Industry-University Cooperative Research Centers; estimates of the national and regional economic impact of NSF Engineering Research Centers, design of the Technology Innovation Centers Program for the King Abdulaziz City for Science and Technology (KACST), Saudi Arabia's national science and technology agency; strategic planning for a university-based innovation center at Universidad Catolica in Chile; and a review of approaches to understanding and measuring interdisciplinary research for the NSF. Dr. Roessner has written numerous technical reports and published in policy-oriented journals such as *Policy Analysis*, *Policy Sciences*, *Journal of Technology Transfer*, *Issues in Science and Technology*, *Research Evaluation, Scientometrics,* and *Research Policy*. Dr. Roessner also is a contributor to and editor of several books, including *Government Innovation Policy: Design, Implementation, Evaluation* (St. Martin's Press, 1988). During 2003-2008 he served as Senior Evaluation Consultant to the National Academies' Keck Futures Initiative. He holds B.S. and M.S. degrees from Brown and Stanford Universities, respectively, and a Ph.D. in Science, Technology and Public Policy from Case Western Reserve University.

Joann Roskoski is Deputy Assistant Director the NSF Biological Sciences Directorate (BIO). She received a B.A. in Bacteriology from Douglass College in 1969, a Masters in Ecology from Rutgers University in 1971, and her doctorate from Yale University in Forest Ecology in 1977. From 1977 through 1983, she studied the microbial ecology of tropical-cropping systems in Mexico first as a Rockefeller postdoc, then as a Research Associate with a Mexican Research Institute and then at the University of Arizona. From 1983 through 1988, she was Director of Research for a U.S. AID international agricultural research and development program at the University of Hawaii. After managing a tropical forestry grants program at the National Research Council (1988-89) for 2 years, she went to NSF in 1989 where she ran the Ecology Program, was Deputy Director for the Division of Environmental Biology, and the Executive Officer for BIO from 2001 through 2009. From 2009 through 2011 she served as Acting Assistant Director for the NSF Biological Sciences Directorate.

Gerald Rubin is Vice President of the Howard Hughes Medical Institute (HHMI) and Executive Director of the Janelia Farm Research Campus. He held faculty positions at Harvard Medical School and the Carnegie Institution of Washington's Department of Embryology before moving to the University of California, Berkeley, in 1983, to assume the John D. MacArthur Professorship (held until 1999). He became a Howard Hughes Medical Institute investigator in 1987. Dr. Rubin served as HHMI's Vice President for Biomedical Research (2000—2002) and Vice President and Director of Planning for Janelia Farm Campus (2002), and he became Vice President and Executive Director of the Janelia Farm Research Campus in 2003. His research has included studies of the structure and biology of transposable elements and molecular mechanisms of cell fate determination during development of the Drosophila retina. In 1982, he and Allan Spradling developed methods for making transgenic Drosophila, the first successful germ-line genetic engineering of a multicellular animal. Dr. Rubin served as the leader of the publicly funded effort to sequence the Drosophila melanogaster genome, which included collaborating with Celera Genomics Inc. to demonstrate that the whole genome shotgun method could successfully sequence an animal genome. Dr. Rubin has been a member of the National Academy of Sciences since 1987. He is also a member of the Institute of Medicine and the American Academy of Arts and Sciences and a foreign member of the Royal Society (U.K.). He has received numerous awards, including the American Chemical Society Eli Lilly Award in Biological Chemistry, the National Academy of Sciences U.S. Steel Foundation Award in Molecular Biology, and the Genetics Society of America Medal.

Phillip A. Sharp is Institute Professor at the Massachusetts Institute of Technology. Much of Dr. Sharp's scientific work has been conducted at MIT's Center for Cancer Research (now the Koch Institute), which he joined in 1974 and directed from 1985 to 1991. He subsequently led the Department of Biology from 1991 to 1999 before assuming the directorship of the McGovern Institute from 2000-2004. His research interests have centered on the molecular biology of gene expression relevant to cancer and the mechanisms of RNA splicing. His landmark achievement was the discovery of RNA splicing in 1977, which provided one of the first indications of the phenomenon of “discontinuous genes” in mammalian cells. This discovery, which fundamentally changed scientists' understanding of the structure of genes, earned Dr. Sharp the 1993 Nobel Prize in Physiology or Medicine. Dr. Sharp has authored over 385 scientific papers, has received numerous awards and honorary degrees, and has served on advisory boards for the government, academic institutions, scientific societies, and companies. His awards include the Gairdner Foundation International Award, General Motors Research Foundation Alfred P. Sloan, Jr. Prize for Cancer Research, the Albert Lasker Basic Medical Research Award, the National Medal of Science and the inaugural Double Helix Medal from CSHL. He is an elected member of the National Academy of Sciences, the Institute of Medicine, the American Academy of Arts and Sciences, the American Philosophical Society, and is a Foreign Fellow of the Royal Society, UK. A native of Kentucky, Dr. Sharp earned a B.A. degree from Union College, K.Y. in 1966, and a Ph.D. in chemistry from the

University of Illinois, Champaign-Urbana in 1969. He did his postdoctoral training at the California Institute of Technology, where he studied the molecular biology of plasmids from bacteria in Professor Norman Davidson's laboratory. Prior to joining MIT, he was Senior Scientist at Cold Spring Harbor Laboratory. In 1978 Dr. Sharp co-founded Biogen (now Biogen Idec) and in 2002 he co-founded Alnylam Pharmaceuticals, an early-stage therapeutics company.

Carla J. Shatz is Director of Bio-X, Sapp Family Provostial Professor, and Professor of Biology and Neurobiology at Stanford University. Dr. Shatz's research aims to understand how early developing brain circuits are transformed into adult connections during critical periods of development. Her work, which focuses on the development of the mammalian visual system, has relevance not only for treating disorders such as autism and schizophrenia, but also for understanding how the nervous and immune systems interact. Dr. Shatz graduated from Radcliffe College in 1969 with a B.A. in Chemistry. She was honored with a Marshall Scholarship to study at University College London, where she received an M.Phil. in Physiology in 1971. In 1976, she received a Ph.D. in Neurobiology from Harvard Medical School, where she studied with David Hubel and Torsten Wiesel. During this period, she was appointed as a Harvard Junior Fellow. From 1976 to 1978 she obtained postdoctoral training with Pasko Rakic in the Department of Neuroscience, Harvard Medical School. In 1978, Dr. Shatz moved to Stanford University, where she attained the rank of Professor of Neurobiology in 1989. In 1992, she moved her laboratory to the University of California, Berkeley, where she was Professor of Neurobiology and an Investigator of the Howard Hughes Medical Institute. In 2000, she assumed the Chair of the Department of Neurobiology at Harvard Medical School as the Nathan Marsh Pusey Professor of Neurobiology. She returned to Stanford in 2007, where she directs Bio-X, Stanford's pioneering biosciences program that brings together faculty from across the entire university—clinicians, biologists, engineers, physicists, computer scientists—to unlock the secrets of the human body. Dr. Shatz has received many awards including the Gill Prize in Neuroscience in 2006. In 1992, she was elected to the American Academy of Arts and Sciences, in 1995 to the National Academy of Sciences, in 1997 to the American Philosophical Society, and in 1999 to the Institute of Medicine. In 2009 she received the Mika Salpeter Lifetime Achievement Award from the Society for Neuroscience. Most recently, Dr. Shatz was awarded an honorary degree from Cold Spring Harbor Laboratory.

Carl P. Simon is Professor of Mathematics, Economics, Complex Systems, and Public Policy at the University of Michigan (UM). He also serves as Director of the UM Science, Technology, and Public Policy Program. Dr. Simon's research interests center around mathematical models which involve natural dynamics or motion over time. He has applied dynamic modeling to the movements of an economy over time, the spread of AIDS, of staph infection, and of crime, and the evolution of biological, economic systems and of literary genre. His research team won the 1995 Teman Prize for their research estimating the contagiousness of HIV. In May 1999, the University established the Center for the Study of Complex Systems and appointed Dr. Simon Director--a position he held for ten years. The University awarded him the LS&A Distinguished Senior Lecturer Award in 2007 and the Distinguished University Faculty Achievement Award in 2012. He is co-author of a textbook *Mathematics for Economists* and is a member of the Board on Mathematical Sciences and their Applications of the National Academies of Science.

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Susan Rundell Singer is the Laurence McKinley Gould Professor in the Biology and Cognitive Science Departments at Carleton College and is currently serving as Director of the National Science Foundation's Division of Undergraduate Education. Dr. Singer pursues a career that integrates science and education. In addition to a Ph.D. in biology from Rensselaer, she completed a teacher certification program in New York State. A developmental biologist who also does research on learning in genomics, Dr. Singer is a AAAS Fellow and received both the American Society of Plant Biology teaching award and Botanical Society of America Charles Bessey teaching award. She directed Carleton's Perlman Center for Learning and Teaching and is a co-author of the *Vision and Change in Undergraduate Biology* report as well as an introductory biology text. She serves on numerous boards, including the NSF EHR advisory committee, Biological Sciences Curriculum Study Board, and the Botanical Society Board of Directors; is a member-at-large for the AAAS Education Section; participates in the Minnesota Next Generation Science Standards team; and was a member of the National Academies' Board on Science Education. She has participated in six National Academies studies, including chairing the committees that authored *America's Lab Report, Promising Practices in STEM Undergraduate Education* and *Discipline-based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering*.

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Key Terminology and Concepts for "Convergence"

Julie Thompson Klein and David Roessner

Context

The goal of merging expertise to address complex problems is not new. It was central to the earliest major investments in interdisciplinary research, most notably the Manhattan Project to develop the basic science and technology for building an atomic bomb. It has also been a common feature of U.S. industrial research laboratories since the 1920s. Convergence represents a more radical, greatly expanded form of ***Interdisciplinarity*** in which bodies of specialized knowledge comprise large and diverse "macro" domains of research activity. When effectively integrated, they foster the possibility of a new and transforming paradigm or field. The expected outcomes are new ideas, discoveries, methodological and conceptual approaches, and tools that stimulate new understandings in basic research; they may also lead to new inventions, innovations, treatment protocols, and forms and strategies of education and training.

At the same time, Convergence encompasses a family of related approaches that are crucial to developing a new paradigm or field. These approaches are often conflated without informed awareness of consensus on terms and concepts that are embedded, explicitly or implicitly, in descriptions of Convergence. This discussion document presents authoritative definitions for those approaches in order to render the context of Convergence more precise: Unidisciplinary (UD), Multidisciplinary (MD), Interdisciplinary (ID), and Transdisciplinary (TD) as well as attendant processes of Knowledge Integration and Collaboration.

Disciplinarity a particular branch of learning or body of knowledge whose defining elements—e.g., objects and subjects of study, phenomena, assumptions, epistemology, concepts, theories, and methods—distinguish it from other knowledge formations. Biology and chemistry, for example, are separate domains typically segmented into departments in academic institutions.

Unidisciplinarity (UD) is a process in which researchers from a single discipline, field, or area of established research and education practice work singly or together to study an object or address a common question, problem, topic, or theme.

Multidisciplinarity (MD) juxtaposes two or more disciplines focused on a question, problem, topic, or theme. Juxtaposition fosters wider information, knowledge, and methods. Yet, disciplines remain separate and the existing structure of knowledge is not questioned. Individuals and even a team working on a common problem of environmental sustainability or a public health initiative, for instance, would work separately, and their results typically be issued separately or compiled in encyclopedic alignment rather than synthesized.

Interdisciplinarity (ID) integrates information, data, methods, tools, concepts, and/or theories from two or more disciplines focused on a complex question, problem, topic, or theme. The scope and goals of research programs differ: from incorporating borrowed tools and methods and integrating them into the practice of another discipline to generating a new conceptual framework or theoretical explanation and large-scale initiatives such as the Human Genome Project. The key defining concept of interdisciplinarity is **Integration**, a blending of diverse inputs that differs from and is more than the simple sum of the parts. Individuals may perform work alone, but increasingly research is team-based.

Collaboration introduces social integration into the process, requiring attention to project management and the dynamics of communication.

Transdisciplinarity (TD) transcends disciplinary approaches through more comprehensive frameworks, including the synthetic paradigms of general systems theory and sustainability, as well as the shift from a disease model to the new paradigm of health and wellness. In the late 20th century, it also became aligned with problem-oriented research that crosses the boundaries of both academic and the public and private spheres. In this second connotation, mutual learning, joint work, and knowledge integration are key to solving "real-world" problems. Both constructs go beyond interdisciplinary combinations of existing approaches to foster new worldviews or domains. The difference is apparent in the Degree of Integration that occurs along a continuum:

DEGREE OF INTEGRATION

UNIDISCIPLINARY	MULTIDISCIPLINARY	INTERDISCIPLINARY	TRANSDISCIPLINARY
Focusing	Juxtaposing	Integrating	Transcending
Concentrating	Sequencing	Interacting	Transgressing
Analyzing	Coordinating	Linking	Transforming
Segmenting		Focusing	Overarching
		Blending	
		Hybridizing	
		Synthesizing	

Transdisciplinarity and Convergence

As the graphic suggests, many characteristics of Transdisciplinarity are similar to or even identical with defining traits of Convergence, key among them merging of distinct and diverse approaches into a unified whole. The new paradigm or field refigures both disciplinary approaches and interdisciplinary research areas such as molecular and cellular biology and genomics. The formation of new Interdisciplines is not new: social psychology, biochemistry, child development, nanotechnology, bioinformatics, and tissue engineering are among the many examples of hybrid domains. The transdisciplinary imperative of Convergence differs in fostering a more comprehensive synthetic framework such as the merging of engineering with physical and life sciences in areas such as integrative cancer biology, computational biology, and imaging technology

Some groundwork has already been established for structures, institutional arrangements, and incentives that foster Convergence, and Committee members have identified numerous examples of organizations engaged successfully in fostering Convergent processes. The challenge now is to identify and document the key characteristics, policies, and practices in these examples in a form that facilitates their use and institutionalization in other organizations and fields of endeavor. It is important, as well, to recognize that unidisciplinary and interdisciplinary areas and teams will continue to exist in institutions and contribute substantially to advances in research. Convergence is not an evolutionary endpoint, rather a framework and strategy for particular forms of transdisciplinary integration and collaboration.

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INPUT PROVIDED BY PARTICIPANTS

Please provide a 4-5 sentence overview of the fundamentals of your program / institution / laboratory, as appropriate, such as its focus, when it was established, the types of people involved, and the general way that it is funded. This will help provide background on the programs represented at the workshop. You are also welcome to include a link to a program website or prospectus that contains this information.

QB3 is a consortium of three University of California campuses, Berkeley, UCSF and UCSC created in 2001 to foster research at the interface of the physical and biological sciences (Quantitative Biosciences) and to promote practical application of that research to society problems. Funds to build new labs ($100M) and to support the work of its 220 research labs ($4M/year) came from the State of California channeled through the University President's Office. QB3 uses the networking skills of its scientific staff to assemble teams to address what it calls "Wicked Problems", leading for example to the Energy Bioscience Institute at Berkeley and the Cancer Genomics Hub at UCSC. Staff also connect QB3 scientists with enablers in the private sector to encourage start-up creation based on QB3 research. To help the start-ups convert discoveries to society benefits, QB3 has its own venture fund and operates an Incubator Network that now houses 62 start-up companies in shared lab space.

I am a 4th year graduate student in the polymers/materials division of the chemistry department at UNC-Chapel Hill. I work in the laboratory of Dr. Joseph DeSimone. In the lab, our research focuses on a materials and nano-particle based approach to life sciences topics such as oncology and vaccines. The lab shifted to a life sciences focus in the mid-2000s with the development of PRINT, a nanoparticle fabrication technology. We have lab members from a wide variety of backgrounds such as biology, immunology, chemistry, medicine, and engineering. The lab is primarily funded by NIH and DoD grants as well as a company, Liquidia, that was spun out of the lab in the late 2000s.

Systems Biology Center New York is a multi-institutional Center funded by a P50 Center grant from NIGMS. It has been in existence since 2007 and grant funding was recently renewed for a five year term from 2013-2018. Our research focus is on systems pharmacology and systems pathophysiology. Our educational focus is in bringing strong quantitative and mathematical reasoning into biochemistry, cell and tissue biology. We recently offered a MOOC entitled "Introduction to Systems Biology" on Coursera which had 16,591 active students of whom 1,187 took exams and quizzes and "passed" the course. Recent publications by members of the Center and other offerings on Coursera can be seen on the Center website - www.sbcny.org

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The Raymond and Beverly Sackler Foundation is a private non-profit family financed foundation that has long supported basic research, with a focus on astrophysics, chemistry, physics, and biomedical sciences. Relying on preeminent scientists and physicians as advisers, the Foundation awards research grants, lectureships, prizes and related programs to support and encourage (largely emerging) scientists. The Foundation seeks ways to identify individuals and programs less likely to receive support from larger traditional funding sources, and to transition the people and programs to more stable funding if successful. With that goal, the Foundation leadership embraced the concept of convergence as defined by Phillip Sharp from MIT and launched an effort to endow a series of programs at institutions in the US and Europe undertaking research in the physical, biomedical engineering sciences promoting convergence.

I direct an analytical biochemistry laboratory at the J Craig Venter Institute with primary interests in: - infectious diseases - human host-associated microbial communities - human disease biomarker discovery - translating genomics and proteomics research into medical applications

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Jacksonville University is a small (total enrollment 4,073), private, non-affiliated, comprehensive university founded by the business community in Jacksonville in the late 1950's. Although we primarily serve undergraduates, the university is expanding graduate program offerings. The Division of Science and Mathematics is the organizational unit for Biology, Chemistry (including Biochemistry), Computing Sciences, Engineering (Dual Degree program), Marine Science, Mathematics and Physics. We have masters degrees in Mathematics and Marine Science and are the largest division in the College of Arts and Sciences. University funding is tuition-based, although there is a growing understanding that grants are important as we expand graduate programs.

The Laboratory of Systems Biology (LSB) was created in 2011 as a formal entity to follow on to a prior effort to build a systems biology program within NIAID, NIH focused on the areas of computational biology, bioinformatics, and host-pathogen interactions. It consists on one tenured investigator (R. N. Germain) and 5 tenure track investigators, 4 of whom were directly recruited to the new LSB to undertake a combination of PI-specific and large scale collaborative efforts in systems immunology. Scientists with expertise in immunology, proteomics, bioinformatics and statistics, computational biology and modeling, and biochemistry and cell biology make up the group, selected so that the major disciplines needed for systems scale research were part of a consciously designed organization. The offer letters for new recruits specified that they are expected to undertake multidisciplinary research with their colleagues as a major aspect of the research program and changes were made to the NIH tenure policy to support career development of scientists engaged in such research. This program is entirely supported by NIH intramural funds.

On July 1, 2013, North Carolina State University established a College of Sciences, bringing together into one organizational unit, faculty and programs that span the mathematical and statistical sciences, the biological sciences, the chemical and physical sciences, and the earth system sciences. This reorganization of science programs at NC State followed on a university-wide strategic planning effort and a further, more targeted study of academic science programs. The decision to create the new college was driven by a recognition that solutions to many of the great societal challenges of the day - certainly in health, but also in energy and the environment - are being found at the intersections of the sciences, and that placing all the sciences in one unit would facilitate those interdisciplinary interactions, including those that occur by serendipity of administrative or physical contiguity. The January, 2011 MIT white paper on the "Convergence of the Life Sciences, Physical Sciences, and Engineering" was frequently cited in the discussion. The fine details of the process leading to the establishment of NC State's College of Sciences are available at http://provost.ncsu.edu/special-initiatives/college-of-sciences/index.php. An outside firm assisted in a national study that interviewed thought leaders across the country including the leadership of six comparison institutions. The results are informing our decisions on administrative and other organizational structures to promote interdisciplinarity, and on our selection of research, education and outreach areas of strategic opportunity for NC State. While strategic positioning of the College is still in progress, it is clear that there will be an emphasis in quantitative biosciences, notably in areas of human and environmental health. It seems relevant to note that despite hosting substantial existing programs of quantitative sciences in biomedicine, NC State does not have a school of human medicine.

My laboratory is in the building of the Parker H. Petit Institute for Bioengineering and Bioscience (IBB) at Georgia Tech. IBB was established in 1995 to bring together biochemists, bioengineers, and biologists. IBB moved into its new building in 1999. This building was designed for the faculty to do interdisciplinary research and to promote collaboration between engineers and scientists. Key elements in the design of the IBB building was (1) the co-location of researchers, (2) shared core instrumentation facilities, and (3) a design that allowed for enhanced "chance" meetings. The faculty that are housed in the IBB building have their academic, tenure-track appointments in one of the participating academic departments.

My laboratory at the University of Pennsylvania was established in 2009. We study protein folding, misfolding, conformational change, and proteolysis through the incorporation of synthetic amino acids into proteins. Thus far, the graduate students and postdocs in my lab have come from Organic or Biological Chemistry backgrounds, although this year it appears that a Physical Chemistry and M.D./Ph.D. student will join the lab. We have established collaborations with laboratories in the medical school at UPenn allowing us to expand the applications of our ideas in cells. Our funding has come from the NSF (for the development of new protein labeling methods), the NIH (for the study of alpha-synuclein misfolding relevant to Parkinson's Disease), and private early career awards.

Program level = Department of Chemical Engineering: http://www.mtu.edu/chemical/
The vision of the department is to be a nationally recognized undergraduate chemical engineering program coupled with research strengths in process safety, process systems engineering, applied thermodynamics, polymers, mineral processing, and biochemical engineering.

Institution level = Michigan Technological University: http://www.mtu.edu

Laboratory level = Medical microDevice Engineering Research Laboratory: http://www.mderl.org
The mission of M.D. - ERL is to explore the use of electrokinetics, specifically dielectrophoresis, in microdevices with the goal of developing medical diagnostic devices to detect and quantify diseases and disease progression. The ultimate goal is to detect a variety of blood diseases and return quantitative values for the number of infected / unhealthy cells relative to the number of healthy cells - all within a single drop of blood

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The National Cancer Institute's (NCI's) Office of Physical Sciences Oncology (OPSO; http://physics.cancer.gov) leads the NCI's efforts to establish research projects that bring together cancer biologists and oncologists with scientists from the fields of physics, mathematics, chemistry, and engineering to address some of the major questions and barriers in cancer research. OPSO also supports the development of this burgeoning field through running workshops, scientific conferences and other funding support mechanisms in partnership with other NCI divisions, NIH institutes, and other government agencies (e.g., DOD, DOE, & NSF; see http://www.nsf.gov/pubs/2012/nsf12514/nsf12514.htm; http://physicsandcancer2.blogspot.com/). In 2009, the NCI OPSO launched the Physical Sciences Oncology Centers (PS-OC) Program (http://grants.nih.gov/grants/guide/rfa-files/RFA-CA-09-009.html), a collaborative network of 12 centers, that promote a physical sciences perspective of cancer and foster the convergence of physical science and cancer research by forming transdisciplinary teams of physical scientists (e.g., physicists, mathematicians, chemists, engineers, computer scientists) and cancer researchers (e.g., cancer biologists, oncologists, pathologists) who work closely together to advance our understanding of cancer. Moreover, the OPSO is actively engaged in a prospective evaluation of the PS-OC program to better understand transdisciplinary collaboration and field convergence (see http://ip-science.thomsonreuters.com/m/pdfs/fed-res/nmm_research_impact_panel.pdf). For further reference, several articles related to PS-OC program and its investigators have been written (see http://www.nature.com/nature/outlook/physical_scientists_cancer/index.html, http://www.nature.com/nrc/journal/v11/n9/full/nrc3092.html) including a PS-OC Network publication which included nearly 100 investigators across 20 laboratories (http://www.nature.com/srep/2013/130422/srep01449/full/srep01449.html; http://stm.sciencemag.org/content/5/183/183fs14.full).

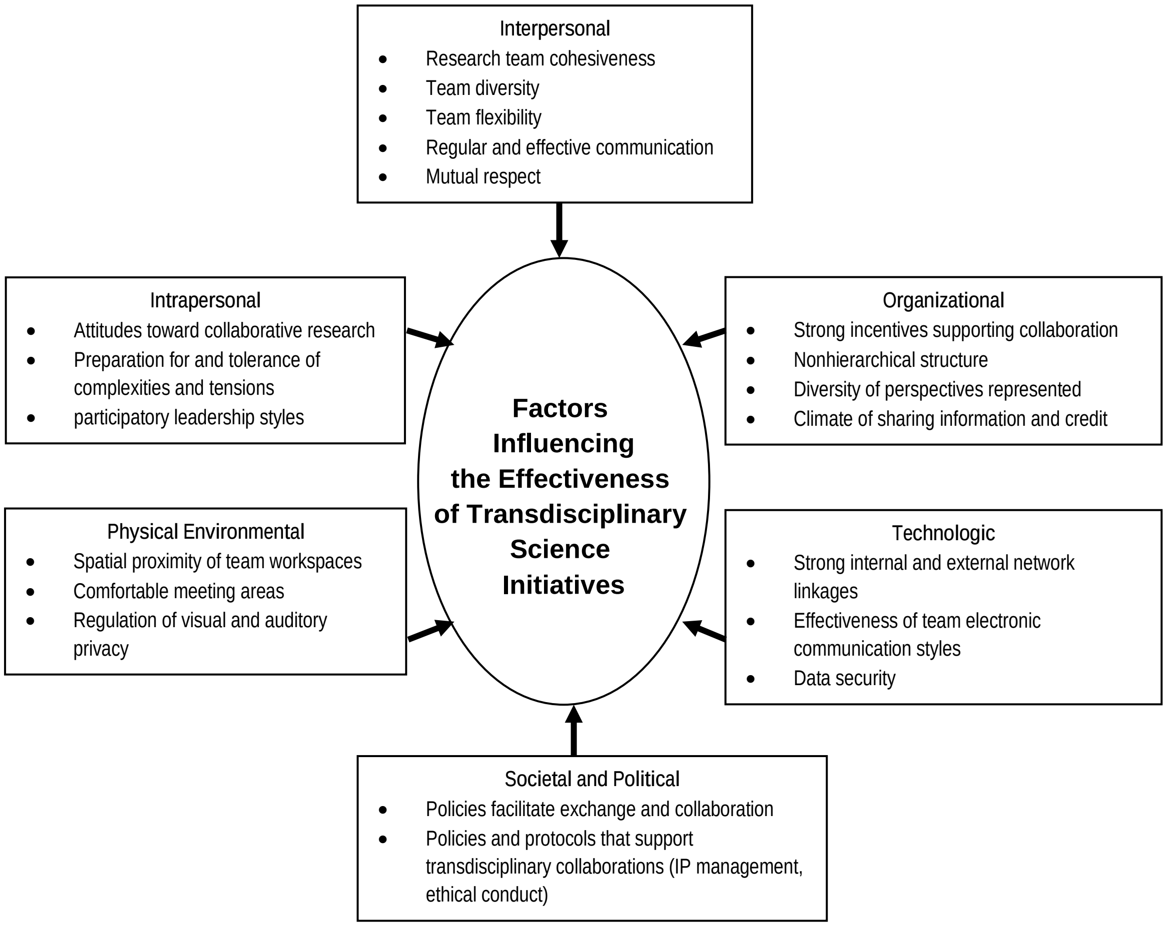
The New Mexico Alliance for Minority Participation (New Mexico AMP) is designed to increase the enrollment and graduation rate of historically underrepresented groups in science, technology, engineering and mathematics (STEM).

Begun November 1, 1993, New Mexico AMP is a partnership representing the state's public two-year postsecondary institutions, including two federally funded institutions serving American Indian students, and the state-supported four-year universities. New Mexico AMP's goal is to increase the number of minority students who complete their B.S. degrees and who are currently underrepresented in the STEM disciplines. The Alliance is primarily funded with multiple NSF grants.
http://www.nmsu.edu/~nmamp/

The National Center for Convergence Technology is an ATE NSF Center that is an Applied Technology Center focused on technician education. When the Center was established in the 2004 time frame, technicians handling data networking and those handling telephony were in two totally separate areas within almost all companies, and education for these workers was separate as well, These areas were beginning to converge in the 2004 time frame and have continued to converge. Additional disciplines have also converged as well. While our focus is still largely information technology, information technology underpins almost every discipline, and the concepts that the Center faced in converging data networking and telephony in 2004 are the same concepts that are faced in any convergence effort.

The Institute for Systems Biology (ISB) (http://www.systemsbiology.org) was founded in 2000 to catalyze biological research convergence in the area of systems biology. It is funded mainly through govt grants and contracts. The ISB's researchers are faculty members, senior scientists, postdocs, graduate students (from U of Washington), and technical personnel. The researchers have backgrounds in biology, engineering, physics, computer science, chemistry, and medicine.

I oversee research at Singularity University, which educates a select group of leaders about the exponentially growing technologies that are soon going to change our world. These advances in fields such as robotics, A.I., computing, synthetic biology, 3D printing, medicine, and nanomaterials are making it possible for small teams to do what was once possible only for governments and large corporations to do: solve the grand challenges in education, water, food, shelter, health, and security.



Source: Adapted from Stokols, D., et al., (2008). The Ecology of Team Science, *American Journal of Preventive Medicine*, 35 (2S): S111.

Please identify policies or practices, including informal ones you and/or your institution have implemented that, in your judgment, have had a significant positive influence on facilitating transdisciplinary/convergent research or education. For each of the policies or practices you have identified, what contextual factors do you consider critical to the successful outcomes achieved? "Contextual factors" include local institutional cultures and the particularities of different knowledge fields. Please also consider the possible influence that each of the following may have had, referring to the graphic above. You need not discuss every item in each category of the graphic; instead, emphasize the ones of greatest relevance from your perspective (you do not need to respond in all categories unless you wish.

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b. Interpersonal. We have developed the concept of a faculty member designated as an academic generalist who, in place of running their own lab, devote their intellectual energies to connecting their colleagues to form productive teams. c. Organizational. The QB3 InnoLab focuses on bringing jobs and investment to the local community around the university. Through their offices of technology management, universities usually seek to maximize licensing revenue for themselves independent of local benefit. d. Technological. QB3 has developed research facilities, such as high throughput screening centers, that allow potentially commercializable to be de-risked in a university context. e. We have minimized the investment necessary to launch companies by acquiring a warehouse and converting it into inexpensive lab space near the university.

Within the DeSimone lab at UNC, one of the strongest factors in encouraging convergent research is the physical environment. On the UNC campus, we have access to almost every technology we could want for our research, and the few we do not have are usually within the Triangle area. The lab space is well connected with other labs within our group and with other groups in the department, encouraging scientific discussion among peers. Additionally, interpersonal/organizational considerations have influenced our effectiveness in trans-disciplinary research. The broad diversity of students and post docs encourages everyone to utilize each person's individual skill set to help move projects forward.

The Foundation in seeking out and developing endowed programs promoting convergence research gravitated to those institutions with recognized excellence in basic science fields of mathematics, physics, chemistry and a reputation for establishing programs across disciplines and in association with the more applied biomedical engineering schools. In many, but not all cases, this involved major universities with an established medical research center, often with a shared and integrated faculty. Possible influences on selecting and developing programs. Intrapersonal: the environment described above is expected to attract and harbor unique researchers, facilitate and make comfortable individuals willing to cross traditional academic boundaries and seek out required and existing resources and collaborators. It was assumed that smaller institutions could not accomplish the same. Organizational: The Foundation sought evidence of a clear past history and current desire to take on new ideas, new programs, and not try to simply rename current departments and programs to attract new sources of support. Physical environment: Many of the programs to date support students, fellows, young faculty, visiting scientist who would arise from and collaborate across various departments. As such they are not housed in the same location, and the location may move as projects and people change. Therefore a virtual program with little footprint evolves in many instances, and this has real challenges in tracking understanding and maintaining identity over time.

I am not involved in institutional implementation of such policies/practises and policies at a significant level as my work focuses on scientific research. For my research, cross-institutional relationships are very important. Most of my research relies on collaborations. Most scientists (particularly in small non-profit institutes like JCVI) are very specialized so that they need collaborations to work on multidisciplinary science projects. US funding institutions, suchs as NSF, NIH and DoD also foster these multidisciplinary programs via various funding mechanisms, emphasizing cross-institutional collaborations. It is important that organizational leaderships (management) of small and large institutions promote inter-personal relationsships of their scientific research staff with peers at other institutions to foster effective collaborative, multi-disciplinary research. Regarding science educational aspects, it is important that small non-profit research institutes participate. These institutions provide a different environment than a university for students (and this is highly beneficial to their professional development) (e.g. summer internships and fellowships of students). Societal and political: simplified processes and lower costs related to immigration policy to allow foreign students (currently in or outside the US) to participate in scientific research opportunities are important. More flexibility in supporting the most talented students - independent of nationality and country of residence - and scientists in the US (internships, pre and post-doctoral fellowships, short term visits for exchange students and scholars) would eventually benefit scientific progress and innovation in the US and abroad.

We have instituted several annual events that bring people together across campus for intellectual discourse. The first in an annual panel discussion, typically in February, with short presentations from faculty across all disciplines in the College of Arts and Sciences followed by Q&A with the panel. We are in our 5th year of this tradition: Yr 1--Complicity, Yr 2--Race, Yr 3--Envisioning the Future--Role of the Past, Yr 4-- Cuban Missile Crisis. The topic for this year's discussion has not been chosen yet. The second is an annual Faculty-Student Research Symposium that started in the Division of Science & Mathematics and now includes all disciplines. The third is a curriculum change that links courses together to form "interest networks" particularly for entering students. The Freshmen Interest Network (FIN) courses allow students and faculty to form learning communities and work on larger, more complex problems/projects across two or three courses. We have yet to expand the idea to upper division classes despite the success of the FIN program. As the Division Chair I have actively worked to bring our department heads together to work through facilities, curriculum and budget challenges, plan division-wide activities and encourage inter/trans disciplinary collaboration. The discussions among the chairs help to allow all of us to facilitate interactions among students and faculty. We have established one gathering/working space (Networking Center) with 6 computers and a printer that can be used by students and faculty, but the space is small. The biggest challenge we face is the lack of budget support and facilities that encourage interaction-- no general gathering space other than the division office. Biology, Marine Science & Chemistry are each in separate buildings. Engineering shares a building with some biology labs, but none of the faculty. Physics, Computing Sciences & Mathematics are all in the same building, but each maintains their own classrooms/labs.

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a/b. The faculty of the LSB was selected in a manner that all recruits participated in the selection of the others and felt that excellent working relationships would likely emerge. Several days of formal scientific and informal social/family activities were spent in attempting to reach these goals. A major aspect of the scientific interactions and discussions during each recruit visit focused on whether the recruit actively desired to work in a setting in which substantial collaboration was expected.

c. Beyond the direct statement that collaborative work would form a major part of the evaluation for promotion and tenure, a flat structure was implemented in terms of scientific goals, with all investigators having equal say in the directions chosen - the goals are not set in a top-down manner. Opportunities for speaking that come to the tenured Laboratory Chief are routinely shifted to the junior faculty to promote their visibility in the field; likewise for request for review articles.

d. The LSB faculty share core staff support in IT and bioinformatics and a LIMS system is being established to centralize data storage and access. Ongoing work from all labs is discussed in both department-wide and PI-focused meetings to be sure everyone is aware of all ongoing research activities.

e. As noted above, the Laboratory Chief was able to get changes made to the NIH central tenure policy that supports collaborative research efforts during the tenure review process.

f. The LSB occupies a full floor in a newly renovated building. ALL staff are located on this floor. The laboratories have an open design, so there is little 'territoriality'. Fellows share desk and wet lab space, the PI offices are all within a 1 minute walk from each other, and the computational people are close to the experimentalists, while having the quiet environment they require. Major equipment is shared, as are tissue culture and related facilities. There is a common 'kitchen-break' room and a small conference room for meetings.

NC State University is in the midst of an interdisciplinary cluster hiring program that began with a campus-wide invitation for teams of faculty to self-organize, develop and submit proposals for hiring clusters of new faculty in areas of emerging strength. Preference was to be given to proposals representing multiple departments and colleges. A broad-based committee made recommendations to the provost who selected 12 clusters for funding that will bring a total of about 40 new faculty. Details of the process are available at http://provost.ncsu.edu/special-initiatives/chancellors-faculty-excellence/ and the current state of the new hires can be found at http://workthatmatters.ncsu.edu/ The design of the process was informed by a study of successes and challenges of cluster hire programs at other institutions. It is managed out of the provost's office, which provides the bulk of the salaries and part of the startup funding, but with required commitments from the eventual tenure-home department/college. The searches are managed by a multidisciplinary cluster committee with administrative assistance from a "lead dean", potential hires are identified, the lead dean coordinates offers between the cluster committee and the proposed tenure-home department/college. A key feature is that for each hire, a written plan must be prepared describing the responsibilities of the new faculty member to the cluster and to the home department. While the new hires are just arriving, the process has generated substantial enthusiasm and energy across the faculty, a great morale boost in the current challenging financial environment for state universities.

Keys to the success of IBB is its independence combined with a philosophy of working closely with the academic departments from which the IBB faculty come. IBB organizationally comes under the office of the Executive Vice President for Research (EVPR) and has a budget provided by the EVPR office. It also has an endowment that generates approximately 20% of its budget. The IBB building has three floors and has an atrium to provide what the architects called "vertical integration." The atrium has a cafe not only to provide food and drink but to be a meeting place where interaction can take place. There are monthly social events, many times with a poster session, to promote even further interaction. Finally there is a seed grant program where a proposal submitted must have two co-PIs, one from the sciences and one from engineering. A faculty member's office is not by his/her laboratory, but in a centralized faculty office area on each floor. Each laboratory area houses the labs of 4-5 faculty, with each of these in general having both science and engineering faculty. These laboratory areas have been designed to minimize walls as much as possible and appropriate so as to encourage interactions between research groups. Finally, by promoting the sharing of laboratory space by faculty in a laboratory area, this in effect means that each faculty member has more space than they otherwise would.

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a. Intrapersonal - Researchers must be comfortable with operating outside of their comfort zone and with not having their own space (in an interdisciplinary lab, space must be allocated according to equipment/tasks rather than each researcher getting their own space) b. Interpersonal - A good interdisciplinary research team must be made of two (or more) layers, an lab that is itself interdisciplinary, but also outside collaborations. There is an inherent need to balance cross-pollination of ideas with sufficient expertise to carry out advanced experiments. It is also important to import the perspectives of researchers of different fields who value different aspects of a project. c. Organizational - Organization must make effort to recognize the contributions of junior investigators in collaborations, otherwise collaborations are de-incentivized. f. Physical Environmental - Shared equipment resources are essential, it relieves the fund-raising burden on younger investigators to acquire equipment that has capabilities that are already available on campus.

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a. University implemented overhead (F&A return) incentives to encourage researchers to submit proposals and work in research centers instead of departments.
b. While managing my own research group, I've learned to explain the why behind changes or current emphases.
c. The development of shared instrumentation and open user facilities is a good start. Having a guiding committee can be successful.
d. Technology has to be easy and accessible or purchases/maintained at a level above the researchers. Time spent problem solving technology is not time spent on the science.
e. The entrepreneurial community is an interesting one for this category. There are an amazing number of supporting resources, and the challenge is finding the right one at the right time, without losing too much time on the 'noise' surrounding it.
f. I can recognize this is a factor, but unless I end up in something uncomfortable, wouldn't recognize that is better.

For the OPSO PS-OC Program, organizational, inter/intrapersoanal categories were critical factors for having a positive influence on transdisciplinary science. A driver for this positive influence is the cooperative agreement (NIH U-mechanism) where NCI program staff has substantial scientific or programmatic involvement. Specifically, periodic teleconference calls with the senior leadership from each of the centers was vital for investigators from disparate disciplines to come together and collaboratively interact with each other.

The long-term success of this state-wide alliance to increase the graduation of underrepresented students in STEM has been successful in large part to the following factors: a) stable project leadership at the partner institutions. Having the same investigators included for many years has led to a close-knit team that can work together even at a distance b) a shared commitment to the goals of the program by all the partner institutions c) an opportunity for the participants to get together at least once a year to present results of research projects

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The difficulty in overcoming local institutional and business cultures that have traditionally kept disciplines siloed was and is a major barrier to convergence. It is important to have support from above (administrative or management) to accomplish convergent research or projects; however, support from above is not sufficient for success. It is equally important to have methods for building informal relationships between the faculty and/or workers who are involved in the two departments or organizations that are to converge informally or formally. The National Convergence Technology Center has techniques for building these informal relationships. Technology is a supporting player, and is typically not the barrier to success.

Intrapersonal: The ISB is a mid-size (about 200 people) organization that tends to attract people who are interested in collaborative transdisciplinary work. Organizational dedication to a vision of research convergence is central to this attraction. Convergent research is best in teams of collaborators who each bring some deep expertise and who each have a functional level of understanding and practical capability in the other disciplines represented in the team. To achieve this, students/postdocs are encouraged to contribute directly to work that falls outside their previous training.

Interpersonal: Transdisciplinary collaborative research is culturally complicated. The emotional ground state of people is to undervalue contributions they don’t understand well, and to neglect opportunities to teach colleagues about their own area of expertise.   The group leader must make sustained efforts to overcome these reflexes, because transdisciplinary ideas don’t come from putting different people in a room together; they come from groups of people with overlapping understanding and complementary expertise. Frequent informal small (3-5 people) project meetings in which participants are expected to explain and teach about their contributions are a good way to do this. An important role of the leader is to consistently push team members to teach each other and learn from each other. This takes a lot of time. The rewards are research accomplishments that are not otherwise possible, and team members of ever higher value.

Organizational: ISB has benefitted by having Seattle neighbors (U Washington, Fred Hutchinson CRC, Seattle Biomed, Gates Foundation, Google, Amazon, Microsoft, etc) providing a critical mass of talent, ideas, expertise, and resources. To capitalize on this, the ISB readily and frequently explores and forms partnerships and collaborations with commercial organizations, government entities, as well as academic colleagues. Within the organization, there are very low barriers to the exploration, formation, and execution of collaborations. Project teams are fluid. The attitudes and expectations promulgated by the faculty are essential to this freedom.

Technological: A key part of the ISB ethos is its dedication to technology development not only as a means to answer pressing questions, but also to enable the asking of new questions. Societal Political: Researchers will tend to organize themselves according to the availability of resources. In the last 15 or so years, the growth of grant programs designed to fund multi-investigator transdisciplinary research has been essential for the growth and impact of ISB. For example, a NIGMS-funded Center for Systems Biology is housed at the ISB.

Physical Environmental: Reflecting the fluid movement of people among projects, the research space of different groups are not walled off, but are rather often mixed. The structure of the spaces follows function, not group membership. Equipment and core facilities that tend to create a din are typically in enclosed spaces with plenty of windows. Near the labs are small quiet group offices in which intensive computational work or paper writing goes on.

It's all about entrepreneurship--and connecting people from different disciplines.

Please think about other significant efforts you know about to achieve transdisciplinary/convergent processes in research and/or education that failed to achieve the desired results. As above, try to identify the factors that impeded each effort, considering the effect that the form or absence of each influence had on impeding or preventing desired outcomes.

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b. Interpersonal. QB3 asked its faculty to define "Grand Challenges" as a way of focusing its thinking. The effort led to little because there was no source of funding. ideas without funding are of little value. c. Organizational. We tried to use an Innovation Prize mechanism to foster and reward creativity and convergent thinking. The work involved exceeded the benefits. Pilot grants for collaborative research were much more effective. c. Organizational. We also have explored entrepreneurial classes. They have turned out to be less valuable than providing entrepreneurial services on an "as needed" basis. d. Technological. Attempts to connect all QB3 faculty by video technology failed. Effective and inexpensive technology that let events and classes be shared across campuses never materialized. e. Little political support although we bring $150m/year into the local economy.

The only factor that has discouraged transdisciplinary research has been societal/political. Due to circumstances regarding out-of-university collaborations and IP management, some promising collaborations have fallen through. These same policies, however, have also allowed for on-campus collaborations to flourish and progress quickly.

Intrapersonal --- a lack of understanding by researchers in one field regarding the complexity and i critical issues in another field.

Organizational --- lack of support from the institution such as seed funds and or space to carry out " risky" collaborative researchers

Tendency of internal review panels to support safe - boring science

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Intellectual property issues can be a huge barrier for collaborations, not only between industry/private companies on the one hand and universities/non-profict institutes on the other, but also among non-profit institutions. It is difficult to identify policies/practises that could make this easier.

We had an Environmental Science major in the 90's that was eliminated for several reasons: dwindling number of students, change in the general education requirements that undermined components of the program, lack of effective leadership/stewardship for the program. The last item (leadership) crosses both the Intra- and Inter-personal categories but the real problem was a lack of communication and support for the program from an organizational perspective. The program was directed by a committee, rather than a dedicated director. Each individual had a primary appointment to a traditional department. Furthermore, the program had no budget and students were never sure if they were part of an existing department or something separate. Faculty teaching and leading the program were not rewarded for their service in either annual evaluations or T&P considerations. In short, the traditional departments didn't know how to treat the major which crossed departmental and divisional boundaries and included courses from the other colleges as well.

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a. Little attention to the opportunities for success of the individual even in a group setting.

b. Recruitment without regard for likely compatibility in terms of personality and research activity.

c. Top down imposition of research goals; accrual ufo opportunities and kudos only by the group leader.

d. Insufficient support to conduct cutting edge studies.

e. An atmosphere that doesn't provide clear and ongoing support for maximal advancement.

f. Separation of laboratories by walls, floors, and even buildings. Outdated laboratory space. Overcrowding.

One of the greatest challenges for both the new College of Sciences and the interdisciplinary cluster hiring program at NC State University is the allocation, reassignment and renovation of space to serve these new programs. A culture change is called for and beginning to take shape that moves ownership of space to more central levels of the university. External restrictions that constrain opportunities for funding new construction from traditional sources (state appropriations or bonds) has us pursuing other models to generate incremental space, especially for research.

Academic departments need to feel "ownership" in an interdisciplinary activity. Also, to build interdisciplinary research one needs faculty who not only intellectually are at the top, but individuals that also are team players or as I like to say will be "good neighbors." Critical for an institution that wants to promote interdisciplinary research is a promotion and tenure system that recognizes the importance of interdisciplinary research in the evaluation of a faculty candidate for promotion and/or tenure. At Georgia Tech this is through the appointment of an area committee or what I call a first level committee which is made up of the 3-4 faculty on campus, independent of their academic home, that can best evaluate the scholarship of the candidate. This area or first level committee writes a report on their evaluation which becomes part of the package that works its way up from the department to the college and finally to the provost. If at any level there is disagreement with the area committee report, it cannot be ignored and must be addressed in a substantive way.

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a. Intrapersonal - The institution can affect the types of students that enter labs by recruiting those with interdisciplinary interests and fostering interdisciplinary programs. By showing that the institution values these convergent approaches, it will cause the students who are already there to value these approaches. My Chemistry department does not do a particularly good job of this. Although the institution does have a Chemistry/Biology interface training grant, it is not well advertised at the departmental level and incoming students only really find out about it upon visiting the campus after admission.

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a. Indoctrinating new faculty/researchers to inflexible procedures/policies.
b. Top down mandate that certain individuals work together
c. Giving one time money for equipment/infrastructure without ongoing support to sustain it.
d. ??
e. Changing expectations/metric mid-project.
f. Too much detail on a metric to judge fairness vs. equity. It puts the researchers into a competition for control (e.g. tallying square footage of lab space as a means to judge long-term research productivity).

A situation where transdisciplinary work has been less successful is a case where the primary conflicts seem to be in communication and sharing of credit. Members of the team are expected to give much of the credit to the center director, which causes conflict between that director and the administrators at the institution. The members of the team indicate that they are happy with the structure of the projects, but the larger institutional hierarchy is not informed of the requirements put on the team by the center director. If communication were better between the administrators and the center director, perhaps the transdisciplinary effort would be better received.

Opinion from experience: Lack of organizational support can doom such projects. Lack of informal relationships and respect between the ones doing the work can doom such projects Societal/political issues can also doom such projects. Technological and physical environment issue can be overcome.

At Singularity University, we do achieve the right results. This summer alone, there were 16 companies created that use converging, exponential technologies to solve big problems.

COMMITTEE ON KEY CHALLENGE AREAS FOR CONVERGENCE AND HEALTH

Statement of Task

The National Research Council (NRC) will appoint an expert committee to explore the application of "convergence" approaches to biomedical research. This approach is intended to realize the untapped potential from the merger of multiple disciplines to address key challenges that require such close collaborations. As its primary information-gathering activity, the committee will convene a workshop to examine examples or models drawn, if possible, from a range of on-going programs, both large and small, public and private, in which such approaches are being implemented. The goal of the workshop is to facilitate understanding of how convergence in biomedical research can be fostered effectively through institutional and programmatic structures and policies, education and training programs, and funding mechanisms. The resulting report will summarize the lessons learned on successful approaches to implementing convergence in different types of biomedical research institutions.

Committee Roster

Joseph M. DeSimone, Chair (NAS, NAE)
Frank Hawkins Kenan Institute of Private Enterprise, University of North Carolina, and North Carolina State University

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EMD Millipore Corporation and Institute for Systems Biology

James M. Gentile
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Cherry A. Murray (NAS, NAE)
Harvard University

Monica Olvera de la Cruz (NAS)
Northwestern University

Nicholas A. Peppas (NAE, IOM)
University of Texas at Austin

Lynne J. Regan
Yale University

J. David Roessner
SRI International

Julie Thompson Klein
Wayne State University

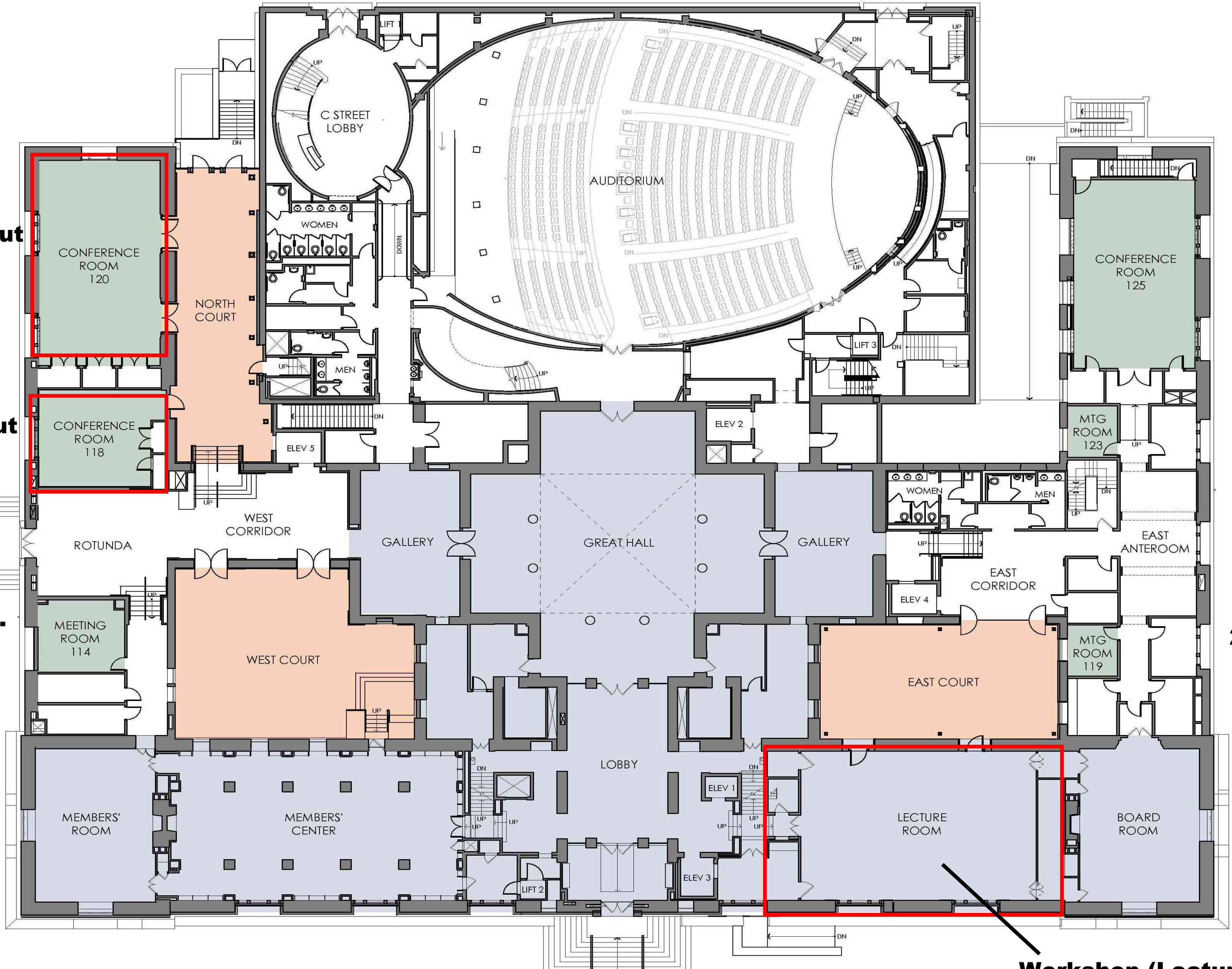
NAS BUILDING (First Floor Layout)

C Street Entrance

Breakout A

Breakout C

22nd St.



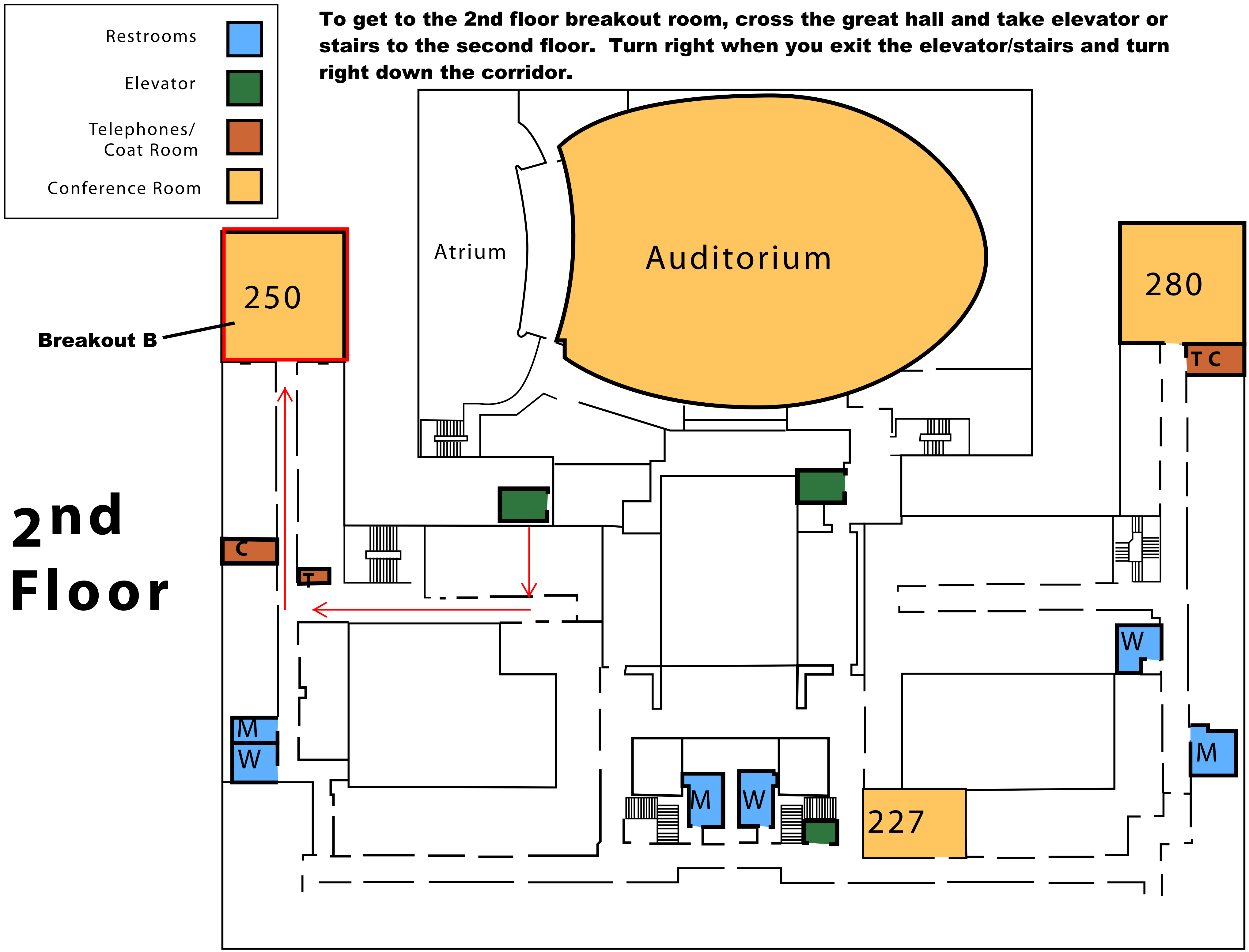
21st St.

Front Entrance (Constitution Ave.)

Workshop (Lecture Room)

Breakout D

To get to the 2nd floor breakout room, cross the great hall and take elevator or stairs to the second floor. Turn right when you exit the elevator/stairs and turn right down the corridor.



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