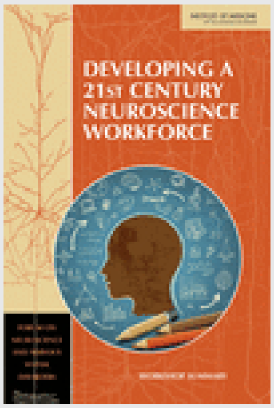

Developing a 21st Century Neuroscience Workforce: Workshop Summary

DETAILS

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DEVELOPING A 21ST CENTURY NEUROSCIENCE WORKFORCE

WORKSHOP SUMMARY

Sheena M. Posey Norris, Christopher Palmer, Clare Stroud, and
Bruce M. Altevogt, *Rapporteurs*

Forum on Neuroscience and
Nervous System Disorders

Board on Health Sciences Policy

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"Knowing is not enough; we must apply.
Willing is not enough; we must do."
—Goethe

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This workshop summary has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published workshop summary as sound as possible and to ensure that the workshop summary meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the process. We wish to thank the following individuals for their review of this workshop summary:

HOWARD FEDEROFF, Georgetown University
EVE MARDER, Brandeis University
CAROL MASON, Columbia University
JULIO RAMIREZ, Davidson College
FRANK YOCCA, AstraZeneca Pharmaceuticals

Although the reviewers listed above have provided many constructive comments and suggestions, they did not see the final draft of the workshop summary before its release. The review of this workshop summary was overseen by **ENRIQUETA BOND,** Burroughs Wellcome Fund. Appointed by the Institute of Medicine, she was responsible for making certain that an independent examination of this workshop summary was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this workshop summary rests entirely with the rapporteurs and the institution.

Contents

1

Introduction and Overview[1]

From its very beginning, neuroscience has been fundamentally interdisciplinary. As a result of rapid technological advances and the advent of large collaborative projects, however, neuroscience is expanding well beyond traditional subdisciplines and intellectual boundaries to rely on expertise from many other fields, such as engineering, computer science, and applied mathematics. This raises important questions about how to develop and train the next generation of neuroscientists to ensure innovation in research and technology in the neurosciences. In addition, the advent of new types of data and the growing importance of large datasets raise additional questions about how to train students in approaches to data analysis and sharing. These concerns dovetail with the need to teach improved scientific practices ranging from experimental design (e.g., powering of studies and appropriate blinding) to improved sophistication in statistics. Of equal importance is the increasing need not only for basic researchers and teams that will develop the next generation of tools, but also for investigators who are able to bridge the translational gap between basic and clinical neuroscience.

[1]The planning committee's role was limited to planning the workshop, and the summary has been prepared by the workshop rapporteurs (with acknowledgment of the assistance of staff as appropriate) as a factual summary of what occurred at the workshop. Statements, recommendations, and opinions expressed are those of individual presenters and participants, and are not necessarily endorsed or verified by the Institute of Medicine, and they should not be construed as reflecting any group consensus.

WORKSHOP OBJECTIVES

Given the changing landscape resulting from technological advances and the growing importance of interdisciplinary and collaborative science, the Institute of Medicine's (IOM's) Forum on Neuroscience and Nervous System Disorders convened a workshop on October 28 and 29, 2014, in Washington, DC, to explore future workforce needs and how these needs should inform training programs (see Box 1-1 for the Statement of Task). Workshop participants considered what new subdisciplines and collaborations might be needed, including an examination of opportunities for cross-training of neuroscience research programs with other areas. In addition, current and new components of training programs were discussed to identify methods for enhancing data handling and analysis capabilities, increasing scientific accuracy, and improving research practices. Lastly, the roles of mentors, mentees, training program administrators, and funders in the development and execution of revised training programs for new and current researchers were considered.

ORGANIZATION OF THE REPORT

The following report summarizes the presentations from expert speakers and discussions among workshop participants, starting with a review of the current and future diversity of neuroscience in this chapter. The ensuing chapters provide an overview of the challenges and opportunities in training related to basic research, tool development and big data (Chapter 2), protocol design and experimental rigor (Chapter 3), transdisciplinary research (Chapter 4), and translational research (Chapter 5). Cited references, the workshop agenda, a list of registered attendees, and participant biographies can be found in the appendixes of this report.

BOX 1-1
Statement of Task

- Explore future workforce needs in light of new and emerging tools, technologies, and techniques.
  - Consider what new subdisciplines and/or collaborations with other fields might be needed moving forward.
  - Describe opportunities and challenges for cross-training of neuroscience research programs with other areas (e.g.,

engineering, computer science, mathematics, physical sciences) and across research environments (e.g., academia, industry).

- Identify current components of training programs that could be leveraged and new components that could be developed that might lead to the following:
  - Greater interdisciplinary and collaborative approaches.
  - Enhanced data handling and analysis capabilities.
  - Increased scientific accuracy and reproducibility.
  - Improved awareness of ethical research practices.
- Examine roles of training program funders (e.g., government, fellowships), administrators, mentors, and mentees in developing and executing revised training programs to meet the needs outlined above.
- Consider mechanisms for updating researcher competencies at multiple levels (e.g., postdoctoral, independent investigators) to meet the needs outlined above.

THE CURRENT AND FUTURE DIVERSITY OF NEUROSCIENCE

There are two key considerations in developing a neuroscience workforce for the 21st century: the intellectual and scientific progress in the field is shaping the need for new training, and challenges related to funding and advancement opportunities make it increasingly important to prepare trainees for a range of careers. To set the stage for discussions about developing training programs to prepare trainees for the future of neuroscience and ensuring that the field has individuals with the appropriate backgrounds, Story Landis, former director of the National Institute of Neurological Disorders and Stroke (NINDS), described the current state of neuroscience, including both the challenges and potential opportunities. The remainder of the workshop summary focuses primarily on the new training needed to continue to make intellectual and scientific progress in neuroscience.

The field of neuroscience finds itself in the midst of an era of unprecedented growth and popularity, she noted. For the past decade, the number of new neuroscience Ph.D.s has significantly outpaced every other life sciences discipline, with the next most popular field producing only half as many graduates per year (see Figure 1-1). Relative to other fields, neuroscience funding is also on the rise. In 2014 the National Institutes of Health (NIH) funded more neuroscience research than cancer research for the first time in its history, noted Landis. Yet, she added, despite living in what can be considered a "golden age" of neuroscience, there is a feeling of doom and gloom regarding career prospects.

Challenges for the Next Generation of Scientists

Over the past decade, the United States has seen an overall decrease in scientific research and development spending (when adjusted for inflation), particularly for the life sciences (Macilwain, 2013; Rockey and Collins, 2013; Wadman, 2013). This decrease in spending was exacerbated by the sequestration in 2013, in which major funding agencies, such as NIH and the National Science Foundation (NSF), were affected by additional budget cuts, directly affecting the number of new and ongoing research projects that could be supported. The current financial climate, coupled with the increasing size of the workforce, has put the goals of obtaining a faculty position and establishing a laboratory out of reach for the vast majority of graduates. The reality is that less than one in five Ph.D. graduates will go on to take a research faculty position, despite such a position being reported as the goal of more than 50 percent of graduate students (Cyranoski et al., 2011; Sauermann and Roach, 2012). Landis referred to this disparity as the "training valley of death."

Even when trainees do transition into research faculty positions, data show that career trajectories start later with each passing year. The average age at which those with a Ph.D. in the life sciences receive their first R01[2] grant has been steadily increasing for decades, rising from age 36 in 1980 to age 42 in 2011 (see Figure 1-2). By comparison, said Terry Sejnowski, professor of the Computational Neurobiology Laboratory at the Salk Institute for Biological Studies, the average age of the National Aeronautics and Space Administration (NASA) engineers who put the first man on the moon was 26, meaning that they were 18 when President Kennedy gave his famous "moonshot" speech.

Training and Career Path Diversity

To address the uncertain career prospects faced by young trainees, Landis pointed to two solutions that could be executed in parallel. First, she said there is a moral imperative to provide students with opportunities for training in non-academic careers. Second, she suggested that the

[2]See http://grants.nih.gov/grants/funding/r01.htm (accessed October 28, 2014).

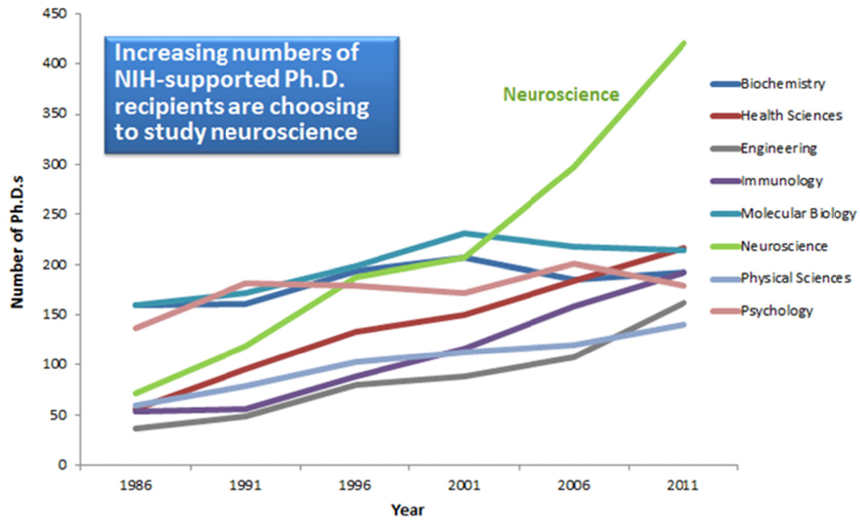

FIGURE 1-1 Number of Ph.D.s awarded on an annual basis in different fields of science and engineering.
NOTE: NIH = National Institutes of Health.
SOURCE: Story Landis presentation, NINDS, October 28, 2014.

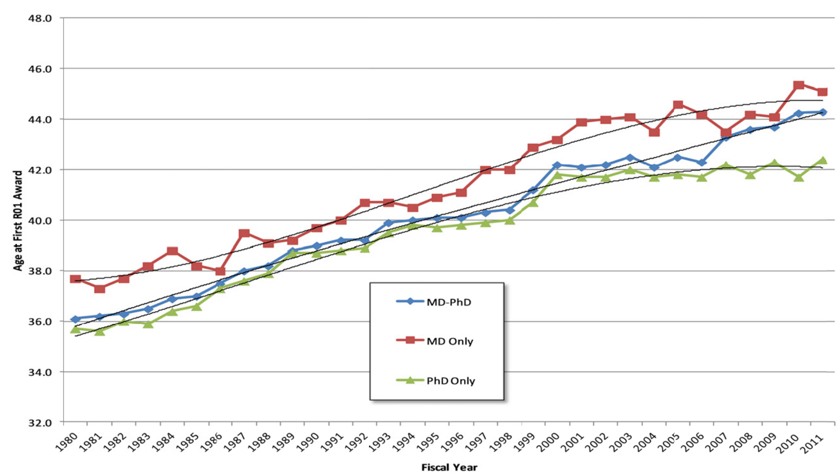

FIGURE 1-2 Average age of principal investigators with M.D.-Ph.D., M.D., or Ph.D. at the time of first R01 equivalent award from the National Institutes of Health, fiscal years 1980 to 2011.
SOURCE: Story Landis presentation, NINDS, October 28, 2014, based on materials from a blog post by Sally Rockey. http://nexus.od.nih.gov/all/2013/11/14/%20whats-trending-in-phd-fields (accessed October 28, 2014).

field needed to take a serious look at the idea of “right-sizing” training—gradually reducing the number of students entering Ph.D. programs—an idea that has been around for a while and was recently addressed in a high-profile commentary written by National Cancer Institute director Harold Varmus and others (Alberts et al., 2014). Along with right-sizing, Alberts and colleagues (2014) suggested limiting the number of years a postdoctoral fellow can be supported by federal grants, increasing the number of permanent staff scientist positions at universities, and reversing the trend over the past few years of supporting trainees with investigators’ research grants in the form of research assistantships. Several workshop participants voiced similar suggestions, saying that training grants, which are peer reviewed, allow students and postdoctoral researchers the freedom of instigating their own projects and provide experience that can help them flourish in the early stages of their careers. Alberts and colleagues (2014) further suggested that trainees be offered more opportunities to explore non-academic careers through extracurricular courses, internships, conferences, or workshops (see Box 1-2).

BOX 1-2
Examples of Non-Academic Careers and Training Opportunities

Science Advocacy and Policy

- American Association for the Advancement of Science (AAAS) Science and Technology Policy Fellowship
- Presidential Management Fellowship
- Hellman Fellowship in Science and Technology Fellowship
- Office of Science and Technology Policy Student Volunteer Program
- Society for Neuroscience Early Career Policy Fellows Program
- National Academies Christine Mirzayan Science & Technology Policy Graduate Fellowship Program
- The Optical Society and International Society for Optics and Photonics Arthur H. Guenther Congressional Fellowship

Science Communication

- AAAS Mass Media Fellowship
- Master’s-level programs in Science Writing at the University of California, Santa Cruz; New York University; Johns Hopkins University
- NeuWrite program at Columbia University
- Director of Communication for Neuroscience Institutes/Programs/Universities (Public Relations)
- Director of Outreach: assembles programs for K–12 education and Brain Awareness Week

Science Publishing

- *Journal of Emerging Investigators*: Students in the Harvard "Paths in DMS (Division of Medical Sciences)" program science-writing path run an online journal dedicated to publishing outstanding high school science fair research projects. The volume of quality submissions has spurred the expansion of the journal to other universities.

Teaching

- Northwestern University Searle Center for Teaching Excellence certificate program

Research in Biotechnology and Pharmaceutical Industry

- Drexel University Master of Science Program in Drug Discovery and Development (see Chapter 5 for more details)
- Postdoctoral fellowships are offered by biotechnology companies such as Amgen, Biogen IDEC, Chiron, GE Healthcare, Genentech, Genzyme, Gilead, Millennium, Serono, and Siemens and pharmaceutical companies such as Abbott, AstraZeneca, Aventis, Eli Lilly, Johnson & Johnson, Novartis, Pfizer, Roche, and Wyeth.

Government

- Program Officer at the National Institutes of Health or National Science Foundation

Business and Consulting

- Consultant (e.g., McKinsey & Company)

Law

- Technology Transfer Specialist at Universities
- Intellectual Property (Patent) Law

Disease Foundations

- Research and Scientific Officer (e.g., Alzheimer's Association, Simons Foundation, and National Multiple Sclerosis Society)

Data Curation

- Data Curators

NOTE: The items in this list were addressed by individual participants and were identified and summarized for this report by the rapporteurs. This is not intended to reflect a consensus among workshop participants.

Several workshop participants noted that this can be a complex challenge because some mentors might not see the value in such opportunities and view any time that trainees spend away from the bench as time wasted. Two graduate students and a postdoctoral researcher said they, like many of their peers, are hesitant to pursue faculty positions because of the perception that faculty are overstressed and underpaid. Sofia Jurgensen, a postdoctoral researcher at Albert Einstein College of Medicine, said that students and postdocs need more freedom to explore such careers and gain real-world experience during their training periods. Marguerite Matthews, a postdoctoral researcher at Oregon Health & Science University, shared Jurgensen's sentiment, adding that she has heard many of her fellow trainees who are considering non-academic careers despair that all they know is how to carry out research. Most trainees do have transferrable skills—project management, communication, teaching—but what they lack, said Matthews, is the recognition of the value of those skills and the opportunities to develop them into satisfying careers. Several workshop participants noted the importance of the role for institutions to facilitate the exploration of non-academic careers among students (see case example of Harvard University's "Paths in DMS [Division of Medical Sciences]" program in Box 1-3). In addition, a few workshop participants suggested that allowing students to have more than one mentor might be beneficial to help facilitate this diversity.

BOX 1-3
Program Example: Harvard University's Paths in DMS (Division of Medical Sciences) Program[a]

David Lopes Cardozo, associate dean for graduate studies and director of the Division of Medical Sciences at Harvard University, shared his experience counseling trainees in career decisions. Roughly half of his students over the past few years have expressed interest in non-academic careers. Cardozo directs a program at Harvard called "Paths in DMS" that works with trainees to navigate non-academic career opportunities in neuroscience. The program takes four primary approaches to formalizing training in career diversity:

- **Institutional Buy-In**
  Obtaining approval for career diversity training from the highest levels of the school sent a message to students, especially those experiencing anxiety and despair over their career prospects, that there is no stigma associated with non-academic careers. Important positions such as journal editors, policy makers, and sci-

ence communicators all need to be filled with well-educated people, and the university recognizes that training people to succeed in those positions is part of its mission.

- **Career Tracks**
  The program encourages students to organize into career tracks and provides relevant coursework to prepare them to enter specific careers. The six paths are biotechnology/pharmaceutical, consulting/business, patent law, science writing and publishing, education and public outreach, and government and public sector. In addition, the program is rolling out an online course that introduces students to the full variety of career options.
- **Network and Mentoring Events**
  Alumni and friends of the program—leaders from local companies—are eager to help and are much better prepared to mentor students in finding appropriate non-academic careers than faculty members who often have no experience with jobs outside academia.
- **Certification**
  Students completing the curriculum associated with each path earn a certificate that demonstrates to potential employers the students' commitment to a specific career track.

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[a]See http://www.hms.harvard.edu/dms/resources/paths.html (accessed October 29, 2014).
SOURCE: David Lopes Cardozo presentation, Harvard University, October 29, 2014.

Training a New Generation of Students

Marie-Francoise Chesselet, professor of neurology at the University of California, Los Angeles, and Thomas Insel, director of the National Institute of Mental Health, noted that the next generation of neuroscientists is truly a "new breed" with respect to this generation being the first to grow up with the technological advances that we have today, namely the Internet. Given this experience, they have different approaches to learning, working with information, and overall social interactions, said Chesselet. A few participants added that from their perspective, the new generation of digital natives often lack the oral and written skills that were seen in earlier generations. Darcy Kelley, professor of biological sciences at Columbia University, agreed, stating that at her institution second-year neuroscience graduate students complete a qualifying exam, which is their thesis proposal. She noted that, in addition to working with an in-house professional writing consultant, her department hired a professional non-fiction science writer to help develop the writing skills of students. Several participants stressed that program administrators should be aware of the characteristics of this new generation of neuroscientists when modifying their training programs.

TOPICS HIGHLIGHTED DURING PRESENTATIONS AND DISCUSSIONS

Given the changing intellectual and scientific landscape within the field of neuroscience, trainers (program directors, funding bodies, etc.) seek to develop new courses and training vehicles to prepare students in the best practices in scientific research. Workshop co-chairs Huda Akil, professor of neurosciences at the University of Michigan, and Stevin Zorn, executive vice president of neuroscience research at Lundbeck Research USA, challenged participants to think deeply about the nature of the field of neuroscience. Akil asked workshop participants to consider how neuroscientists might define themselves in terms that are not so rigid that the spirit of being a neuroscientist is lost. Zorn's questions drilled down further into neuroscience's identity. Is neuroscience a discipline? Is it an interdisciplinary science? How do we train students to work across disciplines to ensure innovation going forward?

Throughout the workshop, discussions focused primarily on the changing needs and opportunities of graduate neuroscience programs, given the growing importance of interdisciplinary and collaborative science and technological advances in the field. Individual participants discussed a number of central themes, summarized below and expanded on in succeeding chapters. Individual participants also identified areas of core competence in which trainees would benefit from training (see Box 1-4).

BOX 1-4
Suggested Core Competencies for Neuroscience Trainees Presented by Individual Speakers

- Ethics
- Mentoring
- Written and oral communication
- Knowledge of general neuroscience literature and deeper knowledge of subdiscipline literature
- Lab and office management
- Grant-writing skills

- Teaching
- Experimental rigor
- Protocol design (randomization, blinding, sample size calculations)
- Common sense and intuition about data
- Statistical reasoning
- Computer programming (matrix laboratory [Matlab], R, Python, Apache, Hadoop)
- Computer modeling
- Algorithm development
- Data visualization
- Data analysis (regression, multivariate data, multidimensional data, cloud computing, feature extraction, versioning)
- Data literacy (data rights, data licenses)
- Data management (data formats, data platforms)
- Data sharing (application programming interfaces, web scraping, data repositories)
- Tool development (knowledge in physics and engineering)
- Tool implementation (knowledge of optics, genetics, molecular biology)
- Translational science (biomarkers, stem cells, behavioral assays)
- Clinical science (neurobiology of disease)

NOTE: The items in this list were addressed by individual participants and were identified and summarized for this report by the rapporteurs. This is not intended to reflect a consensus among workshop participants.

- **Basic Research**
  Basic research is the backbone of the neuroscience enterprise, according to Story Landis; without discoveries of fundamental principles of how neurons and the brain work, clinical treatments are not possible. Participants discussed the importance of making trainees aware of the need to create a balance among basic, clinical, and translational research using an interdisciplinary approach.
- **Experimental Rigor and Quantitative Skills**
  Many participants discussed the need for improved training in experimental design and rigor, and noted that without these critical elements, studies are difficult to replicate, which undermines the entire scientific process. In addition, several workshop participants noted that the lack of quantitative skills exacerbates this problem. Participants listed many of the causes of irreproducibility (e.g., poor understanding of statistics, unreliable resources such as cell lines and antibodies, and lack of transparency of re-

porting methods and raw data in journals) and suggested strategies and opportunities for enhancing the training of students in these areas. The most important skill, argued one participant, is statistical reasoning, which comes only from an intuitive understanding of probability. Participants discussed innovative approaches to teaching quantitative skills to graduate students and postdoctoral fellows and the need to increase collaborations with expert statisticians.

- **Next-Generation Tools and Technologies**
Powerful new tools are allowing neuroscientists to peer deeper into the workings of the nervous system than ever before. Participants discussed the skills and training necessary to keep up with the already rapid pace of innovation, and opportunities for training students not only in using next-generation tools, but in thinking deeply about their limits and how best to deploy them. Several participants discussed the importance of allowing students to explore external resources outside their institution to learn new techniques from experts in the field and creators of the technology.
- **Data Handling and Analysis**
The era of big data in neuroscience has arrived and brought with it numerous opportunities for powerful analyses of the voluminous data produced by neuroscience's new tools. Along with those opportunities come challenges in the three main aspects of data handling: data literacy, data management, and data sharing. Several workshop participants discussed specific challenges in these areas, which include developing common data standards and standardized platforms; learning the etiquette regarding the sharing of data; determining which data should be shared; assigning credit to data sharers; and determining efficient methods to annotate data with all of the metadata needed to understand the experimental context. Many participants also described the skills needed to integrate different data types and analyze multidimensional datasets.
- **Transdisciplinary Neuroscience**
As neuroscience becomes more expansive, individuals with skills and knowledge from nearly every discipline of science are needed to work together on increasingly complex projects. Several participants noted that it is in this space where innovation will arise and where there are opportunities to train scientists to

work toward a sum greater than the collected parts. For example, developing new tools and technologies requires collaboration with material scientists, chemists, and myriad types of engineers; analyzing multidimensional data requires statisticians and informaticians; and drug development requires clinical experts. To facilitate innovation in the field, several participants discussed the importance of incentivizing a team science approach in neuroscience, and providing students with hands-on experience working in transdisciplinary teams.

- **Translational Neuroscience**
  Workshop participants discussed ways to make all neuroscience trainees aware of the steps required to translate a basic research discovery into a treatment, regardless of their specific role in the process. Several participants also discussed the recent transition within the pharmaceutical industry to focus on rare diseases with a known genetic component that can be exploited to identify biomarkers as a way to stratify patients—a critical step in testing and validating new treatments. Lastly, the need to build strong interdisciplinary teams to conduct translational research was noted by many participants.
- **Bridging the Gap Between Basic and Clinical Science**
  Although basic neuroscience has long relied on clinical science to validate and deploy treatments based on fundamental discoveries of the nervous system, a few participants noted that there is a surprising disconnect and lack of cross-training between the two fields. A workshop participant stated that the consequences of the lack of cross-training include inefficient attempts to translate basic findings into treatments and missed opportunities to leverage the clinical setting for important basic research. Opportunities for cross-training noted by a few workshop participants include additional neurobiology of disease and other clinically focused courses, increased availability of clinical rotations to neuroscience graduate students, increased opportunities for clinicians to be exposed to basic neuroscience courses and hands-on research experience, and interdepartmental teams focused on shared clinical goals involving both M.D.s and Ph.D.s (e.g., Parkinson's disease centers).
- **Non-Academic Career Paths and Training Models**
  As neuroscience Ph.D.s continue to pursue career paths beyond academia, participants discussed opportunities available to train-

ees to explore such tracks in graduate programs and postdoctoral fellowships. In addition, several participants reviewed alternative models of training beyond the traditional Ph.D. programs, including certificate programs, M.S. programs, and a proposed doctor of neuroscience training program.

- **Training *of* Neuroscientists Versus Training *in* Neuroscience**
  Throughout the workshop, many participants asked if it were an unreasonable expectation for trainees to be knowledgeable in each of the many subfields of neuroscience. For example, should students with a cellular and molecular focus also need to have deep knowledge in cognitive and systems neuroscience or techniques like functional magnetic resonance imaging? Would students be better off choosing subfield tracks within graduate school? Other ways of creating tracks to cater to the many skill sets and aspirations of trainees were also addressed by participants. Can there be separate tracks for students who are set on careers in academic research and for students who want to develop expert knowledge about fundamental basic neuroscience versus traditional neuroscience? Are separate programs needed for the training *of* neuroscientists and for training *in* neuroscience?

2

Training Neuroscientists in Basic Research, Tool and Technology Development, and Big Data

Key Highlights Discussed by Individual Participants

- Basic research is the foundation of the neuroscience enterprise (Landis).
- Exposing trainees to the interplays among basic, translational, and clinical research can help to ensure a proper balance of the three is maintained through the next generation of neuroscientists (Landis).
- Trainees need to understand the fundamental principles that underlie the tools they use in order to understand the limitations of those tools and the situations in which they can be appropriately deployed (Marder).
- As the complexity of new tools increases, novel mechanisms for teaching trainees and other scientists to use them can facilitate widespread adoption (Landis).
- Handling and analyzing large amounts of data will be a major challenge in the next era of neuroscience (Sejnowski).
- There are three major aspects to working with big data: data literacy, data management, and data sharing (Martone).

NOTE: The items in this list were addressed by individual participants and were identified and summarized for this report by the rapporteurs. This is not intended to reflect a consensus among workshop participants.

Basic research is the fuel that powers advances in neuroscience, noted Story Landis. A solid understanding of how neurons function, form neural circuits, and ultimately influence behavior underlies every effort to develop clinical treatments for neurological diseases (Koroshetz and

Landis, 2014). Several speakers and workshop participants discussed how to structure graduate programs to instill in trainees the best practices for conducting basic research. In addition, many participants highlighted the need for trainees to have a fundamental knowledge of the new tools and technology that are used to make basic research discoveries, as well as the ability to properly handle and analyze the big data that are generated from them.

THE NEED FOR INCREASED TRAINING IN BASIC RESEARCH

In her presentation, Landis called attention to the important role that basic research plays in neuroscience. Without basic science discoveries, she said, there would be nothing to translate into clinical treatments and the whole neuroscience enterprise would collapse. Yet, an analysis of NINDS's funding portfolio,[1] overseen by Landis during her tenure as director, revealed that the institute's funding of basic science has decreased over the years (see Figure 2-1). In 1997, basic research accounted for 52 percent of NINDS's overall budget. By 2012 that proportion dropped to 27 percent, while funding of clinical and translational science increased by a corresponding amount (Landis, 2014). Looking at data from 2 years, 2008 and 2011, requests for funding of so-called basic-basic research dropped by 21 percent, while disease-focused basic requests increased 23 percent, applied-translational requests increased 42 percent, and applied-clinical requests increased 38 percent (Landis, 2014). The success rate for basic science grants, however, remained unchanged over that time period (and was actually higher than all other categories in both 2008 and 2011). While similar trends were not seen at the National Institute of Mental Health or NSF, Landis and several workshop participants expressed the need for training programs to emphasize to graduate students and postdoctoral researchers the importance of basic research, its relationship to translational and clinical research, and the

[1]See http://blog.ninds.nih.gov/2014/03/27/back-to-basics (accessed October 28, 2014).

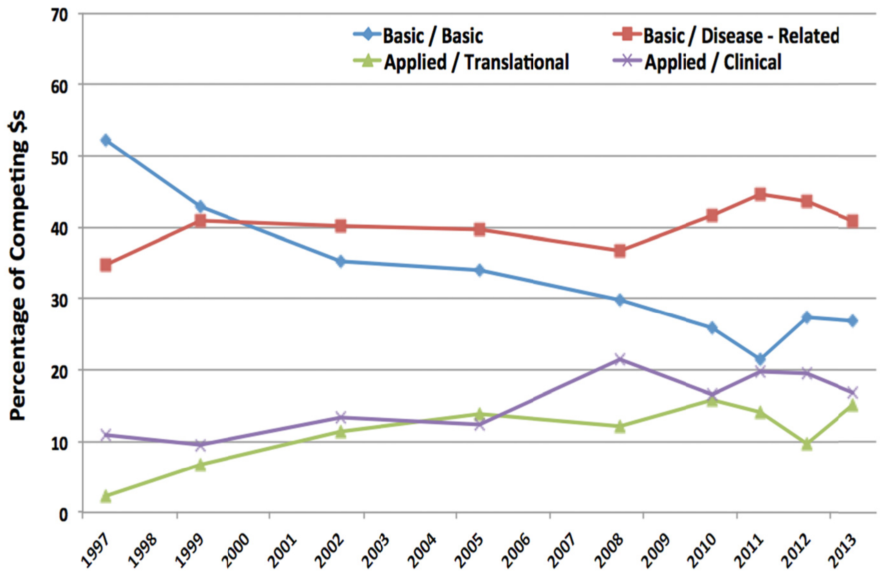

FIGURE 2-1 Percentage of the competing budget spent on unsolicited, investigator-initiated grants in the four subcategories at the National Institute of Neurological Disorders and Stroke.
SOURCE: Landis, 2014.

need for balance among these three areas (Yamaner, 2014). In particular, Landis and Eve Marder, professor of biology at Brandeis University, stated that trainees need to hear the message that not everyone has to conduct translational research to get jobs and funding. Exposure to this message about the critical role of basic science could occur in core courses as well as nano-courses or seminars that use successful neurological treatments as case examples to trace through lines from basic science discoveries, to their translation into drugs or devices, treatments, and finally to clinical testing. There is scope for specialization; however, one participant noted that training programs can become centers of excellence for basic, clinical, or translational science.

TRAINING IN TOOL AND TECHNOLOGY DEVELOPMENT

Increasingly, basic research discoveries have become dependent on the development of new tools and technologies, as well as the ability to handle, manage, and analyze the large quantities of data being collected with those tools. One participant recalled the deep reluctance that many students in the past had toward working to develop probes or assays, or otherwise push the technological aspects of neuroscience forward. Work on such projects was not highly valued, the participant noted; instead, students were more excited to use the new tools to make discoveries. While making important discoveries is still a priority, much of the current excitement in neuroscience stems from the development of tools and technologies, for example, optogenetics,[2] CLARITY,[3] and CRISPR.[4] Many workshop participants noted that along with this excitement come a number of challenges, not only in training students how to develop powerful tools but also in training students on how best to deploy them while thinking deeply about their limits. As technologies are applied to advanced discoveries in basic neuroscience, there is also a growing realization that those same or similar technologies can be used to provide therapeutic functions, noted Douglas Weber, program manager of the Biological Technologies Office at the Defense Advanced Research Project Agency (DARPA).

Enabling Tool Development Through Transdisciplinary Collaboration

Using DARPA's Revolutionizing Prosthetics Program as an example, Weber discussed the myriad skill sets needed to develop the next generation of tools and technology. With the rapid growth and diversification of the field of neuroscience, he said, there has been a tendency for disparate groups to work in silos. He noted that groups work across different scales—from molecules to cells to networks—and study different systems—from autonomic and sensory systems to cognitive functions.

[2]The use of genetically encoded light-sensitive proteins to control neural activity with flashes of light.

[3]**C**lear, **L**ipid-exchanged, **A**crylamide-hybridized **R**igid, **I**maging/immunostaining compatible, **T**issue h**Y**drogel. A process for replacing brain tissue with hydrogels to make the brain transparent in order to visualize neural ensembles.

[4]**C**lustered **R**egularly **I**nterspaced **S**hort **P**alindromic **R**epeats. An RNA-based gene-editing platform that allows scientists to engineer any part of the human genome with extremely accurate precision.

Integrating information across these many scales and systems can be challenging. However, Weber expressed hope that these challenges can be overcome through programs such as the Brain Research through Advancing Innovative Neurotechnologies (BRAIN) Initiative,[5] which incorporates a strong focus on finding ways to synthesize information across these many scales to yield a more holistic understanding of how the brain works.

The goal of DARPA's program is to modernize the design and function of prosthetic hands and arms, which have lagged far behind lower limb prosthetics, he noted. Until recently, artificial hands consisted of a hook system attached to a cable wrapped around the user's shoulder that is controlled using simple shoulder shrug maneuvers. This basic design had remained relatively untouched since the days of the Civil War. In thinking about its redesign, DARPA used as its inspiration the prosthetic hand given to Luke Skywalker after his had been severed at the wrist. That is, they sought to build a realistic-looking articulated hand with several degrees of freedom for the wrist and each digit, all integrated into the user's nervous system and controlled directly by the brain. Weber mentioned several skill sets that the 400-member team charged with creating the integral pieces of DARPA's revolutionary prosthetic hand needed:

- Neuroscientists with expertise in sensory feedback and haptics, neural motor decoding and neural stimulation
- Materials science: Materials for every physical piece of the hand—from the lifelike cosmetic covering that needs to be flexible, durable, and waterproof to the biocompatible electrodes that interface with the user's nerves—need to be carefully selected, designed, and tested
- Systems engineering
- Mechanical engineering
- Software engineering
- Wireless communications
- Signal processing
- Modeling: Models for how information to control specific motor movements (e.g., reaching and grasping) is encoded in the patterns of neural activity that are represented in the brain
- Human factors

[5] See http://www.whitehouse.gov/share/brain-initiative (accessed October 29, 2014).

- Data analysis
- Behavioral analysis
- Surgery
- Physical therapy
- Occupational therapy
- Human subjects research
- Manufacturing
- Project and program management

Several workshop participants discussed strategies for enabling this type of transdisciplinary collaboration at the level of graduate training programs to encourage tool development. One example would be developing courses with other departments that offer hands-on labs for students to examine specific topics might encourage collaboration among disciplines. One example of this approach is the University of Pennsylvania's course on "Brain-Computer Interfaces" in which neuroscientists work collaboratively with engineers and physical scientists on programming projects.[6] A few workshop participants noted that another method for encouraging transdiscipline approaches is the NSF Research Traineeship (NRT) grant program (formerly the IGERT [Integrative Graduate Education and Research Traineeship] program),[7] which provides training funds for a group of graduate students from different departments within a university to work together on a single project. NIH can facilitate cross-discipline approaches by issuing awards similar to NRT and through the creation of centers of excellence, such as the Morris K. Udall Centers for Parkinson's Disease Research, which are hosted at nine universities. NINDS has created a novel type of center, called the Epilepsy Centers without Walls, which bring together dozens of scientists to work on a single aspect of epilepsy regardless of their physical location. One center is focused on the investigation of sudden death in epilepsy and includes expertise in neuroscience, genetics, anatomy, clinical research, imaging, pathology, stem cells, informatics, molecular biology, and data analytics. John Morrison, professor of neuroscience at the Icahn School of Medicine at Mount Sinai, also emphasized the importance of neuroengineering and suggested that neuroscience departments establish links with schools of engineering. He also suggested that more universities develop Ph.D. programs in neuroengineering to create more expertise in this area.

[6]See Chapter 3 for further discussion about this course.
[7]See Chapter 3 for further discussion about NSF Research Traineeship grants.

Demystifying Neuroscience Tools

Each new neuroscience tool and technique has its own idiosyncrasies and drawbacks, as well as unique demands related to analyzing the data it produces, said Landis. Therefore, she cautioned, it will not be enough to simply know how to use a tool, but rather it is important for trainees to know the fundamentals of the tool and its function(s) and shortcomings, which in turn help them to troubleshoot problems that arise. Marder agreed, stating that trainees need to demystify all of the tools they are using, and not be mere consumers. She highlighted that this is particularly true when it comes to optics and microscopy. For fluorescence microscopy, it is intuitive how the microscope works as one manually focuses and changes the objective. But for 2-photon microscopy and other less intuitive tools, students' lack of understanding of the technology can be a detriment because they are less likely to recognize when a problem is occurring. Marder is equally concerned with whether next-generation microscopes will be too complicated for most students to learn to use proficiently. The expense of these new microscopes, which can run in the millions of dollars, means that only students enrolled in a few well-endowed programs will have the opportunity to learn to use them. Marder identified this issue as having the potential to be a major gap in training. One step Marder has taken to close the gap in understanding the fundamentals of optics is by encouraging her students to take a microscope and optics lab course at Brandeis University (which is open to neuroscientists), in which students build their own microscopes.

Marder suggested a number of steps that graduate programs can take to enhance students' understanding of the tools they use. Programs can develop more tool-based lab courses and they can also look to outside sources of training. For example, programs can encourage students to attend courses at Cold Spring Harbor Laboratory and the Marine Biological Laboratory at Woods Hole[8] that focus on teaching the fundamentals of a variety of lab tools and techniques. Programs can also fund student enrollment in mini-courses devoted to single techniques that teach trainees the practicalities and specific details of new tools and techniques.

[8]See further discussion about these courses are provided later on in this chapter.

Dissemination of Tools

To close the gap in student understanding of new tools, several workshop participants asserted that novel mechanisms for tool dissemination are needed. Landis suggested that plans for dissemination of any new tool could be part of the grant applications seeking funding to build the tool. While the BRAIN Initiative has no requirement for such plans in the grants it issues, the *BRAIN 2025: A Scientific Vision*[9] report clearly values the widespread dissemination of the new tools that it is funding (NIH, 2014). Accordingly, the NIH BRAIN Initiative is funding a short course in the use of new tools and another in the analysis of large datasets.[10]

Some neuroscientists have taken the initiative to set up training opportunities to ensure the spread of the technology they have developed, rather than restricting its access. Optogenetics has been successful in part because its creator, Karl Deisseroth of Stanford University, used a research supplement from NINDS to organize free 3-day workshops to train faculty and students from around the world in the required surgeries and techniques. These are held both in university settings and in course modules at Cold Spring Harbor Laboratory and the Marine Biological Laboratory at Woods Hole. Furthermore, when Deisseroth discovered that scientists were struggling to use one of his more recent technologies, CLARITY, he published a highly detailed methods paper to explain some of the more complex aspects of the technique (Tomer et al., 2014). He has also organized free 3-day workshops on CLARITY throughout the year at Stanford. As is the case for the optogenetics workshops, the CLARITY workshops have a dedicated expert in the technique to act as education manager.

Mark Schnitzer, a scientist at Stanford University, has taken a different approach to disseminating his state-of-the-art invention. Along with several colleagues, Schnitzer founded a company called Inscopix to produce the nVista *HD*—a miniaturized, head-mounted microscope to visualize large-scale neural circuit dynamics in freely behaving animals. To encourage scientists to use the device, Inscopix has set up a competitive grant program that will offer the use of one to four nVista *HD* microscopes as well as extensive training in their operation.

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[9]See http://www.braininitiative.nih.gov/2025/BRAIN2025.pdf (accessed October 29, 2014).

[10]These courses are described in more detail in Chapter 4.

Another enterprising neuroscientist, Raphael Yuste of Columbia University, has recently founded the NeuroTechnology Center along with a chemist, bioengineer, and statistician. The goal of the center is to develop advanced optical, electrical, and computational technologies to study the nervous system. In addition, the center plans to use funds from the Kavli Foundation to offer training in these new technologies to neuroscientists at all levels.

Several workshop participants also discussed opportunities for graduate students and postdoctoral researchers to engage in intensive summer courses in the use of cutting-edge tools, including courses offered by two well-established training facilities:

- **Marine Biological Laboratory Summer Courses**[11]
  - Neurobiology
  - Neural Systems and Behavior

- **Cold Spring Harbor Laboratory Summer Courses**[12]
  - Advanced Techniques in Molecular Neuroscience
  - Imaging Structure and Function in the Nervous System

TRAINING IN BIG DATA

Until recently, the primary challenge in neuroscience has been collecting useful information about the brain, said Sejnowski. In the first half of the 20th century, neuroscientists exploited principles of physics to record electrical signals from neurons and develop optical methods to visualize anatomy and morphology. In the latter half of the century, molecular biology techniques further expanded the repertoire of data that could be collected. The next era of neuroscience will be dominated by challenges in the ability to handle, manage, and analyze all of the data that are now becoming readily available, noted Sejnowski. Not only will there be challenges in how to manage this large amount of data, but entirely new methods will be needed for integrating different data types and analyzing enormous, multidimensional datasets, he added.

Neuroscience is not the first discipline to be faced with big data issues. For decades, physicists have had to manage large amounts of data;

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[11] See http://www.mbl.edu/education/summer-courses (accessed October 29, 2014).
[12] See http://meetings.cshl.edu/courses.html (accessed October 29, 2014).

however, many of the datasets in physics are collected in manners that have standardized data structures and annotation. Neuroscience data collection is less standardized and the scale and organization more closely resemble the field of genetics, which has been deluged by servers full of genetic data generated by increasingly more powerful sequencing machines since the first genome was cracked more than 20 years ago (Choudhury et al., 2014). Walter Koroshetz, acting director of NINDS, suggested that neuroscience would benefit from considering lessons learned by geneticists regarding their strategies for managing data. Maryanne Martone, co-director of the National Center for Microscopy and Imaging Research at the University of California, San Diego, discussed the critical need for training future scientists to work with big data, focusing on data literacy, data management, and data sharing.

Defining the Gaps in Handling Big Data

In discussing the big data challenges facing neuroscience trainees, Martone quoted Michael Nielsen, author of *Reinventing Discovery*, "An unaided human's ability to process large datasets is comparable to a dog's ability to do arithmetic, and not much more valuable" (Nielsen, 2012, pp. 112–113). She went on to discuss three highly interrelated aspects of data handling that all trainees need to be educated about data literacy, data management, and data sharing.

Data Literacy

Martone noted that although not all neuroscientists need to be data scientists they will be required to use platforms to share and analyze data, and need to be able to understand the fundamentals of large datasets. She made the analogy of taking a class on auto mechanics in high school, not because she ever intended to fix her car, but because she wanted to be able to talk to the people who were going to fix the car. Likewise, attaining a minimum level of data literacy will require some specialized training in areas such as data type, structured data, databases, metadata, query languages, and data formats. In addition, an important aspect of data literacy, said Martone, is being able to navigate the "web of data" to find the right dataset. Knowledge of Web services, application programming interfaces (APIs),[13] data repositories, Web scraping,[14] and online spreadsheets are all helpful for identifying sources of data.

Martone pointed out that most of the data that scientists encounter are not actionable. Instead, data get locked away within journals as static figures due to the current publication process. Some journals, such as *Nature Scientific Data,* are already providing open access databases for all of the data presented in an article's figures and tables. Martone added that the more that trainees are taught to understand the difference between static and actionable data, the more pressure will be put on all journals to adopt similar practices. Open access to data will also enhance a culture of sharing and make the scientific enterprise more transparent, she noted. Several participants stated that both of these developments might help to address the crisis of irreproducible data that the scientific community is now beginning to face.

Another aspect of data literacy, according to Martone, pertains to knowing one's data rights. Trainees need to know what rights they have to their data when making them public. They also need to know the rules concerning the use of publicly available data. Specifically, Martone said that trainees need the skills to evaluate which datasets are relevant to their own projects and have been collected with the proper vigilance and rigor.

Data Management

For data to be useful, they need to be properly managed, noted Martone. That is, they need to be collected in an appropriate standardized format, made readily accessible and interoperable on standardized platforms, annotated, and securely stored. She added that part of the challenge of sharing data is properly annotating them in order for others to understand the context in which they were collected. Having annotation standards in place ensures that each lab that collects a certain type of data could effectively use data shared from another lab. Standards take the guesswork out of what information to collect during the experiment. Many participants stated that standard data formats are also critical to sharing data. According to Brian Litt, director of the Center for Neuroengineering and Therapeutics at the University of Pennsylvania, standard data platforms, rather than a proliferation of individual databases, are helpful for groups and

[13]Snippets of computer code that allow web-based applications to share information with one another.

[14]The automatic extraction of useful data from websites.

individuals to keep track of their data, share data with others, and find relevant data that others have shared. Data platforms are central Web-based hubs that can be used to integrate and validate multidimensional, heterogeneous data from multiple sources and present them in a clean, standardized manner. Data platforms can also be used to share experimental procedures, analytics programs, and models.

For high-output labs, which can produce more than a petabyte per year (see Box 2-1), and even many smaller labs, backing up data has become more complicated than simply saving everything to a series of external hard drives or DVDs. Without a well-considered data management strategy in place, data are at risk of being lost, and older data can be difficult to trace. Martone noted that she has heard senior scientists lament the fact that they feel like they have lost control of their own lab because they no longer know where their data are stored.

Some funding agencies, such as NSF, have mandated data management plans to ensure that data generated via agency grants are secure and easily shared. However, because the plans are not enforced, sharing has been stymied and a significant number of labs are still at risk of potential data loss, noted Martone. A change in the overall culture, starting with trainees, regarding data management will be the only effective means of ensuring widespread sharing and prevention of potential data loss, she added.

Martone mentioned several opportunities to improve data management. For example, some labs manage data with electronic laboratory notebooks to keep track of their data and to maintain digital records of experiment notes. Martone also noted that while most universities do not have centralized data depositories or support networks in place many libraries have been serving as curators of the digital assets that the labs at their universities produce. Data curators will be essential to the neuroscience enterprise; however, there is currently a lack of training programs and defined career paths to consider. Until the field of data curation becomes more formalized and more valued by universities, many data scientists will likely occupy a status in labs similar to research technicians employed directly by investigators, said Martone.

BOX 2-1
How Big Are Big Data?

How much neuroscience data are currently being collected is difficult to quantify, but some high-profile projects have estimated their output:

- Jeff Lichtman at Harvard University estimates his connectomics projects can generate 1 terabyte (Tb) per day (or 365 Tb/year), with a 1 cc brain tissue sample containing roughly 2,000 Tb of data.[a]
- The Human Connectome Project, which plans to collect diffusion tensor imaging and resting state functional magnetic resonance imaging from 1,200 human subjects, is expected to generate more than 30 Tb of data.[b]
- The Kavli Foundation estimates that a single advanced brain laboratory could produce 3,000 Tb of data annually—roughly as much data as the world's largest and most complex science projects currently produce.[c]
- Calcium imaging studies in mice produce approximately 1 gigabit per second of data; anatomical datasets will readily grow to the approximately 10 petabyte scale and beyond.[d]

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[a]http://www.quantamagazine.org/20131007-our-bodies-our-data (accessed October 29, 2014).
[b]http://www.humanconnectome.org/documentation/Q1/data-sizes.html (accessed October 29, 2014).
[c]http://www.kavlifoundation.org/science-spotlights/brain-initiative-survivingdata-deluge (accessed October 29, 2014).
[d]http://www.braininitiative.nih.gov/2025/BRAIN2025.pdf (accessed October 29, 2014).

Data Sharing

Of all the aspects of big data, data sharing was the most frequently discussed by the workshop speakers and participants. See Box 2-2 for recommendations and key points for academic institutions noted in *Sharing Clinical Trial Data: Maximizing Benefits, Minimizing Risk,* a report by the IOM's Committee on Strategies for Responsible Sharing of Clinical Trial Data (IOM, 2015). Although most scientists would agree that making data public helps push science forward, at the individual level there are reservations about sharing that revolve around control, trust, and fear. Several workshop participants noted that educating trainees about the benefits and risks of sharing data can help to alleviate these emotional concerns and facilitate a shift in culture around sharing. Control over one's data has always been sacrosanct in science. But as Landis pointed out, data sharing is "the wave of the future" and scientists will no longer be able to take their data to their graves. Trainees, she said, need to embrace the idea of making their data public. Akil brought up a potentially common anxiety among trainees, and scientists in general, about immediately making public the data they spend months or even years of their lives collecting, only to watch their colleagues publish the initial articles related to those data (Soranno et al., 2014).

Litt suggested two potential mechanisms for creating a system that respects the rights of data collectors while maximizing the community's access to important or hard-to-acquire data. First is the idea of using data licenses to share data in stages or layers. Perhaps data can be initially shared among collaborators or a smaller group of scientists after a set period of time, and then later shared with the whole scientific community, noted Litt. The second idea is a sharing index, or S-index, akin to the well-known impact factor of the proposed H-index.[15] The S-index, which would need support from universities, funding agencies, and publishers, could reward prolific sharing by playing a role in hiring and promotional decisions as well as in grant review.

BOX 2-2

Sharing Clinical Trial Data: Maximizing Benefits, Minimizing Risk

The Institute of Medicine convened an ad hoc committee to develop guiding principles and a framework for the responsible sharing of clinical trial data. Related recommendations and key points for trainees are listed below.

- **Recommendation 1:** Stakeholders in clinical trials should foster a culture in which data sharing is the expected norm, and should commit to responsible strategies aimed at maximizing the benefits, minimizing the risks, and overcoming the challenges of sharing clinical trial data for all parties.
- **Recommendation 2:** Sponsors and investigators should share the various types of clinical trial data no later than the times specified in this (IOM, 2015) report (e.g., the full analyzable dataset with metadata no later than 18 months after study completion—with specified exceptions for trials intended to support a regulatory

[15]Index used to measure the impact and scientific importance of a researcher's publications.

application—and the analytic dataset supporting publication results no later than 6 months after publication).

- **Recommendation 3:** Holders of clinical trial data should mitigate the risks and enhance the benefits of sharing sensitive data by implementing operational strategies that include employing data use agreements, designating an independent review panel, including members of the lay public in governance, and making access to clinical trial data transparent.

Research Institutes and Universities

- **Infrastructure Support: "**High-quality data curation and management are required to prepare for data sharing, so that investigators must both recognize this need and have appropriately skilled personnel available to them…. Better overall support of the clinical trials enterprise within most institutions is needed to support the kinds of data structuring and documentation that will be needed for data sharing" (p. 62).
- **Incentives: "**Appropriate recognition of data sharing activities in the promotion process would provide incentives for sharing data and obtaining maximal value from completed trials. Other promotion-related incentives for data sharing would exist if promotion committees took into account secondary publications by others based on clinical trial data produced and shared by their faculty" (p. 63).
- **Training:** "Most of the workforce that would be involved in activities related to the sharing of clinical trial data are trained in universities. Currently, there is little or no training within traditional clinical research education in the procedures and structures needed to share data. The development of such modules, either online or in classroom settings, could be instrumental in helping to move the field of data sharing forward" (p. 63).

SOURCE: IOM, 2015.

Similar to the idea of an S-index, Martone proposed the notion of separate acknowledgment in papers for those scientists who originally collected the data upon which the paper was based. Headed by Martone, FORCE 11[16]—a community of scholars, librarians, archivists, publishers, and research funders seeking to improve data sharing—is actively trying to create a mechanism to issue such data citations. Several participants noted that such incentives might help to reduce the anxiety among trainees and investigators, and encourage data sharing.

[16]See https://www.force11.org (accessed October 29, 2014).

A few participants noted that trust was another challenge with making data public. Much like clinical trial data, several workshop participants noted that there is a moral imperative to share data to offer the greatest return to the public (see IOM, 2015). In addition, trainees need to learn how to effectively evaluate the trustworthiness of public data, as well as engender trust in data they themselves make public. Several participants stressed that without mechanisms in place to create trust scientists will be reluctant to devote large amounts of time analyzing shared data, or to put their reputations at risk publishing papers about those analyses. Fear of scrutiny and criticism are additional concerns that Martone speculated might make some scientists reluctant to share data. Scientists may be afraid that errors found in the raw data they make public could lead to embarrassment or more serious repercussions.[17] One way to alleviate such fears, she offered, is for a certain level of data etiquette to develop around sharing so that unintentional errors found in data are dealt with in a non-punitive fashion.

Setting aside the various reservations scientists have about making their data public, Koroshetz, as well as several other participants, said that annotations, or metadata, are the most expensive and time consuming part of sharing data. Most experimental data have several pieces of metadata associated with them to include stereotaxic coordinates, cell type, stimulation parameters, and other experimental conditions. Even seemingly innocuous factors, such as the sex of the experimenter or the source of the food, have been known to significantly alter results in experiments with rodents. According to a few participants, tagging each set of electrophysiology traces or fluorescent images with the appropriate annotations is not trivial, but this information needs to be integrated into the experiment workflow to maximize the utility of any shared data. Another challenge with metadata noted by several workshop participants is determining which parameters need to be included and which can be reasonably excluded.

Several participants agreed that not all data are worthy of being shared, particularly given the potential cost; for example, Koroshetz noted

[17] *The Research Council of Norway: Norwegian Researchers Want to Share Data but Fear Jeopardizing Their Career*. See http://erc.europa.eu/sites/default/files/content/pages/pdf/2.4%20Roar%20Skalin.pdf (accessed October 29, 2014).

Survey data in this workshop summary show that approximately one quarter of scientists say data sharing will negatively impact their careers due to at least one of the following reasons: making data available takes away valuable time for research; lack of technical infrastructure; open access would reduce possibilities of scientific publications; concerns connected to misinterpretation of data; and/or cannot give access due to sensitivity issues. Scientists with less than 3 years' experience reported fewer concerns over sharing data.

the cost of NINDS's databases for traumatic brain injuries ($2 million/year), autism ($2 million/year), and Alzheimer's disease ($1.5 million/year). Some data, such as the human subject data from the Framingham Heart Study,[18] are rare, while other data will become obsolete as technology continues to improve. In addition, Litt stated that public data deemed to be more valuable are also more likely to be annotated by users until they eventually become a gold standard. Sejnowski recounted an example from astrophysics with regard to creating high-quality public data. Grants for the Hubble Space Telescope are issued in two tracks: (1) a typical R01-style study where data collection leads to individual publications; and (2) the collection of archival datasets that require significant effort to calibrate, but that are still used extensively as standards against which to compare new data. Sejnowski noted that neuroscience would benefit if NIH funded similar types of calibrated datasets.

As Landis mentioned, it is not enough to hope that trainees will pick up enough knowledge about data handling through informal means; trainers need to have an active role structuring programs for these competencies to be developed. Trainees can be exposed to data-handling issues in lab courses, seminar series, or webinar series (see example skills in Box 2-3). According to a few workshop participants, training programs can set requirements that students write data-management plans for their projects to accompany their thesis proposal or their Ruth L. Kirschstein National Research Services Award or NSF grants, which many programs already require as part of students' qualifying exams. In addition, training programs can consider having an expert on data handling on staff, or share such a person with one or more departments, to act as a resource for students and faculty.

BOX 2-3
Example Data Handling Skills and Knowledge Presented by Individual Participants

- Data management plans (and funding agency requirements)
- Data-sharing platforms
- Incentives for sharing (data citation, S-index)
- Evaluation of data trustworthiness
- Evaluation of data worth
- Data licenses

[18]See https://www.framinghamheartstudy.org/about-fhs/history.php (accessed October 29, 2014).

- Data rights
- Data standardization
- Data formats
- Data annotation
- Open-access journals
- Actionable versus static data
- Application program interfaces
- Web scraping
- Web services
- Online databases
- Cloud computing
- Data storage

NOTE: The items in this list were addressed by individual participants and were identified and summarized for this report by the rapporteurs. This is not intended to reflect a consensus among workshop participants.

Defining the Gaps in Data Analysis

Although all neuroscientist trainees would benefit from training in best practices for data literacy, management, and sharing, a number of special skills are required to analyze large, complex datasets. Litt enumerated those skills and identified the best disciplines outside of neuroscience with which to build collaborations to address gaps in data analysis (see Box 2-4). Litt also described two projects he is involved with that strive to enhance training in data analysis among graduate students:

1. American Epilepsy Society Seizure Prediction Competition: Competitors are invited to download large datasets of intracranial electroencephalogram (EEG) recordings from dogs with epilepsy and develop algorithms to optimally predict seizure onset.
2. www.ieeg.org: Litt engineered a model data-handling platform—found at ieeg.org—that lives on Amazon's S3 browser-based cloud computing service. The platform, currently used by more than 500 people, enables sharing and annotation of computer code and EEG data from epilepsy patients. It also provides tools for large-scale analyses. Trainees at University of Pennsylvania's Center for Neuroengineering and Therapeutics are required to use this platform, not Litt. They learn how to version their code, share data (structuring it into a common format), and use the cloud.

BOX 2-4
Data Analysis: Relevant Skills for Neuroscientists and Disciplines to Build Collaborations

Data Analysis Skills Relevant to Neuroscientists

- Matlab[a]
- R[b]
- Python[c]
- Apache[d]
- Hadoop[e]
- Visualization software
- Multivariate statistical analysis
- Competence in cloud computing (storage, retrieval, and distributed processing)
- Versioning of computer code script files
- Digital signal processing (aliasing, Nyquist, analog to digital transforms, filtering)
- Feature extraction (time, frequency, wavelet, chaotic)
- Data classifiers (supervised and unsupervised)
- Regression
- K-nearest neighbor algorithm[f]
- Support vector machines
- Data clustering
- Data basics (storage, databasing, integration, search, provenance)

Disciplines with Which to Collaborate on Data Analyses

- Computer science
- Machine learning
- Engineering
- Signal processing
- Materials science
- Nanotechnology

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[a] http://www.mathworks.com/products/matlab (accessed October 29, 2014).
[b] http://www.r-project.org (accessed October 29, 2014).
[c] https://www.python.org (accessed October 29, 2014).
[d] http://www.apache.org (accessed October 29, 2014).
[e] http://hadoop.apache.org (accessed October 29, 2014).
[f] http://www.statsoft.com/textbook/k-nearest-neighbors (accessed October 29, 2014).

SOURCE: Brian Litt presentation, University of Pennsylvania, October 28, 2014.

Institute Example: Allen Institute for Brain Science

Jane Roskams, executive director of strategy and alliances at the Allen Institute for Brain Science (AIBS), described the goal of AIBS as making neuroscience tools, data, and knowledge readily and freely available to the scientific community. AIBS employs multidisciplinary teams with experts in neuroscience, cell biology, modeling, data analysis, theory, engineering, and genetics. Over the past 10 years, AIBS has collected more than 30 brain atlases (mouse, non-human primate, and human) and other large neuroscience-related databases. These atlases and databases, which contain more than three terabytes of combined data, are freely available to the public via an online portal. AIBS offers numerous opportunities for collaboration and training related to data management and analysis through traditional classroom training sessions, summer workshops, hackathons, and online webinars.[19]

[19]See http://alleninstitute.org/news-events/events-training (accessed October 29, 2014).

3

Improving Training in Protocol Design, Experimental Rigor, and Quantitative Skills

Key Highlights Discussed by Individual Participants

- Steps to improve reproducibility of experimental results can be implemented by graduate programs (additional curriculum courses on experimental rigor and design), publishers (publish both positive and negative experimental results as well as detailed experimental methods), and funding agencies (issue longer awards and support replication studies) (Landis and Mason).
- Experimental design can be enhanced by incorporating discussions of best practices into every course taken by trainees, regardless of topic, thus ensuring ongoing learning that can be applied in a variety of contexts (Chesselet).
- Trainees need to have an understanding of what outcome measures are needed to appropriately test their hypotheses when designing their experiments (Marder).
- Scientists often do not have the statistical training required to determine the most appropriate analyses to perform for their experiments (Brown).
- Statistics modules tailored to the key subdisciplines of neuroscience can augment general courses on statistics, providing a more specific set of analytical skills that might benefit trainees according to their concentration (Brown).
- In addition to enhancing training in statistics, the field of neuroscience could benefit from more collaboration with statisticians (Brown and Weber).

NOTE: The items in this list were addressed by individual participants and were identified and summarized for this report by the rapporteurs. This is not intended to reflect a consensus among workshop participants.

Over the course of the workshop, participants discussed several opportunities for trainers to think differently about how to train the next generation of neuroscientists, in areas such as cross-discipline collaborations, handling of large datasets, and the development of new tools and technology, as described in the previous chapter. Despite the inherent challenges, including significant changes to the culture of neuroscience, training in these areas appears to have generated an overall sense of positivity and excitement within the neuroscience community. In contrast, many workshop participants identified noticeable gaps in three areas of neuroscience training: protocol design, experimental rigor, and quantitative skills.

Many participants discussed several challenges associated with trainees not learning the fundamentals of conducting rigorous experiments, including the risk of irreproducible findings. Marder led the discussion on protocol design, emphasizing the importance of using common sense and deep intuition about data to design and execute the right experiments as the landscape of neuroscience continues to evolve. Emery Brown, professor of computational neuroscience at the Massachusetts Institute of Technology, outlined gaps in the training on quantitative skills and the need for recruitment of experts in statistics to the field of neuroscience.

ENHANCING EXPERIMENTAL RIGOR AND REPRODUCIBILITY

The Problem

The enterprise of science is based on making discoveries that can capture new knowledge about the world. That knowledge may be exploited to make predictions about the occurrence of natural phenomena, or it can be the inspiration to potentially manipulate the natural world. However, if discoveries are not repeatable, those predictions are insignificant and manipulations will be ineffective. Several workshop participants addressed science's irreproducibility problem, which has been well documented in the past few years, notably in an article in *The Economist*, as well as in several journal articles (Begley and Ellis, 2012; Chatterjee, 2007; *The Economist*, 2013; Perrin, 2014; Prinz et al., 2011; Scott et al., 2008; Steward et al., 2012).

The Causes

Participants discussed some causes of irreproducibility. Brown said the inability to reproduce results boils down to scientists' inability to reason under uncertainty and understand how to analyze data. Martone also mentioned the role of data, specifically how the data are handled and tracked, as being critical for reproducing findings. Carol Mason, professor of pathology and cell biology, neuroscience, and ophthalmic science at Columbia University, informed participants about the *Enhancing Reproducibility of Neuroscience Studies*[1] symposium that occurred at the 2014 Society for Neuroscience meeting, during which invited speakers listed several likely causes of poor reproducibility to include (Landis et al. 2012; Steward and Balice-Gordon, 2014):

- Difficulty of generating cutting-edge science
- Confounding variables
- Unreliable resources (cell lines, chemicals, antibodies)
- Deficient experimental procedures
- Lack of transparency in reporting findings
- Randomization, blinding, sample size estimations
- Publication bias

Potential Solutions

One workshop participant placed the responsibility for changing the culture around experimental rigor primarily on faculty members within graduate programs. He said that as journal reviewers and editors, grant reviewers, mentors, and hiring and promotion advisory board members faculty are in the best position to demand change and to model it to trainees. Landis suggested the development of curriculum for courses about experimental rigor that can be shared across universities to ensure that all students and faculty alike receive the same training in best practices (see program example in Box 3-1). In addition, Mason suggested that enhanced

[1]See http://www.abstractsonline.com/Plan/ViewSession.aspx?sKey=014e2bf7-f60a-41e3-aaa6-668d88a03ad9&mKey=54c85d94-6d69-4b09-afaa-502c0e680ca7 (accessed October 29, 2014).

BOX 3-1
Program Example: Harvard University Data Boot Camp

The methods used to teach the data analysis skills that Brian Litt mentioned are critical, according to Michael Springer, assistant professor of systems biology at Harvard Medical School. Along with colleague Rick Born, professor of neurobiology at Harvard Medical School, Springer runs a Matlab-based boot camp[a] in programming and quantitative skills that employs innovative training methods. Boot camp students not only learn how to use programming tools, but they also learn the best tools to use for specific problems and how to evaluate if their tools are working properly. The boot camp focuses on image development, statistics, and bioinformatics and modeling. Through lectures, long examples, and hands-on experiences, students learn how to visualize data and how to approach them from different directions. Based on responses that students give during in-lecture quizzes using an interactive tool, teaching assistants can identify who would benefit from one-on-one interactions. Springer also finds that peer-to-peer mentoring can be more effective than classroom lectures in some situations.

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[a]http://springerlab.org/qmbc (accessed October 28, 2014).
SOURCE: Michael Springer presentation, Harvard University, October 28, 2014.

training in ethics might help to address the increasing manipulation of data and plagiarism. She added that webinars on statistical reasoning and proper experimental design might help raise awareness of issues related to randomization, blinding, and calculating sample size.

DESIGNING EXPERIMENTS WITH COMMON SENSE AND INTUITION

The biggest challenge facing neuroscience is training students to comprehend the data they are collecting, said Marder. As next-generation technologies proliferate and experiments become more complex and multifaceted, she opined that common sense and intuition will be increasingly critical. Without the basic understanding of what their data should look like and what they mean, scientists will be unable to determine what experimental design details matter for what problem. Part of this understanding includes knowing the appropriate statistical tests to use for a study ahead of time, and what outcome measures to test. According to Marder, simple prestudy power analyses should inform how much data should be collected rather than collecting data until a *p*-value reaches significance. She noted that intuition and communication are also important when working collaboratively; a statistician might not know how the data were collected or their meaning after conducting the statistical analyses.

Marder contends that it is difficult to comprehend one's data without working with raw, unprocessed data. Neuroscientists too often become separated from their raw data by models embedded in the hardware they use to collect data and in off-the-shelf programs they use to analyze those data. Students working with functional magnetic resonance imaging (fMRI), for example, may not fully understand the algorithms that preprocess their data before they examine them. As a result, some students have difficulty with experimental design by not understanding their data analysis tools better, said Marder. She added that a lack of intuition about data also makes it challenging to troubleshoot problematic data, and can lead to faulty interpretations of the experimental results. Marder suggested that the development of new methodologies to help visualize large datasets and reduce the dimensionality might facilitate the comprehension of one's data.

According to several workshop participants, another challenge to designing the right experiment is knowing what tool to use to collect the appropriate data. Akil warned that "falling in love with a tool" can get in the way of asking the right questions. Another participant quoted a colleague who told participants at a recent conference that "just because you have optogenetics does not mean you can turn your own brain off." It is not always the case, that participant continued, that the best way to probe the function of a circuit is through an inducible knock out. Sometimes an "old-fashioned" pharmacological agent or antidromic activation is a better way. The goal, said the participant, is to get students to really think about what the question is and to have a broad enough perspective to say what the right technique is for that question. Marder added that trainees should ask themselves, how do I design experiments to capture the data needed to inform my understanding? What are the outcome measures needed? One way to encourage thinking of the right experimental design questions was offered by Indira Raman, professor of neurobiology and physiology at Northwestern University. She described a class she teaches in which students discuss classic neuroscience papers to get a sense of the history of experimental design and how people express ideas. Marie-Francoise Chesselet suggested that rather than offering a single course on experimental design graduate programs should incorporate discussions of best practices in design, as well as statistics and ethics, into every neuroscience course, regardless of the topic, thereby ensuring ongoing learning that can be applied in a variety of contexts.

Marder further emphasized the importance of theory in experimental design. She pointed to a directive of the BRAIN Initiative, which states that experiments of the future need to be an interaction between theory, modeling, computation, and statistics. The BRAIN 2025 report also lists the following three important outputs of using theory to support experimental design (NIH, 2014):

- Predictions: "Theoretical studies will allow experimenters to check the rigor and robustness of new conceptualizations and to identify distinctive predictions of competing ideas to help direct further experiments." (p. 90)
- Integration: "Theory and modeling should be woven into successive stages of ongoing experiments, enabling bridges to be built from single cells to connectivity, population dynamics, and behavior." (p. 7)
- Multiscale models: "New analytic and computational methods are required to understand how behavior emerges from signaling events at the molecular, cellular, and circuit levels." (p. 90)

Marder concluded by noting that no matter how well students are trained, graduate programs have difficulty today in training students to design the experiments they are going to be doing 20 or 30 years from now. The only way for scientists to stay relevant is to build on a base of common sense and intuition and continually develop new skills and knowledge throughout their careers.

DEFINING THE GAPS IN THE TRAINING OF QUANTITATIVE SKILLS

At the heart of scientists' ability to determine whether models accurately and reliably describe data and the inferences that can be made from data, Brown said, is statistical reasoning, which itself is derived from a deep understanding of probability. However, he noted that most people lack intuition about statistics and probability. Such intuition takes longer to develop than the single graduate-level statistics course that most students take. According to Brown, developing intuition about probability should begin in elementary school and develop throughout the student's education. The current Common Core State Standards used for developing U.S. math curricula[2] do not expressly address training in probability understanding. However, Brown suggested that teachers could incorporate training in probability into existing lessons.

Due to inadequate training in statistics, said Brown, students often consider what analyses they will employ on their data after the data have been collected. The result can be a study published with insufficient statistical power to properly test a hypothesis, unfortunately an all-too-common problem in neuroscience, especially human fMRI studies (Button et al., 2013). Another common pitfall, occurring in a significant number of neuroscience journal articles, is failing to account for the clustering, or dependency, of data from nearby or otherwise similar neurons, an error that produces false-positive results (Aarts et al., 2014). In addition to enhancing overall training in statistics, Brown suggested that graduate departments develop unique statistics modules tailored to five or so key subdisciplines of neuroscience. For example, electrophysiologists could learn techniques for decoding spike trains while students working with fMRI could focus on techniques for calculating spatial correlations in images. Bringing like-minded students together to focus on a specific set of analytical skills might enhance their training and sense of community, said Brown.

The NIH BRAIN Initiative Working Group, of which Brown was also a member, formalized objectives and goals focused on improving quantitative expertise at all levels—faculty, postdoctoral, and graduate student. As laid out in the BRAIN 2025 report, the goals are to (1) ensure that all neuroscience postdoctoral fellows and graduate students become proficient with basic statistical reasoning and methods; (2) ensure that trainees are able to analyze data at an appropriate level of sophistication, for example, by writing code; and (3) encourage trainees to construct models as a way to generate ideas and hypotheses or to explore the logic of their thinking.

Finally, Brown said that in addition to taking steps to improve the average trainee's skills in statistical reasoning, the field of neuroscience should examine how to increase collaborations with expert statisticians.

[2]See http://www.corestandards.org/Math (accessed October 29, 2014).

Engineers, physicists, and computer scientists have been increasingly working in neuroscience laboratories, but not statisticians. Bringing this important expertise to neuroscience is critical, said Brown. A recent white paper by an American Statistical Association working group offered a handful of suggestions to encourage the successful integration of statisticians into neuroscience training programs as it relates to the BRAIN Initiative (American Statistical Association, 2014). The authors note that statistician trainees should be

- taught to design data collection and analysis strategies,
- required to "take neuroscience classes and embed themselves in neuroscience labs," (p. 6)
- held to the same writing standards as neuroscience graduate students, and
- "educated in principles of ethical and effective collaborative behavior" (p. 6).

4

Training in Transdisciplinary Research

Key Highlights Discussed by Individual Participants

- Effective collaboration among disparate disciplines is critical (e.g., molecular biology and bioengineering or electrophysiology and physics); in this space innovation will arise and there are opportunities to train scientists to work toward a sum greater than the collected parts and spur innovation (Federoff, Sejnowski, and Steward).
- There is a distinction between training *of* neuroscientists and training *in* neuroscience, and several participants raised the question of whether graduate programs should focus on one or the other (Steward).
- As neuroscience expands in scope, adding various tracks might be beneficial (Landis, Litt, Raman, Sejnowski, and Steward).
- Forming successful transdisciplinary collaborations requires time and involves a considerable amount of risk, and can be encouraged with increased incentives with regard to grant review and hiring/promotion decisions (Sejnowski).
- Opportunities for transdisciplinary training come from a variety of sources, including National Science Foundation grants and BRAIN Initiative short courses (Ferrini-Mundy and Litt).

NOTE: The items in this list were addressed by individual participants and were identified and summarized for this report by the rapporteurs. This is not intended to reflect a consensus among workshop participants.

As neuroscience has evolved as a discipline and incorporated many types of science—microbiology, genetics, statistics, animal behavior, optics, engineering, computational biology, etc.—it has become increasingly less likely that any one individual or laboratory will have all the expertise needed to tackle higher-level problems. Many workshop participants noted that teams of scientists from disparate disciplines are necessary for improving fundamental neuroscience knowledge, developing new treatments, building the next powerful tool, and revolutionizing imaging technology. But it is not a matter of getting out a checklist and making sure each team has a biologist, a physicist, a mathematician, an engineer, and a chemist. Rather, each of these disciplines needs to learn how to work effectively with the others. According to several workshop participants, in this space innovation will arise and there are opportunities to train scientists to work toward a sum greater than the collected parts.

Oswald Steward, director of the Reeve-Irvine Research Center at the University of California Irvine School of Medicine, enumerated several decision points for graduate programs to consider when training students to engage in transdisciplinary research. Terry Sejnowski emphasized the need for better incentives to encourage scientists to collaborate on transdisciplinary projects. Howard Federoff, executive dean of the Georgetown University School of Medicine, provided an overview of how best to enable transdisciplinary teams to do translational science. Finally, Dennis Choi, director of the Neurosciences Institute at Stony Brook University, called for improving collaboration between basic neuroscientists and clinicians.

DEFINING TRANSDISCIPLINARY NEUROSCIENCE

Steward challenged participants to think about the requirements for successful transdisciplinary collaborations and what impact those requirements can have on training students. In his opinion, a transdisciplinary team should be composed of specialists, not people with a general knowledge of their discipline. For example, if a team requires a neuroscientist, he noted that this person needs to be a card-carrying *neuroscientist*, that is, someone with a Ph.D. in neuroscience who regularly does neuroscience research. Similarly, if a neuroscientist were putting together a team requiring a mathematician, the neuroscientist would want a card-carrying *mathematician*, not a neuroscientist with some knowledge of math. Although several participants had differing opinions on the type of neuroscientist needed for such transdisciplinary collaboration—particularly given that most individuals engaged in the neuroscience workforce would not be considered a card-carrying neuroscientist—Steward noted that there is still a need for experts in the discipline of neuroscience.

Related to the question of specialization versus generalization, Steward discussed the differences between the training *of* neuroscientists—training in the core knowledge of a discipline that qualifies one to be called a neuroscientist—and training *in* neuroscience—training for individuals in other disciplines that would allow them to be partners in the greater enterprise of neuroscience research. Steward's opinion was that a single graduate program probably could not effectively accommodate both of these needs. Instead, programs should carefully consider these differences when developing their training goals and either define themselves as institutes, which are cross-disciplinary, or departments, which have a specialized focus.

As for the training *of* neuroscientists, a number of participants asked, what does every card-carrying neuroscientist need to know? While there were no clear answers, many participants agreed there should be a limit to how many additional courses should be required of students given the already long average time to earn a degree, even if that limit means sacrificing breadth of knowledge. According to a few workshop participants, one way around this class time limit is to offer micro- or nano-courses, rather than semester-long courses, to give students a chance to sample relevant topics. In addition, several workshop participants suggested that many neuroscience courses could be more effective as a series of coordinated hands-on exercises or demonstrations rather than traditional didactic lectures. More importantly, graduate students need to be trained in how to do rigorous science (as noted in Chapter 3) and establish effective transdisciplinary collaborations.

Another potential training-related choice that Steward pointed out is training students to be Renaissance scientists or goal-directed scientists. The former operate in a mode of pure exploration and discovery, while the latter can be plugged into teams to solve specific problems and develop treatments for disorders. Again, Steward suggested that different tracks are needed to train each type of scientist.

Reconsidering the One-Size-Fits-All Approach to Training

Several workshop participants also expressed the need for separate tracks in neuroscience training, although the dimensions along which to separate varied. A comment by Landis captured a common sentiment expressed throughout the workshop: "There's too much neuroscience, it's not one thing anymore." She asked how much cellular and molecular neuroscience training is necessary for someone who is doing brain mapping at the macro level? How much magnetic resonance imaging information does someone who is working at the cellular and molecular level need to have? Does a neuroscientist 10 years from now need to be fully articulate in all of the areas of neuroscience? Chesselet noted training programs should be designed in a way in which there is a balance between trainees being aware of a topic compared to having the knowledge (often best acquired in a laboratory setting) to apply it to a research project. Landis suggested that one solution to narrowing students' focus was to look for lessons from the field of neurology, where there is a core residency program, followed by subspecialty training. Several workshop participants stated that separate tracks might allow for more focused courses—and possibly less overall class time for trainees—and might encourage the development of mini-courses that address particular problems in a certain subspecialty. Potential tracks that could be created in graduate neuroscience programs include electrophysiology, optical imaging, fMRI, cellular and molecular neuroscience, translational neuroscience, neuroengineering, theory and modeling, and systems neuroscience. Trainees could also be split into theoretical or experimental tracks, suggested Litt. Such tracks could potentially be organized around current faculty expertise and available core resources and infrastructure at each institution. Several workshop participants noted that these subspecialty tracks might serve as the basis of tight-knit communities among students and alumni that might be advantageous when seeking internships and employment opportunities. Indira Raman suggested stratifying trainees according to their interested career pathway as well (i.e., academia and non-academic careers).

Finally, Sejnowski and Steward suggested that questions about specialization and the formation of graduate school tracks may ultimately be dictated by outside forces; what kind of workforce do employers need, and, to a lesser degree, what kind of training will funding agencies support? Will there be more jobs in goal-directed science? Is the workforce trending toward large teams? Will these teams need a certain ratio of specialists to generalists (who might be in a better position to support or manage all the moving pieces in a lab)? Will workforce needs vary across subfields of neuroscience? Understanding these needs will be critical for optimizing graduate neuroscience training, said Steward.

Challenges to Cooperative Science

Sejnowski mentioned two primary challenges to overcome to encourage more collaborative science: trust and acknowledgment. Forming collaborations with scientists in other fields is similar to getting married, he noted. You have to have trust, get to know the person, and work together long enough to develop a common language. According to Sejnowski, seeking out scientists from other fields to collaborate and be on the same page on large, complex problems can take such a considerable amount of time and risk that collaboration may not be viewed as worth the effort. These factors could especially dissuade new faculty, who are eager to publish high-impact articles and obtain grant funding in order to secure tenure. The field needs a better way, according to Sejnowski, to reward scientists for building cooperative, transdisciplinary teams. One way to do this is to convince academic departments and funding agencies to assign collaborative projects more weight when making decisions about promotions and grants, akin to the suggestion for the sharing index and the data citation mentioned in Chapter 2. NIH, for its part, has begun to recognize the importance of taking risks to encourage interdisciplinary research with the advent of its Common Fund High Risk, High Reward program,[1] which supports the Early Independence Award,[2] the New Innovator Award,[3] the Pioneer Award,[4] and the Transformative Research Award.[5]

Initiatives for Cooperative Science

Transdisciplinary collaboration was a vital part of the discussion among the NIH BRAIN Initiative Working Group, according to Sejnowski, a member of the working group. One of the seven core principles of the initiative that is listed in the BRAIN 2025 report[6] is *cross boundaries in interdisciplinary collaborations* (NIH, 2014). Within the report, potential collaboration scenarios to facilitate the BRAIN Initiative's goals were discussed:

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[1]See http://commonfund.nih.gov/highrisk/index (accessed October 29, 2014).
[2]See http://commonfund.nih.gov/earlyindependence/index (accessed October 29, 2014).
[3]See http://commonfund.nih.gov/newinnovator/index (accessed October 29, 2014).
[4]See http://commonfund.nih.gov/pioneer/index (accessed October 29, 2014).
[5]See http://commonfund.nih.gov/TRA (accessed October 29, 2014).
[6]*BRAIN 2025: A Scientific Vision*. See http://www.braininitiative.nih.gov/2025/BRAIN 2025.pdf (accessed October 28, 2014).

- "The physicists and engineers who develop optical hardware should partner with the biologists and chemists who develop new molecular sensors.
- The tool builders who design new molecules for sensing or regulating neurons should partner with neuroscientists who will rigorously examine their validity in neurons and brains.
- The theorists who develop models for understanding neuronal dynamics should partner with experimentalists, from initial experimental design to execution to interpretation.
- The clinicians and neuroscientists who develop sophisticated imaging methods in humans should partner with scientists working in animal models who can relate imaging signals to the underlying cellular mechanisms with great precision" (p. 51).

Finally, Sejnowski mentioned the imperative for transdisciplinary research held by another science initiative of which he is also an organizing member, the National Academies Keck Futures Initiative (NAKFI). NAKFI brings together scientists from disparate fields to work intensively over 2 days in small teams to address issues related to important science problems. A few years ago, NAKFI conducted a survey of 600 stakeholders to examine how research could be more innovative. The survey asked individuals to rate the importance and ubiquity of several factors that are integral to interdisciplinary collaborations, including data accessibility, institutional support, responsive funding, ingenuity/risk taking, incentives, and education/training (see Figure 4-1). The results revealed that the more critical gaps—those factors rated high in importance and low in ubiquity—were responsive funding, incentives, and ingenuity/risk taking (see Figure 4-2). Katja Brose, editor of *Neuron*, cautioned workshop participants about moving into the direction where it is all about team science. In her opinion, what makes neuroscience special is the diversity of topics and approaches. There are instances in which collaboration at the investigator level or between laboratories is more desired than team science, in which several experts come together for a common goal.

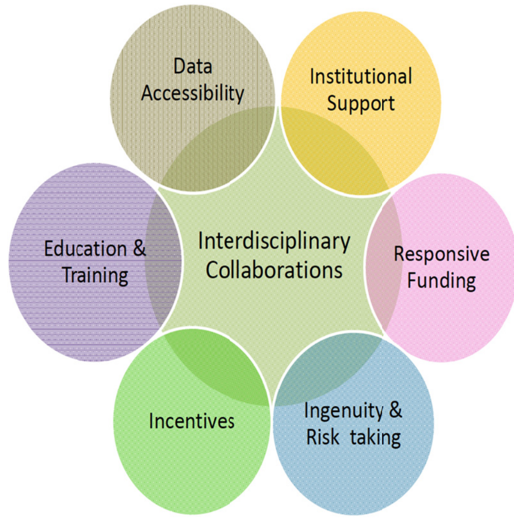

FIGURE 4-1 A conceptual model of the various factors that contribute to enhancing innovative research.
SOURCE: Terry Sejnowski presentation, Salk Institute for Biological Studies, October 28, 2014.

OPPORTUNITIES FOR TRANSDISCIPLINARY TRAINING

Throughout the workshop, several participants discussed a number of opportunities to support transdisciplinary training, to include incorporating courses about collaboration in neuroscience graduate programs. Descriptions of a few of these funding opportunities and courses are provided below. Akil and Chesselet stressed that education about transdisciplinary research should not stop in graduate school, but rather should be modeled after continuing medical education courses for physicians, in which education is incorporated throughout the trainee's lifespan.

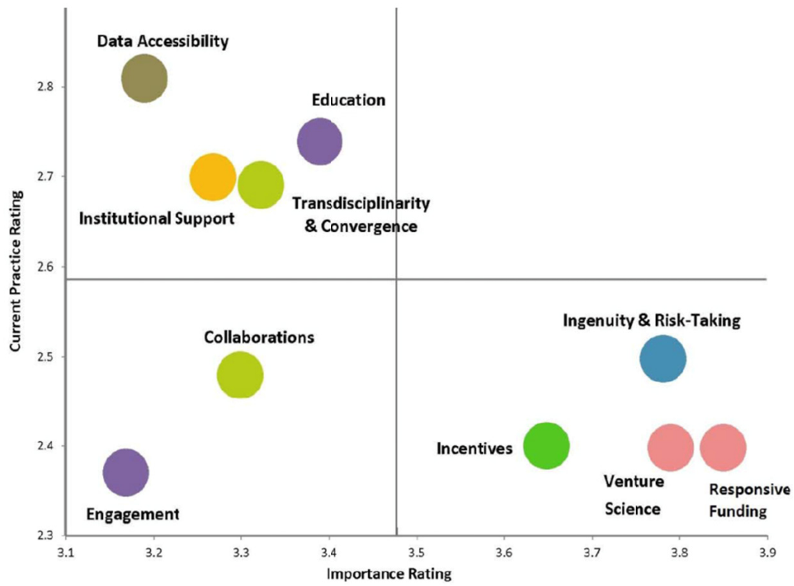

FIGURE 4-2 Results from a survey of scientists across many disciplines responding to questions about the importance of a variety of factors (and their prevalence) for increasing innovation in science.
SOURCE: Terry Sejnowski presentation, Salk Institute for Biological Studies, October 28, 2014.

NSF Research Traineeships

NRT[7] supports the development of innovative training programs for teams of graduate students within a single university or institution around a cross-disciplinary theme related to national research priorities. NRT replaces NSF's IGERT grants, the last of which were issued in 2013. Joan Ferrini-Mundy, assistant director of the Directorate for Education and Human Resources at NSF, noted that between 1998 and 2013, 278 IGERT awards were issued to 100 lead universities in support of 6,500 graduate students. Neuroscience projects accounted for 15 percent of the IGERT awards. Previous neuroscience-related IGERT awards focused on themes such as neuroimaging of non-human primates, neuroprostheses,

[7]See http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=505015 (accessed October 28, 2014).

and computational neurobiology. The initial priority research theme of the new NRT program is Data-Enabled Science and Engineering. However, proposals are encouraged on any other crosscutting, interdisciplinary theme.

Ferrini-Mundy added that time to degree was not slowed for students doing interdisciplinary research on IGERT grants. She also mentioned that students would report anecdotally that their ability to communicate and to get other people excited about their science improved as a result of their IGERT experience.

Integrative Strategies for Understanding Neural and Cognitive Systems (NSF-NCS)

The NSF-NSC grants[8] support transformative science and engineering efforts to accelerate knowledge of neural and cognitive systems. Because the complexities of the brain and behavior touch on many aspects of science and engineering, these grants will cut across NSF's various directorates. For 2015, the NSF-NSC grants are organized around two research themes: (1) Neuroengineering and Brain-Inspired Concepts and Designs and (2) Individuality and Variation. Within each theme, projects will address general advances in theory and methods, technological innovations, educational approaches, enabling research infrastructure, and workforce development.

BRAIN Initiative Short Courses

In recognition of the critical role cross-disciplinary research will play in developing the next generation of tools and computational approaches for studying the brain, the NIH BRAIN Initiative plans to sponsor short courses[9] for training graduate students, medical students, postdoctoral scholars, medical residents, and/or early-career faculty. Courses will be offered to neuroscientists as well as to scientists from other disciplines. One course will focus on tools to classify cell types, reconstruct neural pathways, and record from and manipulate neural circuits using electrical

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[8]See http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=505132 (accessed October 24, 2014).

[9]BRAIN Initiative short course about data analysis/handling. See http://grants.nih.gov/grants/guide/notice-files/NOT-MH-15-005.html (accessed October 28, 2014). BRAIN Initiative short course about innovative tools. See http://grants.nih.gov/grants/guide/notice-files/NOT-MH-15-006. html (accessed October 28, 2014).

and optical techniques. The other course will focus on quantitative methods for analyzing high-dimensional imaging, electrophysiological, anatomical, and behavioral datasets. Aside from using these relatively low-cost short courses as a training tool, the staff organizing the NIH BRAIN Initiative hopes the courses will expose physical and information scientists to the projects in the initiative and help foster cross-discipline collaborations.

National Academies Keck Futures Initiative Seed Grant Program[10]

NAKFI has hosted an annual meeting over the past 10 years on how to push forward innovations through interdisciplinary interactions among many different fields of science and engineering. Previous meetings with a strong neuroscience focus include signaling, complex systems, imaging science, the digital brain, and collective behavior. Participants are invited to self-organize into cross-disciplinary teams to apply for seed grants to further pursue ideas stimulated by conversations and breakout sessions that occur over the course of the 2-day meetings.

University of Pennsylvania's Brain-Computer Interface Course

One challenge in bringing multiple disciplines together to work on a neuroscience problem is communication, said Litt. Every field has its own special language, and to some extent, its own worldview. Litt described his "Brain-Computer Interface" course, which brings together students in neuroscience, physical science, and engineering, as a model for training disparate groups to communicate and collaborate with one another. In addition to classroom lectures on topics such as modeling and simulation, the students work in interdisciplinary teams on 10 hands-on programming projects. Project examples include modeling visual cortex orientation tuning columns, controlling robot arms driven by motor units, classifying speech, and designing cochlear implants.

CROSS-TRAINING IN CLINICAL NEUROSCIENCE

Despite the historic intersection between neuroscience and clinical science, there is little cross-training between the two disciplines, said Choi. The clinical interface is central to neuroscience for at least two rea-

[10]See http://www.keckfutures.org/grants (accessed October 29, 2014).

sons, he added: (1) the potential for medical benefit is a key source of inspiration, purpose, funding, and public support; and (2) the interface represents the necessary experimental platform for investigating, and ultimately understanding, the human mind. Although the clinical dimension in neuroscience training has been around longer than more novel and emerging dimensions, such as genetics, engineering, and informatics, Choi noted that basic neuroscience training typically provides limited exposure to principles of clinical medicine, clinical research, and overall disease biology. The converse is true as well; clinical training typically provides scant exposure to the scientific method.

Choi cited four primary consequences of the lack of cross-training in these areas. First, neuroscientists without clinical training are vulnerable to what Landis referred to as "pseudo-translation"—studies that combine disease models of uncertain value with interventions unlikely to ever be applicable to patients. These ideas can gain inappropriate traction and lead to dilution of resources and disappointment for myriad stakeholders, said Choi. Second, he noted that clinicians without basic neuroscience knowledge are vulnerable to unsubstantiated claims about the brain and are prone to adopting dogmatic approaches based on anecdotes rather than available evidence. Third, without cross-training and collaboration, opportunities to exploit the clinical setting for studies in basic neuroscience can be missed. Choi used work by Edward Chang at the University of California, San Francisco, as an example of such research. Chang took advantage of intraoperative electrocorticography for patients about to undergo epilepsy surgery to test theories about how speech is perceived and generated by the brain. Choi added that as new tools and technologies provide answers to research questions the neuroscience enterprise cannot afford the divide between basic and clinical science. Fourth, the lack of exposure to, and appreciation of, the clinical method creates situations where researchers might not truly understand clinical data. There are fundamental risks, Choi said, for bias in clinicians taking clinical history and in performing examinations of the nervous system. Once those biases are incorporated into databases where phenotype is linked with genetic and imaging information, Choi stated that they become intractable and can greatly affect study outcomes.

Another obstacle to maximizing the potential of the clinical interface is the historical balkanization in the way patients and diseases are managed in medical centers today, noted Choi. The primary example of these long-standing divisions is between neurology and psychiatry. Despite the fact that the distinctions between their missions are blurring, they remain separate departments and their cultures and associated training programs remain fully segregated. Balkanization occurs throughout clinical science, Choi continued. Diseases of the nervous system are typically managed by disparate clinical departments and not just psychiatry, neurology, and neurosurgery:

- Medicine (Alzheimer's disease, fibromyalgia, sleep disorders)
- Pediatrics (cerebral palsy, genetic/metabolic disorders)
- Radiology (stroke)
- Anesthesia (pain)
- Ophthalmology (macular degeneration)
- Otolaryngology (tinnitus, hearing loss)
- Orthopedics (stroke, traumatic brain injury)
- Obstetrics (hot flashes, seizures, hyperemesis)
- Rehabilitation (stroke, traumatic brain injury)
- Emergency medicine (stroke, traumatic brain injury)
- Oncology (central nervous systems cancers, radiation encephalopathy)
- Surgery (neurological intensive care)

Because of this balkanization, Choi said opportunities for collaboration are challenging, but offered several suggestions for improving cross-training between neuroscience and clinical science (see Box 4-1). In addition, a few workshop participants discussed unique challenges for physician-scientists. For example, several speakers noted that M.D./Ph.D. students often accelerate through their Ph.D. coursework to go into their clinical training. Landis asked whether there was a special role for them, given that in principle they could speak to both communities (neuroscience and clinical science).

BOX 4-1
Challenges and Opportunities for Improving Cross-Training Between Neuroscience and Clinical Science

Challenges

- The interface between basic research and clinical science provides both a key source of inspiration, purpose, funding, and public support as well as the necessary experimental platform for investigating and ultimately understanding the human mind.

- Neuroscience training typically provides limited exposure to principles of clinical medicine, clinical research, and overall disease biology, while clinical training typically provides scant exposure to the scientific method.
- Opportunities for improving cross-training between neuroscience and clinical science include increased availability of neurobiology of disease courses and clinical rotations for neuroscience trainees, and completion of research projects and journal clubs for clinical trainees.

Opportunities

- For neuroscience graduate students:
  - Increase the availability and strength of neurobiology of disease (NBD) courses. This type of course could have a greater impact if delivered online due to the labor-intensive steps of bringing in patients and performing all of the clinical interventions (e.g., Society for Neuroscience NBD workshop, National Institute of Neurological Disorders and Stroke/Child Neurology NBD in Children website).
  - Augmented online clinical courses (e.g., Stanford Online, HarvardX) with readings and discussions with faculty—even tests and recognition of achievement.
  - Increase the availability of clinical courses (pathophysiology, clinical research) for neuroscience graduate students.
  - Increase the availability of clinical rotations to neuroscience Medical Engineering and Medical Physics (HST MEMP) program.
- For clinical students:
  - Increase opportunities for exposure to basic neuroscience, as well as physics, informatics, and engineering, for selected medical students (e.g., HST MEMP program)
  - Increase graduate students along the lines of those implemented by the Harvard-Massachusetts Institute of Technology Health Sciences and Technology requirements for the training of clinical residents in core scientific methods, focusing on skills needed to read the clinical literature with a critical eye.
  - Require completion of a research project.
  - Journal clubs focusing on the critical analysis of key papers.
- For both neuroscience and clinical students:
  - Build interdisciplinary and interdepartmental teams around shared clinical research or clinical care goals, involving both M.D.s and Ph.D.s (e.g., Parkinson's disease centers).
  - Merge neurology and psychiatry training—and eventually, departments.

SOURCE: Dennis Choi presentation, Stony Brook University, October 29, 2014.

5

Enhancing Training to Support Translational Research

Key Highlights Discussed by Individual Participants

- Undertranslation, overtranslation, and "pseudotranslation" are all common pitfalls in the translation of basic neuroscience discoveries (Ferrini-Mundy and Landis).
- Many trainees do not understand the drug development pipeline, which creates inefficiencies in identifying and validating targets, and translating discoveries into treatments (Yocca).
- Industry is increasingly turning to academia for help with identifying drug targets, validating those targets, and developing new pipelines (Yocca).
- Training programs need to educate students about the full end-to-end process of drug discovery, development, and translation, even if individual students are not necessarily involved in translational research (Yocca).

NOTE: The items in this list were addressed by individual participants and were identified and summarized for this report by the rapporteurs. This is not intended to reflect a consensus among workshop participants.

A central aspect of the neuroscience enterprise is translating basic science discoveries into therapies that can be used to treat humans. Joan Ferrini-Mundy and Story Landis described three common fallacies surrounding translation: undertranslation, overtranslation, and "pseudotranslation." Frank Yocca, vice president of Neuroscience iMed at AstraZeneca Neuroscience, discussed the pharmaceutical industry's recent transition to targeting rare, gene-linked neurological and psychiatric diseases and their continued interest in partnering with academia to make new discoveries. He explains how neuroscientists can be trained to work in collaborative translational teams and gain the skills necessary for translational science. James Barrett, professor of pharmacology and physiology at the Drexel University College of Medicine, and Anthony Ricci, professor at the Stanford School of Medicine, described programs at their institutions dedicated to training students and postdoctoral researchers in translational science.

UNDER-, OVER-, AND PSEUDO-TRANSLATION

Ferrini-Mundy stated that neuroscientist trainees have to be mindful about both undertranslations—failure to translate promising discoveries from the lab into clinical therapies—as well as overtranslations—misguided attempts to use neuroscience discoveries to explain or solve every human problem. Meanwhile, Story Landis cautioned against the temptation to artificially generate a translational component into basic neuroscience research projects—a process she calls "pseudo-translation." Such interventions are unlikely to ever be applicable to patients, said Landis, yet investigators propose these types of studies under the assumption that granting agencies such as NIH will not fund research that does not have translational relevance. The phenomenon is so widespread that Landis launched a program when she was the director of NINDS to encourage the submission of grant applications for more purely basic research, as described in Chapter 1, which she said has deep intrinsic value as the basis for the discovery and development of treatments (Landis, 2014). She added that trainees need to be taught the importance of basic research as well as how to design translational studies of real significant value.

THE PHARMACEUTICAL INDUSTRY'S PIVOT IN TRANSLATIONAL NEUROSCIENCE

According to several participants, there are numerous gaps in neuroscience expertise around translational science, and training students to have a greater understanding and knowledge in furthering innovative therapeutic development will be critical. The development of each new drug targeting a neurological disorder is a complex endeavor (see Figure 5-1), spanning, on average, 10 to 15 years and requiring an investment of $1 billion to $2 billion, said Barrett. Given the high costs and risk (less than 10 percent success rate) in developing central nervous system drugs, in addition to the general challenges in translational neuroscience (see Box 5-1), the pharmaceutical industry has subsequently reduced its neuroscience research and development spending over the past decade (Abbott, 2011; Miller, 2010).

As a result, Yocca noted that some pharmaceutical companies downsized their neuroscience division, often having to significantly decrease the workforce (e.g., AstraZeneca's neuroscience division decreased from more than 700 scientists in the late 2000s to approximately 50 today). Atul Pande, chief medical officer and executive vice president of Tal Medical, Inc., emphasized that the impact of this withdrawal in neuroscience research and development will be felt progressively over the coming years, which could affect trainees and postdoctoral researchers who would like to pursue a career in industry. The problem, according to Yocca, has not been a lack of commitment, but rather, most drugs fail in phase II trials because they are found to be ineffective. The major challenge in developing effective treatments is a general lack of biomarkers—biological signatures that indicate the progression of a disease, he added. For example, no biomarkers are known to exist for many large-market neurological diseases such as Parkinson's disease and Alzheimer's disease.

With no way to quantify disease progression or to stratify patients into various disease stages, Yocca noted that it is difficult to determine the effect candidate treatments are having in patients. He cautioned that many drugs might show efficacy in some people, but there is variability that cannot be explained without a way to stratify patients, making development of such drugs risky.

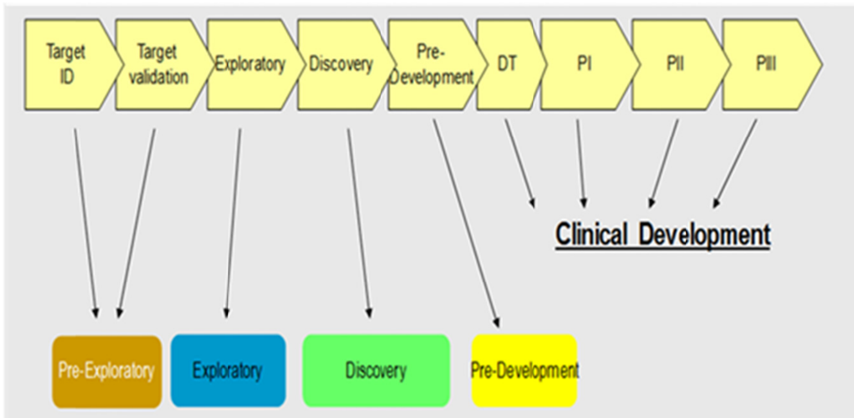

FIGURE 5-1 The steps involved in developing a drug, from pre-exploration to clinical development.
NOTE: DT = developmental therapeutics, PI = phase I, PII = phase II, PIII = phase III.
SOURCE: James Barrett presentation, Drexel University, October 29, 2014.

BOX 5-1
Neuroscience Presents Several Translational Challenges

Scientific
- Biological complexity and nonvalidated targets
- Poor preclinical models
- Challenge of the blood/brain barrier
- Direct examination of drug exposure and target engagement

Clinical
- Patient recruitment
- Patient heterogeneity
- Disease is advanced when symptoms appear
- Capturing therapeutic effects on clinical scales with high variability

Low productivity
- Long cycle times
- High costs
- Low probability of success

SOURCE: Frank Yocca presentation, AstraZeneca Neuroscience, October 28, 2014.

As a consequence of the dismal success rate in developing drugs for neurological disorders, increased regulatory incentives offered by the Rare Disease Act, and the chance to leverage discoveries of rare disease mechanisms into treatments of more prevalent diseases, neuroscience translation has pivoted from big diseases such as depression and schizophrenia to smaller diseases, according to Yocca. Many pharmaceutical companies, including AstraZeneca, are now employing smaller teams to develop treatments for rare neurological diseases that had been largely overlooked in the past due to low potential profit margins (this transition is summarized in Box 5-2). AstraZeneca's general approach to drug discovery, which adheres to the "Five Rs," is summarized in Figure 5-2. Yocca also said that the search for neurological drugs is being modeled after drug development in oncology in which pharmaceutical companies are pursuing smaller neurological diseases that have a genetic basis. See Box 5-3 for the list of novel approaches to translation that Yocca shared with workshop participants.

BOX 5-2
Opportunities for Changing the Approach to Training in Translational Neuroscience

- Large internal teams working on literature targets and follow-on approaches →
  Small internal teams collaborating with academic and biotech partners working on genetically driven innovative targets
- Limitations driven by rigid disease strategies →
  More opportunistic approaches to find tractable targets regardless of disease state
- Template approaches →
  Smart discovery and development strategies (translational focus)
- Focus on larger diseases driven by peak year sales →
  Focus on smaller, genetic-based diseases driven by "line of sight" and return on investment

SOURCE: Frank Yocca presentation, AstraZeneca Neuroscience, October 28, 2014.

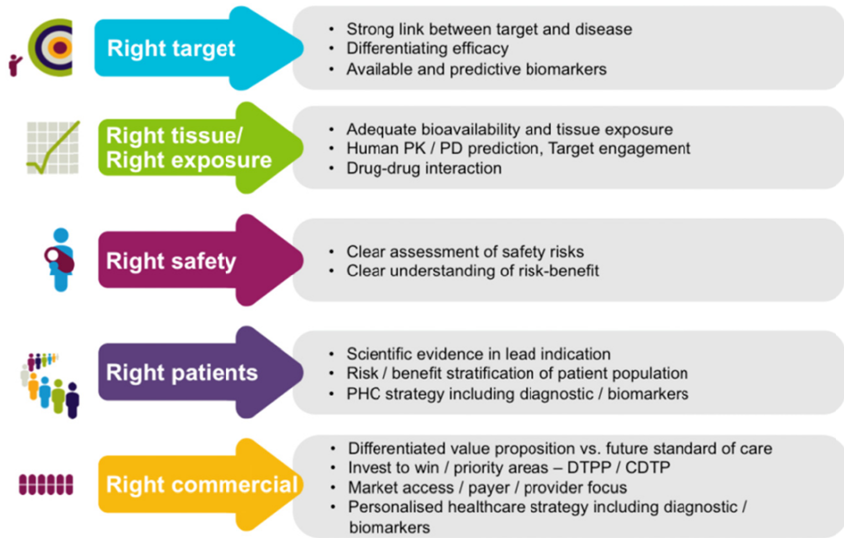

FIGURE 5-2 The "Five Rs" to drug discovery and development.
NOTE: CDTP = Continuing Day Treatment Program; DTPP = Diphtheria-Tetanus-Pertussis-Poliomyelitis; PD = Pharmacodynamics; PHC = Personalized Health Care; PK = Pharmacokinetics.
SOURCE: Frank Yocca presentation, AstraZeneca Neuroscience, October 28, 2014, adapted from Cook et al., 2014.

BOX 5-3
Novel Approaches to Neuroscience Translation

- Large-scale unbiased approaches to data collection and analysis and DNA sequencing
- Optogenetics to focus on circuits involved in diseases
- Identification of biochemical pathways involved in disease pathogenesis
- Akin to cancer, mutations within cells may be proving to be more important to therapy than the cell of origin
- The best way to determine convergent pathophysiological mechanisms lies in starting with genetic discoveries
- Multilevel analysis to elucidate the causal pathway from mutation to behavioral disorder
- Reprogramming skin cells from patients into functional neurons affords us the opportunity to develop cellular disease models

- Substantially reduce investment risk by concentrating drug development efforts either on smaller, biologically stratified subsets of patients guided by genetic findings, or on specific circuits and synaptic processes

SOURCE: Frank Yocca presentation, AstraZeneca Neuroscience, October 28, 2014, based on materials from Hyman (2012) and Karayiorgou et al. (2012).

FOSTERING PARTNERSHIPS BETWEEN INDUSTRY AND ACADEMIA

Industry is increasingly looking to partner with academia, which provides a wide variety of expertise in skills necessary for translational science, said Yocca (see Box 5-4). According to Barrett, industry routinely turns to academia to identify drug targets, validate those targets, and develop new pipelines. Indeed, academia now generates the majority of the basic science discoveries that are being translated into new medicines (Silber, 2010). By continuing in this role, academic institutions have an opportunity to train students to transition into careers within industry. However, Richard Tsien, professor of neuroscience at the New York University Langone Medical Center, emphasized that even though there are many trainees with the right skills and an interest in working on disease-targeted research challenges remain in matching trainees to the right company. Tsien added that similar to the decreased number of positions in academia industry might not be a secure career option for recent graduates.

Yocca said that translating genetic advances into drug discovery and development programs is going to require close collaboration between disease biology experts in academia and the pharmaceutical industry. As an example of the approach to discover targets in gene-linked disorders, Yocca detailed a collaboration between AstraZeneca and the Lieber Institute for Brain Development. The researchers look for genes of interest—either from patients in clinical studies or by using reverse translation (i.e., back-translation)—to drive RNA sequencing in the search for a transcript associated with illness data or genetic risk. Those transcripts can be used to derive molecular mechanisms of association that can be developed and tested in cell-based models and animal models. One specific example of this approach that Yocca mentioned was using human induced pluripotent stem cell (iPSC)-derived neurons from clinically and genetically characterized subjects to probe mechanisms associated with genetic risk in neuropsychiatric disorders.

Another novel program that highlights the symbiosis between industry and academia is Johnson & Johnson's Innovation Centers.[1] These centers in Boston, London, Shanghai, and Silicon Valley, act as regional incubator hubs that bring in entrepreneurs and local start-up companies and support a diversity of new ideas hatched in the labs of local scientists by offering access to costly equipment and services. The purpose of these centers is to fuel innovation and breakthrough science.

BOX 5-4
Expertise Needed for Translational Science in Neuroscience

- Neuroscientists with expertise in informatics/statistics
- Neurobiologists with expertise in genetic manipulations (e.g., **C**lustered **R**egularly **I**nterspaced **S**hort **P**alindromic **R**epeats, or CRISPR)
- Cell biologists with expertise in neuroscience and neurodevelopment
- Cell biologists with expertise in stem cells
- Neurophysiologists with system modeling expertise
- Clinicians with expertise in neuroscience and neurodevelopment
- Neurodevelopmental processes
- Neurophysiologists/neuropsychologists
- High-quality clinical studies
- Novel pharmacology and repositioning tools
- Genetics and patient segmentation
- Objective end-points and biomarkers
- High-quality diagnostics and patient segmentation
- Response biomarkers
- Clinical neurophysiologists and clinical psychologists
- Functional imaging
- High-quality clinical studies
- Novel treatment strategies
- Patient segmentation
- Behavioral analysis, animal models in neuroscience and data capture and data analysis

SOURCES: James Barrett presentation, Drexel University, October 29, 2014, and Frank Yocca presentation, AstraZeneca Neuroscience, October 28, 2014.

[1] See http://www.jnj.com/partners/innovation-centers (accessed November 3, 2014).

Challenges and Opportunities to Improve Training in Translational Neuroscience

One challenge for translational neuroscience is the fact that many trainees do not understand translational science, according to Yocca. That is, they are not fully aware of the drug discovery and development pipeline. Although some trainees go through graduate school without knowing what target validation is, other trainees who actually do target validation may not understand the needs of the next person on the pipeline. Yocca noted that this lack of the big picture of the overall process, as well as the fact that scientists speak different languages depending on where in the pipeline they do research, creates inefficiencies in the discovery and development pipeline. To overcome these challenges, training programs need to educate students about the full scope of translational science, even if individual students are not necessarily involved in translational research, he added (see Box 5-5 for an overview of Drexel University's Master of Science in Drug Discovery and Development program). Incorporating pharmacology and genetics into graduate school curricula will also better prepare trainees to understand and perform translational research. Yocca pointed out that the resulting translational research will also be enhanced, by providing training in translational science and neuroscience to experts in other fields such as cell biologists and clinicians, neurophysiologists, and clinical psychologists.

BOX 5-5
Program Example: Drexel University

Drexel University offers a Master of Science in Drug Discovery and Development that provides the rigorous scientific and technical training necessary to facilitate a smooth transition to a productive career in the biotechnology or pharmaceutical industry. Barrett explained that the primary strength of the program is its integration of the drug discovery and development disciplines as well as emerging disciplines within neuroscience and other biomedical sciences. Below is a list of topics covered in the program's core courses.

Beyond merely bringing together expertise on the laboratory side of drug development, the program engages trainees in the entire discovery and development practice by enlisting the participation of the school of medicine, the school of business law, the school of public health, and the department of biomedical engineering.

The program strives to give trainees real-world experiences, noted Barrett. Faculty present students with detailed drug discovery case studies—both failures and successes. Trainees assemble into teams that bring together expertise in medicinal chemistry, project management, and business. Teams are assigned specific projects and work together to come up with plans for identifying and validating targets. Teams then present their ideas—how to formulate a drug, how to market it, what are the liabilities and risks—to a panel of faculty who judge the viability of the projects.

The program also leverages unique features of the Drexel community. In coordination with the school of public health, the program hosts a section on pharmacoepidemiology, which uses epidemiological data to look at drugs and off-purpose targets. For example, a recent epidemiological statistic showed that schizophrenics on long-term antipsychotics have a lower incidence of cancer. The program also works with Drexel's school of media arts and design to create ways to "gamify" the drug discovery process.

Echoing Yocca's declaration that biomarkers are critical to translation, Barrett said a primary focus of the program is training students to exploit biomarkers in whatever form they can be found, whether they are imaging indicators or genetic markers.

Barrett said the program also emphasizes the analysis of behavior, which he called "the ultimate expression of psychiatric and neurological disorders" when developing drugs. Single-dose treatments in animal models are often poor indicators of clinical success, but the ability to predict clinical outcomes increases to 70 percent if behavioral data are collected to generate full-dose response curves. Barrett cited a recent commentary in *Nature Neuroscience* (Gomez-Marin et al., 2014) that makes the case for behavior being the "foundational problem of neuroscience" and describes opportunities in big behavioral data created by innovations in technology.

SOURCE: James Barrett presentation, Drexel University, October 29, 2014.

Program Example: Stanford University School of Medicine

Ricci discussed some of the innovative approaches that Stanford University is taking in training students in translational neuroscience. The overall philosophy of Stanford's neuroscience program is to create experts and leaders in their respective career track, regardless of whether the track is inside or outside academia. Students are given the freedom to explore whatever topics and technologies they think will best suit their training needs. To accommodate these explorations, the program is associated with 25 departments and schools, spanning the biological, physical, and informational sciences. Students are also given the freedom to select faculty advisers from any department of interest and participate in any internships or similar opportunities outside of the program.

In the first year, each student selects a neuroscience topic, which is usually, but not always, disease oriented. They then choose three mini-courses—from the list of genetics, translational, behavior, computational, cognitive, systems, neuroanatomy, molecular, cellular, and development—to explore per quarter. At the end of each quarter, students produce reports on their topic incorporating lessons from the three mini-courses. They also produce a yearly report and presentation incorporating all of the mini-courses. One notable aspect of this program is that translation is considered just another facet of neuroscience. Optional translational courses also offered are Neurobiology of Disease, Current Issues in Aging, Molecular Mechanisms of Neurodegenerative Diseases, and Experimental Stroke.

Finally, Ricci noted that Stanford also offers three unique professional development programs that prepare trainees for careers in translational neuroscience: Master of Medicine,[2] Biodesign Program,[3] SPARK Program.[4]

SUMMARY

Neuroscience is in an era of growth and popularity. Given the scientific progress in the field, trainers seek to develop and strengthen training programs to better prepare the 21st century neuroscience workforce. Stevin Zorn concluded the workshop by saying, "No time in our history of neuroscience have we ever been more equipped to make the kinds of discoveries that are needed to understand the brain and the underlying diseases that we don't [yet] fully understand. Right now is the time for us to energize a new generation of neuroscientists by putting the call out, just like President Kennedy did in 1961, so that we can build our training programs, our neuroscientists, and the field itself, so that it is capable and ready to face these challenges at this unprecedented and exciting time."

[2]See http://msm.stanford.edu (accessed October 29, 2014).
[3]See http://biodesign.stanford.edu/bdn/index.jsp (accessed October 29, 2014).
[4]See http://sparkmed.stanford.edu (accessed October 29, 2014).

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B

Workshop Agenda

Defining the Expertise Needed for the 21st Century Neuroscience Workforce: A Workshop

October 28–29, 2014

Institute of Medicine
500 Fifth Street NW, Room 100
Washington, DC

Background:
From its very beginnings, neuroscience has been fundamentally interdisciplinary. As a result of rapid technological advance and the advent of large collaborative projects, however, neuroscience is expanding well beyond traditional subdisciplines and intellectual boundaries to include expertise from many other fields, such as engineering, computer science, and applied mathematics. Revolutionary tools are quickly becoming incorporated into the work of many labs. However, the importance and rapid proliferation of mission-critical technologies raises important questions on how to train the next generation of neuroscientists, not only to use particular tools, but to be prepared for a changing technological landscape. In addition, the advent of new types of data and the growing importance of large datasets raise additional questions about how to train the next generation in approaches to data sharing and proper analysis. These concerns dovetail with the need to teach improved scientific practices ranging from experimental design (powering of studies, appropriate blinding) to greater sophistication in statistics. As important is the increasing need for investigators who are able to bridge the translational

gap between basic and clinical neuroscience. Given the changing landscape resulting from technological advance and the growing importance of interdisciplinary and collaborative science, the goal of this workshop is to explore future diverse workforce needs and consider the changing needs of training programs.

Meeting Objectives:

- Explore future workforce needs in light of new and emerging tools, technologies, and techniques
  - Consider what new subdisciplines and/or collaborations with other fields might be needed moving forward
  - Describe opportunities and challenges for cross-training of neuroscience research programs with other areas (e.g., engineering, computer science, mathematics, physical sciences) and across research environments (e.g., academia, industry)
- Identify current components of graduate training programs that could be leveraged and new components that could be developed that might lead to
  - greater interdisciplinary and collaborative approaches,
  - ehanced data handling and analysis capabilities,
  - increased scientific accuracy and reproducibility,
  - improved understanding of translational research, and
  - enhanced awareness of ethical research practices.
- Examine roles of training program funders (e.g., government, fellowships), administrators, mentors, and mentees in developing and executing revised training programs to meet the needs outlined above.
- Consider mechanisms for updating researcher competencies at multiple levels (e.g., postdoctoral, independent investigators) to meet the needs outlined above.

DAY ONE

12:30 p.m. Opening Remarks

HUDA AKIL, *Co-Chair*
Professor of Neurosciences
Department of Psychiatry
University of Michigan

STEVIN ZORN, *Co-Chair*
Executive Vice President
Neuroscience Research
Lundbeck Research USA

12:35 p.m. Challenges for the Next Generation of Scientists

STORY LANDIS
Former Director
National Institute of Neurological Disorders and Stroke

12:55 p.m. The Changing Neuroscience Research Landscape: Opportunities and Challenges

EVE MARDER
Professor of Biology
Brandeis University

1:15 p.m. Imagining the Future Neuroscience Workforce

CAROL MASON
Professor
Department of Pathology and Cell Biology
Columbia University

1:35 p.m. Discussion with Speakers and Participants

- What key workforce characteristics would best position the field to address emerging opportunities and challenges in neuroscience research?

SESSION I: BASIC SCIENTIFIC PRINCIPLES AND FUNDAMENTAL KNOWLEDGE

Session Objectives: Identify current gaps in expertise necessary to advance fundamental knowledge and basic neuroscience research. Explore the impact of integrating additional disciplines into the basic neuroscience research enterprise. Examine innovative programs addressing these gaps. Consider potential strategies for creating and/or updating training of both current and future researchers.

Session Moderator: KATJA BROSE
Editor
Neuron

1:55 p.m. Defining the Gap in Neuroscience Expertise Around Basic Scientific Principles and Fundamental Knowledge

JOAN FERRINI-MUNDY
Assistant Director
Directorate for Education & Human Resources
National Science Foundation

2:15 p.m. Addressing the Gaps Through Cross-Training and Collaboration

- How could disciplines outside the neurosciences help address this gap?
- Which disciplines would provide the greatest value-add?

TERRY SEJNOWSKI
Professor
Computational Neurobiology Laboratory
Salk Institute for Biological Studies

2:35 p.m. Program Example

- On what gaps in knowledge has the program focused? How were these gaps determined?
- What challenges and opportunities have emerged during development and execution of the program?

DARCY KELLEY
Professor
Biological Sciences
Columbia University

2:55 p.m. Discussion with Speakers, Panelists, and Participants

- How could programs be designed to enhance the abilities of current and future researchers to meet the challenges and develop an inter- and multidisciplinary research enterprise?
  - What are priority components of such programs?
- How could enhanced awareness of ethical research practices be incorporated into current programs?

3:20 p.m. BREAK

SESSION II: DATA HANDLING AND ANALYSIS

Session Objectives: Identify current gaps in expertise necessary to advance the ability to handle and analyze data. Explore the impact of integrating additional disciplines into the basic neuroscience research enterprise. Examine innovative programs addressing these gaps. Consider potential strategies for creating and/or updating training of both current and future researchers.

Session Moderator: RICHARD MOHS
Vice President
Neuroscience Clinical Development
Eli Lilly and Company

3:30 p.m. Defining the Gap in Neuroscience Expertise Around Data Handling and Analysis Knowledge

MARYANN MARTONE
Co-Director
National Center for Microscopy and Imaging Research
University of California, San Diego

3:50 p.m. Addressing the Gaps Through Cross-Training and Collaboration

- How could disciplines outside the neurosciences help address this gap?
- Which disciplines would provide the greatest value-add?

BRIAN LITT
Director
Penn Center for Neuroengineering and Therapeutics
University of Pennsylvania

4:10 p.m. Program Example

- On what gaps in knowledge has the program focused? How were these gaps determined?
- What challenges and opportunities have emerged during development and execution of the program?

MICHAEL SPRINGER
Assistant Professor of Systems Biology
Department of Systems Biology
Harvard Medical School

4:30 p.m. Discussion with Speakers, Panelists, and Participants

- How could enhanced teaching of statistical methods bolster research?
- How could programs be designed to enhance the abilities of current and future researchers to meet the challenges and develop an inter- and multidisciplinary research enterprise?
    - What are priority components of such programs?

SESSION III: TRANSLATIONAL SCIENCE

Session Objectives: Identify current gaps in neuroscience expertise around translational science. Explore the impact of greater understanding and knowledge in furthering innovative therapeutic development. Examine current programs focused on improving translational neuroscience research. Consider potential strategies for creating and/or updating training of both current and future researchers.

Session Moderator: ATUL PANDE
President
Verity BioConsulting

4:55 p.m. Defining the Gap in Expertise Around Translational Science Knowledge

FRANK YOCCA
Vice President
Neuroscience iMed
AstraZeneca Neuroscience

5:15 p.m. Addressing the Gaps Through Cross-Training and Collaboration

- How could disciplines outside the neurosciences help address this gap?
- Which disciplines would provide the greatest value-add?

HOWARD FEDEROFF
Executive Dean
School of Medicine
Georgetown University

5:35 p.m. Program Example

- What challenges and opportunities have emerged during development and execution of the program?

ANTHONY RICCI
Edward C. and Amy H. Sewall Professor
Stanford School of Medicine

5:55 p.m. Discussion with Speakers, Panelists, and Participants

- What fields outside the sciences (e.g., regulatory) might also be included in programs designed around developing translational neuroscientists?
- How could programs be designed to enhance the abilities of current and future researchers to meet the challenges and develop an inter- and multidisciplinary research enterprise?
    - What are priority components of such programs?

6:15 p.m. Day One Wrap-Up and ADJOURN

HUDA AKIL, *Co-Chair*
STEVIN ZORN, *Co-Chair*

DAY TWO

8:30 a.m. Opening Remarks

HUDA AKIL, *Co-Chair*
STEVIN ZORN, *Co-Chair*

SESSION IV: EXPERIMENTAL RIGOR AND QUANTITATIVE SKILLS

Session Objectives: Identify current gaps in neuroscience expertise to improve experimental rigor and quantitative skills. Explore the impact of greater expertise in this area on the neuroscience research enterprise. Examine innovative programs addressing these gaps. Consider potential strategies for creating and/or updating training for both current and future researchers.

Session Moderator: RICHARD BORN
Professor
Department of Neurobiology
Harvard Medical School

8:40 a.m. Defining the Gap in Expertise Around Experimental Rigor and Quantitative Skills

- Are there challenges in these areas specifically related to neuroscience research?

EMERY BROWN
Professor of Computational Neuroscience
Department of Brain and Cognitive Sciences
Massachusetts Institute of Technology

8:55 a.m. Addressing the Gaps Through Cross-Training and Collaboration

- How could disciplines outside the neurosciences help address this gap?
- Which disciplines would provide the greatest value-add?

MARK COHEN
Professor
Department of Bioengineering
University of California, Los Angeles

9:15 a.m. Program Example

- What challenges and opportunities have emerged during development and execution of the program?

JAMES BARRETT
Professor and Chair
Department of Pharmacology and Physiology
College of Medicine, Drexel University

9:35 a.m. Discussion with Speakers and Participants

- Which quantitative tools might provide the most benefit?
- How could greater skills in these areas improve the reproducibility of scientific results?
- How could programs be designed to enhance the abilities of current and future researchers to meet the challenges and develop an inter- and multidisciplinary research enterprise?
    - What are priority components of such programs?

10:00 a.m. BREAK

SESSION V: EMERGING TOOLS, TECHNOLOGIES, AND TECHNIQUES

Session Objectives: Explore challenges and opportunities for integrating emerging tools, technologies, and techniques into current neuroscience research practice. Examine innovative programs training neuroscience researchers to use and incorporate new and emerging tools, technologies, and techniques into current research programs. Consider potential strategies for developing a neuroscience research enterprise that seamlessly disseminates and incorporates new and innovative tools, technologies, and techniques.

Session Moderator: JOHN MORRISON
Professor
Department of Neuroscience
Icahn School of Medicine at Mount Sinai

10:15 a.m. Challenges and Opportunities in Neuroscience Research for Real-Time Integration of Emerging Tools, Technologies, and Techniques

DOUGLAS WEBER
Program Manager
Biological Technologies Office
Defense Advanced Research Projects Agency

10:35 a.m. Mechanisms for Integrating Emerging Tools, Technologies, and Techniques

- How are emerging and new tools, technologies, and techniques being integrating in real-time into research programs?

MARIE-FRANCOISE CHESSELET
Charles H. Markham Professor of Neurology
Reed Neurological Research Center
University of California, Los Angeles

10:55 a.m. Discussion with Speakers, Panelists, and Participants

- What skills might provide the greatest benefit to researchers when preparing to integrate new tools, technologies, and techniques into research programs?
- Is there an opportunity related to the BRAIN Initiative?

- How could programs be designed for both current and future researchers to meet the challenges and develop an inter- and multidisciplinary research enterprise?

SESSION VI: DEVELOPING A DIVERSE NEUROSCIENCE RESEARCH ENTERPRISE THROUGH COLLABORATION

Session Objectives: Explore challenges and opportunities associated with developing a diverse neuroscience research enterprise with greater incorporation of collaborative science approaches. Consider the role of cross-disciplinary training of future scientists in increasing collaborative and innovative science.

Session Moderator: WALTER KOROSHETZ
Acting Director
National Institute of Neurological Disorders and Stroke

11:30 a.m. Challenges and Opportunities in Neuroscience Research for Collaborative and Diverse Science

DENNIS CHOI
Director
Neurosciences Institute
Stony Brook University

11:50 a.m. What role can the Big Data Projects (BRAIN, Human Brain Project, Allen Institute) play in developing new opportunities to enhance cross-disciplinary training, and boost the likelihood and ease of future novel collaborations in neuroscience?

JANE ROSKAMS
Executive Director, Strategy and Alliances
Allen Institute for Brain Science

12:10 p.m. LUNCH

1:10 p.m. Increasing Innovative Neuroscience Research Through Collaboration

- How has the collaboration(s) advanced innovative science?
- What challenges and opportunities have emerged during development of the collaboration?

DAVID LOPES CARDOZO
Associate Dean for Graduate Studies
Director, Division of Medical Sciences
Harvard Medical School

1:30 p.m. Discussion with Speakers, Panelists, and Participants

- What are potential mechanisms for training?
  - Can *collaboration be taught?*
- What impact would concerns about career development have on encouraging collaborative research?
- How could programs be designed to enhance the abilities of current and future researchers to meet the challenges and develop an inter- and multidisciplinary research enterprise?

1:55 p.m. BREAK

SESSION VII: DEVELOPING AND EXECUTING REVISED TRAINING PROGRAMS

Session Objectives: Examine the roles of neuroscience training program funders, administrators, mentors, and mentees in developing and executing revised training programs focused on diverse expertise in the areas identified in previous sessions. Consider specific challenges and opportunities related to the potential training program components outlined.

Session Moderator: NANCY DESMOND
Associate Director
Division of Neuroscience and Basic Behavioral Science
National Institute of Mental Health

2:10 p.m. Developing and Executing New Neuroscience Training Programs

OSWALD STEWARD
Director, Reeve-Irvine Research Center
Senior Associate Dean for Research
University of California Irvine School of Medicine

2:30 p.m. Perspectives and Panel Discussion: Integrating New Training Components

- Given the potential new expertise identified, describe current and potential mechanisms for integration. Consider potential challenges for integration.
- Consider how training programs could be different for future researchers vs. current investigators (e.g., postdoctoral fellows, principal investigators)
- Explore new and/or alternative training mechanisms that might facilitate training (e.g., online courses)
- Discuss additional skills that might be critical for researchers to possess (e.g., critical thinking, management, administrative, communication)

Training Program Funder

THOMAS INSEL
Director
National Institute of Mental Health

Department Administrator

RICHARD TSIEN
Druckenmiller Professor of Neuroscience
Director, Neuroscience Institute
Chair, Department of Physiology and Neuroscience
New York University Langone Medical Center

Mentor

INDIRA RAMAN
Professor
Department of Neurobiology and Physiology
Northwestern University

3:15 p.m. Mentor and Mentee Response Panel

- What are the potential challenges and opportunities for integration of new topics into current and future training programs?

DIANE LIPSCOMBE
Professor of Neuroscience
Center for Neurobiology of Cells and Circuits
Brown University

KATHERINE PRATER
Graduate Student
University of Michigan

SOFIA JURGENSEN
Postdoctoral Researcher
Laboratory of Pablo E. Castillo
Dominick P. Purpura Department of Neuroscience
Albert Einstein College of Medicine

MARGUERITE MATTHEWS
Postdoctoral Fellow
Department of Behavioral Neuroscience
Oregon Health & Science University

4:00 p.m. Discussion with Speakers, Panelists, and Participants

SESSION VIII: NEXT STEPS FOR NEUROSCIENCE RESARCH

Session Objectives: Explore priority areas for updating the knowledge and expertise of current and future scientists in an effort to address future neuroscience workforce needs. Identify tangible next steps for developing and integrating new concepts and expertise into current and future training programs. Discuss the role of funders, administrators, mentors, and mentees in this process.

4:50 p.m. Panel Discussion

Session Moderators

5:30 p.m. Final Comments

HUDA AKIL, *Co-Chair*
STEVIN ZORN, *Co-Chair*

5:45 p.m. ADJOURN

C

Registered Attendees

Kathryn Adcock
Medical Research Council

Neeraj Agarwal
National Eye Institute

Huda Akil
University of Michigan

Lowell Aplebaum
Society for Neuroscience

Sheeva Azma
Georgetown University

James Barrett
Drexel University

Richard Born
Harvard University

Lizbet Boroughs
American Psychiatric Association

Katja Brose
Neuron

Emery Brown
Massachusetts Institute of Technology

Erin Cadwalader
Lewis-Burke Associates

David Lopes Cardozo
Harvard Medical School

Maria Carrillo
Alzheimer's Association

J. C. Chen
Keck School of Medicine

Marie-Francoise Chesselet
University of California, Los Angeles

Dennis Choi
Stony Brook University

Allen Ego Cholakian
IRDF Project
Harvard/Columbia

Anne Cleary
National Science Foundation

Pascaline Clerc
Humane Society of the United States

Mark Cohen
University of California, Los Angeles

Alison Cole
National Institute of General Medicine

Heather Dean
National Science Foundation

Jim Deshler
National Science Foundation

Claude Desjardins
Johns Hopkins University

Nancy Desmond
National Institutes of Health

Sam Enna
University of Kansas Medical Center

Greg Farber
National Institutes of Health

Howard Federoff
Georgetown University

Joan Ferrini-Mundy
National Science Foundation

Mimi Ghim
National Institute on Drug Abuse

Lindsey Grandison
National Institute on Alcohol Abuse and Alcoholism

Annette Gray
New York University School of Medicine

Alison Hall
National Institute of General Medical Sciences

Dean Hartley
Alzheimer's Association

Chyren Hunter
National Institutes of Health

Thomas Insel
National Institute of Mental Health

Michelle Jones-London
National Institute of Neurological Disorders and Stroke

Sofia Jurgensen
Albert Einstein College of Medicine

Kristen Keefe
University of Utah

Darcy Kelley
Columbia University

Stephen Korn
National Institutes of Health

Walter Koroshetz
National Institute of Neurological Disorders and Stroke

Story Landis
National Institute of Neurological Disorders and Stroke (retired)

Diane Lipscombe
Brown University

Brian Litt
University of Pennsylvania

Eve Marder
Brandeis University

Maryann Martone
University of California, San Diego

Carol Mason
Columbia University

Marguerite Matthews
Oregon Health & Science University

Richard Mohs
Eli Lilly and Company

John Morrison
Icahn School of Medicine at Mount Sinai

Barbara Myklebust
Self-Employed

Libby O'Hare
National Research Council

Atul Pande
Verity BioConsulting

Diana Pankevich
American Association for the Advancement of Science Science & Technology Policy Fellow

Ian Paul
University of Mississippi

Katherine Prater
University of Michigan

Indira Raman
Northwestern University

Anthony Ricci
Stanford University School of Medicine

Alberto Rivera-Rentas
National Institutes of Health

Erica Rosemond
National Institute of Mental Health

Jane Roskams
Allen Institute for Brain Science

Philip Rubin
White House Office of Science & Technology Policy

Alexander Runko
Department of Health and Human Services

Erik Runko
National Science Foundation

Georgia Sambunaris
Independent Consultant

Justin Sanchez
Defense Advanced Research Projects Agency

Allen Segal
Society for Neuroscience

Terry Sejnowski
Salk Institute for Biological Studies

Michael Springer
Harvard Medical School

Michael Steinmetz
National Eye Institute

Laurie Stepanek
National Science Foundation

Oswald Steward
University of California, Irvine, School of Medicine

Kemi Tomobi
Student National Medical Association

Richard Tsien
New York University
Langone Medical Center

Lauren Ullrich
Society for Neuroscience

Andre van der Merwe
National Institutes of Health

Douglas Weber
Defense Advanced Research Projects Agency

Susan Weiss
National Institute on Drug Abuse

John Williams
Wellcome Trust

Frank Yocca
AstraZeneca Neuroscience

Robin Ann Yurk
Independent Physician

Stevin Zorn
Lundbeck Research USA

D

Participant Biographies

Huda Akil, Ph.D., is the Gardner Quarton Distinguished University Professor of Neuroscience and Psychiatry and the co-director of the Molecular & Behavioral Neuroscience Institute at the University of Michigan. Dr. Akil, together with Dr. Stanley J. Watson and their colleagues, have made seminal contributions to the understanding of the brain biology of emotions, including pain, anxiety, depression, and substance abuse. She and her collaborators provided the first physiological evidence for a role of endorphins in the brain, and showed that endorphins are activated by stress and cause pain inhibition. Dr. Akil's current research investigates the genetic, molecular, and neural mechanisms underlying stress, addiction, and mood disorders. Along with Dr. Watson, she is the Michigan site director of the Pritzker Consortium, which is engaged in large-scale studies to discover new genes and proteins that cause vulnerability to major depression and bipolar illness. She is the author of more than 500 original scientific papers, and has been recognized as one of the most highly cited neuroscientists by the ISI Citation Index.

Dr. Akil's scientific contributions have been recognized with numerous honors and awards. These include the Pacesetter Award from the National Institute on Drug Abuse in 1993 and the Pasarow Award (with S. J. Watson) for Neuroscience Research in 1994. In 1998, she received the Sachar Award from Columbia University, and the Bristol Myers Squibb Unrestricted Research Funds Award. She is also the recipient of the Society for Neuroscience Mika Salpeter Lifetime Achievement Award, the National Alliance for Research on Schizophrenia and Depression Patricia Goldman-Rakic Prize for Cognitive Neuroscience (2007), and the Koch Award from the American College of Neuropsychopharmacology (2010). She has shared with Dr. Watson the Thomas

William Salmon Award in 2010, and the Institute of Medicine (IOM) Sarnat Award in 2012. In 2013, she received the Association of American Medical Colleges Award for Distinguished Research in the Biomedical Sciences. In 1994, Dr. Akil was elected to the membership in the IOM. She was elected as a Fellow of the American Association for the Advancement of Science (AAAS) in 2000. In 2004, she was elected to the American Academy of Arts and Sciences. In 2011 she was elected to the National Academy of Sciences (NAS). Dr. Akil's service includes membership on numerous boards and scientific councils. She has served on several national and international organizations to promote scientific and brain health awareness nationally and globally. She is a past president of the American College of Neuropsychopharmacology (1998) and the Society for Neuroscience (2004), the largest neuroscience organization in the world. She has co-chaired the Neuroscience Steering Committee for Biomarkers Development at the Foundation for the National Institutes of Health. She has served two terms on the Council of the IOM, and currently serves on the National Research Council review board. She is also a member of the Advisory Committee to the Director of the National Institutes of Health (NIH).

James E. Barrett, Ph.D., is professor and chair of pharmacology and physiology as well as founding director of the Drug Discovery and Development Program at Drexel University College of Medicine and of the Clinical and Translational Research Institute, Drexel University. He received his Ph.D. from Pennsylvania State University, followed by postdoctoral training in Neuropsychopharmacology at the Worcester Foundation for Experimental Biology. He has served on the faculty at the University of Maryland and at the Uniformed Services University of the Health Sciences, where he was a professor in the Department of Psychiatry. Dr. Barrett joined Wyeth as vice president of Neuroscience Discovery Research following the merger with Lederle Laboratories, where he had been director of Central Nervous System Research. Prior to his current position at Drexel University College of Medicine, he was senior vice president, chief scientific officer, and president, research at Adolor Corporation, a company focused on pain pharmaceuticals. He moved to Adolor after serving as president of R&D at Memory Pharmaceuticals, a biopharmaceutical company dedicated to the development of drugs for the treatment of debilitating central nervous system (CNS) disorders. He has published more than 275 scientific articles, books, and abstracts in the areas of neuropharmacology, neurobiology, behavioral pharmacology, translational research, and neuroscience, and serves on several editorial boards. He has served as president of the Behavioral Pharmacology Society and of the American Society for Pharmacology and Experimental Therapeutics (ASPET). He served as the chair of the Board of Publication Trustees for ASPET and served on the Board of Directors for the Federation of American Societies for Experimental Biology, where he was a member of the Science Policy Committee and the Public Affairs Committee as well as chair of the Breakthrough Series in Science and Horizons in Bioscience Series. Dr. Barrett recently joined the ASPET Board as series editor for the handbook of experimental pharmacology. He has received the Solvay-Duphar Award for Research on Affective Disorders, the George B. Koelle Award from the Mid-Atlantic Pharmacology Society for contributions to teaching and research, and, most recently, the P.B. Dews Lifetime Achievement Award for Research in Behavioral Pharmacology. Dr. Barrett is a member of the External Scientific Advisory Board, Preclinical Autism Consortium for Therapeutics. He is also president of the Association of Medical School Pharmacology Chairs and was recently elected to the Executive Committee of the International Union of Basic and Clinical Pharmacology. In addition to being a member of ASPET, he is a member of AAAS and the American Pain Society and a Fellow of the American College of Neuropsychopharmacology. His current research emphasis is in the area of pain, its comorbid pathologies, and basic mechanisms and new therapeutics.

Richard T. Born, M.D., is a professor of neurobiology at Harvard Medical School and was director of the Harvard Ph.D. Program in Neuroscience from 2009 to 2014. He earned a B.A. in Chemistry from DePauw University. He attended Harvard Medical School, where he discovered the joys of visual neurophysiology by working with Professors David Hubel and Margaret Livingstone. After receiving his M.D. in 1988, he continued on as a postdoctoral fellow in the Hubel/Livingstone lab, undertook a second postdoc with William Newsome at Stanford, and then returned to Harvard Medical School in 1995 as an assistant professor in the Department of Neurobiology. He is currently a member of the Faculty of 1000 and serves on the Sensory Processing and Cognition Study Section at NIH. His laboratory studies cortical visual processing in nonhuman primates, with a particular interest in the nature of cortico-cortical feedback.

Katja Brose, Ph.D., is editor of *Neuron* and executive editor-neuroscience and director of reviews strategy, Cell Press. As editor of *Neuron*, Dr. Brose represents the journal within the scientific community and is responsible for all aspects of the journal's management, operations, and strategic vision. She earned her undergraduate degree in 1990 from Brown University, with a double concentration in Biology and European History. She received her Ph.D. in biochemistry from the University of California, San Francisco (UCSF). She performed her graduate work in the laboratory of Dr. Marc Tessier Lavigne, focusing on axon guidance mechanisms in the developing spinal cord. In collaboration with Corey Goodman's laboratory at UC Berkeley, her research led to the identification of the receptor Robo and its ligand Slit as a new family of axon guidance molecules.

In 2000, Dr. Brose joined Cell Press as a senior editor at *Neuron*. *Neuron* is the sister journal of *Cell* and is 1 of 12 life science journals at Cell Press, a division of Elsevier Science and Technology journal publishing. Dr. Brose was promoted to deputy editor in 2002 and appointed editor-in-chief in 2004. During her tenure as editor, *Neuron* has undertaken a major expansion of its scope, building on its historical strengths in molecular and cellular neuroscience to now cover all areas of neuroscience, from molecular/cellular mechanisms to systems and cognitive neuroscience, genetics, neurological and psychiatric disease, theoretical neuroscience, and emerging technologies. In 2007, with Cell Press's acquisition of the Trends group of review titles, Dr. Brose was appointed as executive editor of the *Neuroscience Portfolio*, which includes, in addition to *Neuron*, the review journals *Trends in Neurosciences* and *Trends in Cognitive Sciences*. She currently also serves as editorial director for reviews strategy for Cell Press and is a member of the Cell Press senior management team. She speaks frequently on topics related to scientific publishing and communication, including publication ethics.

Emery N. Brown, M.D., Ph.D., is the Edward Hood Professor of Medical Engineering and Computational Neuroscience at Massachusetts Institute of Technology (MIT); the Warren M. Zapol Professor of Anesthesia at Harvard Medical School; and a practicing anesthesiologist at Massachusetts General Hospital. Dr. 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 his Ph.D. in Statistics from Harvard University. Dr. Brown is an anesthesiologist-statistician whose experimental research has made important contributions toward understanding the neuroscience of how anesthetics act in the brain to create the states of general anesthesia. In his statistics research, he has developed signal processing algorithms to solve important data analysis challenges in neuroscience. He served on the NIH BRAIN Initiative Working Group, and is currently a member of the NIH Council of Councils, the National Science Foundation (NSF) Mathematics and Physical Sciences Advisory Committee, the Board of Directors of the Burroughs-Wellcome Fund, and the Board of Trustees of the International Anesthesia Research Society. He is a recipient of an NIH Director's Pioneer Award, an NIH Director's Transformative Research Award, and the 2011 Jerome Sacks Award from the National Institute of Statistical Science. Dr. Brown is a Fellow of the American Statistical Association, AAAS, the Institute of Electrical and Electronics Engineers and the American Academy of Arts and Sciences. He is a member of the IOM and the NAS.

David Lopes Cardozo, Ph.D., has served for the past 7 years as associate dean for graduate studies and director of the Division of Medical Sciences at Harvard Medical School. He received his B.A. in English Literature from Concordia University. This was followed by 7 years of service as an officer in the Royal Canadian Navy and as a master of merchant vessels trading in the Caribbean. Following his career at sea, he received a B.Sc. in Biology from Dalhousie University and a Ph.D. in Neuroscience from Harvard. After his postdoc, he joined the faculty of the Neurobiology Department at Harvard Medical School. His research is directed at studying the filum terminale of the spinal cord as a source for autologous neural stem cells that can be used for the treatment of neurological disease. For 14 years he was the course director for the human nervous system and behavior course, which is taken by second-year medical students.

Marie-Francoise Chesselet, M.D., Ph.D., is the Charles H. Markham Professor of Neurology and Distinguished Professor in the Department of Neurology and the Department of Neurobiology at the University of California, Los Angeles (UCLA). After receiving her M.D. and Ph.D. in Paris, she held research positions in France and faculty positions at the Medical College of Pennsylvania and the University of Pennsylvania, before joining UCLA in 1996. At UCLA, Dr. Chesselet chaired the Department of Neurobiology from 2002 to 2013. She is currently the director of the Integrative Center for Neural Repair, which includes the Center for the Study of Parkinson's Disease at UCLA that she created in 1998. She has directed the NIH-funded UCLA Udall Center for Parkinson's disease research (National Institute of Neurologic Disorders and Stroke, or NINDS; 1998–2013) and UCLA Center for Gene Environment in Parkinson's Disease (National Institute of Environmental Health Sciences, or NIEHS; 2002–2014), and the UCLA Advanced Center for Parkinson's Disease Research of the American Parkinson Disease Association since 1998. Dr. Chesselet has directed graduate programs at the University of Pennsylvania and UCLA and has directed the NINDS-funded Training Program in Neural Repair since 1998. Her laboratory conducts research on the molecular mechanisms of disorders of the basal ganglia and new treatments for Parkinson's and Huntington's diseases. Currently, her work is supported by the Department of Defense, The Michael J. Fox Foundation for Parkinson's Research, California Institute for Regenerative Medicine, and biopharmaceutical companies. Dr. Chesselet is a Fellow of AAAS and the chair-elect of its section on neuroscience. She serves on the National Advisory Environmental Health Sciences Council (NAEHS Council).

Dennis Choi, M.D., Ph.D., is currently professor and chair of the Department of Neurology, and director of the Neurosciences Institute, at Stony Brook University. He was formerly executive vice president at the Simons Foundation in New York City, vice president for Academic Health Affairs at Emory University, executive vice president for neuroscience at Merck Research Labs, and head of neurology at Washington University Medical School. Dr. Choi received his M.D. from the Harvard-MIT Health Sciences and Technology Program, as well as a Ph.D. in pharmacology and neurology training from Harvard. He is a co-discoverer of the physiological mechanism of action of benzodiazepine drugs, and a pioneer in dissecting processes responsible for pathological neurodegeneration. He is a member of the IOM, a fellow of AAAS, a past president of the Society for Neuroscience, and a past vice president of the American Neurological Association.

Mark Cohen, Ph.D., is a professor of psychiatry, neurology, radiology, psychology, biomedical physics, and biomedical engineering at the UCLA Semel Institute for Neuroscience and Behavior and the Staglin Center for Cognitive Neuroscience. Dr. Cohen did his undergraduate studies at both MIT and Stanford University, where he received his bachelor's degree in human biology. He then went to the Rockefeller

University, where he trained under Victor Wilson, Donald Pfaff, and Susan Schwartz Giblin, receiving his Ph.D. for his work on the pudendal nerve evoked response and its modulation by steroid hormones. In 1985 Dr. Cohen joined the magnetic resonance imaging (MRI) Applications Group at Siemens Healthcare, where he began a career in nuclear magnetic resonance (NMR) focused originally on education, and on technological improvements to reduce scan times. From 1988 to 1990, he directed the applications program at Advanced NMR Systems, a small start-up dedicated to the creation of a practical echo-planar imaging instrument. He joined the faculty at Harvard/Massachusetts General Hospital (MGH) in 1990, when he directed the "Hyperscan" fast imaging laboratory, and the MRI education program until 1993. Since then he has been at UCLA, where he developed, with John Mazziotta, the first dedicated functional MRI (fMRI) center.

Dr. Cohen's training is equal parts engineering and neuroscience. His contributions include his critical role in the development of practical echo-planar scanning, ultra-fast MRI applications, contrast-based and blood oxygenation level dependent (BOLD) fMRI, applications of linear systems analysis to increase fMRI sensitivity and resolution, and concurrent recordings of electroencephalography and fMRI to better understand brain dynamics and distributed processing. He and his lab have contributed to an understanding of the power of pattern recognition and machine learning to both interpret/classify neural data and as a source of discovery of the processes that result in cognition, perception, emotion, and pathology.

Dr. Cohen is passionate about graduate and postgraduate education. As the creator and director of the UCLA/Semel NeuroImaging Training Program, he has pushed his students to an integrative understanding of the role of imaging in neuroscience: the use of images as hypothesis tests; the relationships among blurring, convolution, statistical error, and inference from images; and an understanding of the structures common to neuroimages regardless of imaging modality. His current focus now includes inquiry into the broader problems of images, beyond neuroscience, to encompass astronomy and nanoscale imaging, aesthetics to statistics, dimensional compression, and dimensional expansion.

Nancy L. Desmond, Ph.D., is currently an associate director in the Division of Neuroscience and Basic Behavioral Science (DNBBS) at the National Institute of Mental Health (NIMH). Before joining NIH in 2003, Dr. Desmond was associate professor of neurosurgery at the University of Virginia School of Medicine and a member of the Neuroscience Graduate Program there. She was the principal investigator (PI) on grants from NIMH/NIH and NSF that focused on understanding synaptic modification in the hippocampus. Dr. Desmond served as a peer reviewer of grants for NIH, NSF, and other agencies. She obtained her Ph.D. in physiological psychology from the University of California, Riverside, and then did postdoctoral training in Neuroscience at the University of Virginia. At NIMH, Dr. Desmond directs the DNBBS Office of Research Training and Career Development, co-coordinates research training for NIMH, and is chief of the Neuroendocrinology and Neuroimmunology Program. She has contributed to multiple NIH-wide efforts related to research training and career development, including a stint as co-chair of the NIH Training Advisory Committee, participating in NIH Roadmap, Blueprint for Neuroscience Research, and BRAIN training initiatives, and recently serving as the acting NIH research training officer. In that position, she led the reissuance of the parent NIH training and career development funding announcements, and contributed to implementation of the recommendations of the Biomedical Research Workforce Working Group to the NIH Advisory Committee to the Director. Current NIH-level activities include co-chairing the policy subcommittee of the NIH Training Advisory Committee; co-coordinating the working group for the NIH Common Fund program, Strengthening the Biomedical Research Workforce; and participating in the Trans-NIH Microbiome Working Group.

Howard Federoff, M.D., Ph.D., is the executive vice president for health sciences at Georgetown University and executive dean of the School of Medicine. Dr. Federoff is responsible for Georgetown University Medical Center. He is a professor of neurology and neuroscience. Prior to Georgetown, he held appointments as senior associate dean; professor of neurology, medicine, microbiology, and immunology; and professor of oncology and genetics at the University of Rochester School of Medicine, and as founding director of the Center for Aging and Development Biology at the Aab Institute of Biomedical Sciences and founding division chief of Molecular Medicine and Gene Therapy. He also directed the University of Rochester's Interdepartmental Neuroscience Program. Dr. Federoff's research interests include gene therapy and neurodegenerative diseases. He has published more than 250 peer reviewed and invited articles and acts as a reviewer for many journals. He is on the editorial boards of the *Journal of Parkinson's Disease*, *Open Genomics*

Journal, and *Journal of Experimental Neurology*. Dr. Federoff served as chair of the NIH Recombinant DNA Advisory Committee from 2007 to 2010. He chairs the Gene Therapy Resource Program for the National Heart, Lung, and Blood Institute, was president of the American Society for Neural Therapy and Repair (2012–2013), and is president of the American Society for Experimental Neurotherapeutics. Dr. Federoff received his M.S., Ph.D., and M.D. from the Albert Einstein College of Medicine. He did his internship, residency, and clinical and research Fellowships at MGH/Harvard Medical School, and practiced medicine at the Albert Einstein College of Medicine and University of Rochester. He is a Fellow of AAAS and National Academy of Inventors.

Joan Ferrini-Mundy, Ph.D., is the assistant director of NSF's Education and Human Resources, a position she has held since 2011. Previously at NSF she served as the inaugural division director of the Division of Research on Learning in Formal and Informal Settings. Dr. Ferrini-Mundy served as an ex officio member of the U.S. President's National Mathematics Advisory Panel, and co-chaired its Instructional Practices Task Group. She was a member of the Mathematics Expert Group of the Programme for International Student Assessment. Currently Dr. Ferrini-Mundy is co-chair of the White House National Science and Technology Council's Federal Coordination in Science, Technology, Engineering and Mathematics Education Task Force. Prior to joining NSF, she was a University Distinguished Professor of Mathematics Education at Michigan State University. She holds a Ph.D. in Mathematics Education from the University of New Hampshire. She was elected a fellow of AAAS, and a member of the Executive Committee of the Association of Women in Mathematics. Her research interests are in calculus learning, mathematics teacher knowledge, and K–12 STEM education policy.

Thomas Insel, M.D., graduated from Boston University, where he received a B.A. from the College of Liberal Arts and an M.D. from the Medical School. He did his internship at Berkshire Medical Center, Pittsfield, Massachusetts, and his residency at the Langley Porter Neuropsychiatric Institute at UCSF. In 1979 Dr. Insel joined NIMH, where he served in various scientific research positions until 1994, when he went to Emory University as professor, Department of Psychiatry, Emory University School of Medicine, and director of the Yerkes Regional Primate Research Center. As director of Yerkes, Dr. Insel built one of the nation's leading HIV vaccine research programs. He also served as the founding director of the Center for Behavioral Neuroscience, a Science and Technology Center funded by NSF to develop an interdisciplinary consortium for research and education at eight Atlanta colleges and universities.

Dr. Insel's scientific interests have ranged from clinical studies of obsessive-compulsive disorder to explorations of the molecular basis of social behaviors in rodents and non-human primates. His research on oxytocin and affiliative behaviors, such as parental care and pair bonding, helped to launch the field of social neuroscience. Dr. Insel oversees NIMH's $1.4 billion research budget, which provides support to investigators at universities throughout the country in the areas of basic science; clinical research, including large-scale trials of new treatments; and studies of the organization and delivery of mental health service.

Sofia Jurgensen, Ph.D., Pharm.D., received her Ph.D. in Biochemistry and Neuroscience in 2011 from Federal University of Rio de Janeiro, Brazil. She also has a master's in Pharmacology and a Pharm.D., both from Federal University of Santa Catarina, Brazil. After a postdoc of 1 year in Brazil, she joined the laboratory of Dr. Pablo Castillo at Albert Einstein College of Medicine, in New York, where she has been a Research Fellow in Neuroscience since 2012. Her areas of expertise are synaptic physiology, autism spectrum disorders, and Alzheimer's disease. Dr. Jurgensen serves several roles at the Society for Neuroscience, including being the current chair of the Trainee Advisory Committee and a member of the Latin America Training Program Advisory Group.

Darcy Kelley, Ph.D., is the Harold Weintraub Professor of Biological Sciences at Columbia University. Her laboratory studies vocal communication, focusing on molecular, neural, behavioral, and evolutionary mechanisms that underlie the match between hearing and utterance. She has identified sex-specific structures, neural circuits, and interactive vocal behaviors shaped by the expression of sex steroids and their receptors in African clawed frogs. Her laboratory has identified a diverse array of CNS and peripheral mechanisms responsible for producing the signature male courtship songs of different species. In 2014, she became a Fellow of the International Society for Neuroethology. Dr. Kelley has a longstanding interest in neuroscience education. She established Columbia's undergraduate major in Neuroscience and Behavior in 1986 and founded Columbia's graduate program in Neurobiology and Behavior in 1995. In 2002 she was appointed to a Howard Hughes Medical Institute

(HHMI) Professorship to support educational innovation. She also has a strong interest in the portrayal of science in theater and films. Dr. Kelley is a scientific consultant on plays and movies for the Sloan Foundation and has participated in the Sundance, New York, Hamptons, Imagine, and Tribeca Film Festivals. She is on the Board of Trustees of the Wenner Gren Foundation and the American Association of Colleges & Universities.

Walter Koroshetz, M.D., became the acting director of NINDS in October, 2014. Previously, he served as deputy director of NINDS under Dr. Story Landis. Together, they directed program planning and budgeting, and oversaw the scientific and administrative functions of the institute. He has held leadership roles in a number of NIH and NINDS programs, including the NIH's BRAIN Initiative, the Traumatic Brain Injury Center collaborative effort between the NIH intramural program and the Uniformed Health Services University, and the multiyear work to develop and establish the NIH Office of Emergency Care Research to coordinate NIH emergency care research and research training. Before joining NINDS, Dr. Koroshetz served as vice chair of the neurology service and director of stroke and neurointensive care services at Massachusetts General Hospital (MGH). He was a professor of neurology at Harvard Medical School and led neurology resident training at MGH between 1990 and 2007. Over that same period, he co-directed the HMS Neurobiology of Disease course with Drs. Edward Kravitz and Robert H. Brown.

A native of Brooklyn, New York, Dr. Koroshetz graduated from Georgetown University and received his M.D. from the University of Chicago. He trained in internal medicine at the University of Chicago and MGH. Dr. Koroshetz trained in neurology at MGH, after which he did postdoctoral studies in cellular neurophysiology at MGH with Dr. David Corey, and later at the Harvard neurobiology department with Dr. Edward Furshpan, studying mechanisms of excitoxicity and neuroprotection. He joined the neurology staff, first in the Huntington's disease (HD) unit, followed by the stroke and neurointensive care service. A major focus of his clinical research career was to develop measures in patients that reflect the underlying biology of their conditions. With the MGH team he discovered increased brain lactate in HD patients using MR spectroscopy. He helped the team to pioneer the use of diffusion/perfusion-weighted MR imaging and CT angiography/perfusion imaging in acute stroke.

Active in the American Academy of Neurology (AAN), Dr. Koroshetz chaired the professional organization's Public Information Committee, led the AAN's efforts to establish acute stroke therapy in the United States, founded the Stroke Systems Working Group, and was a member of the AAN board of directors.

Story Landis, Ph.D., was director of NINDS from 2003 to 2014. A native of New England, Dr. Landis received her undergraduate degree from Wellesley College and her Ph.D. from Harvard University. After postdoctoral work at Harvard University, she served on the faculty of its Department of Neurobiology. In 1985, she joined the faculty of Case Western Reserve University School of Medicine. She created the Department of Neurosciences, which, under her leadership, achieved an international reputation for excellence. Throughout her research career, Dr. Landis made fundamental contributions to the understanding of nervous system development. She is an elected fellow of the IOM, the American Academy of Arts and Sciences, and AAAS. In 2002 she was elected president of the Society for Neuroscience. Dr. Landis joined NINDS in 1995 as scientific director and worked to reengineer the institute's intramural research programs. Between 1999 and 2000, she led the movement, together with the NIMH scientific director, to bring a sense of unity and common purpose to 200 neuroscience laboratories from 11 NIH Institutes. As NINDS director, Dr. Landis oversaw an annual budget of $1.5 billion that supported research by investigators in public and private institutions across the country, as well as by scientists working in its intramural program. Together with the directors of NIMH and the National Institute on Aging, she co-chaired the NIH Blueprint for Neuroscience Research, a roadmap-like effort to support trans-NIH activities in the brain sciences.

Diane Lipscombe, Ph.D., is a professor of neuroscience at Brown University. Dr. Lipscombe co-directs the Center for the Neurobiology of Cells and Circuits; chairs the steering committee for the Neuroscience Graduate Program and Graduate Partnerships Program with NIH; and directed the Neuroscience Graduate Program from 2004 to 2012. She is PI of the NIMH Jointly Sponsored Predoctoral Training Program in Neuroscience and co-PI of the Advanced NINDS Predoctoral Training Program in Neural Dynamics. Dr. Lipscombe is recognized for her studies of neuronal ion channels, in particular voltage-gated calcium ion channels in neurons. She studies cell-specific mechanisms that control processing of voltage-gated calcium ion channel RNAs in neurons, and the functional role of voltage-gated calcium ion channels in normal and disease states, including in chronic pain. Dr. Lipscombe is a regular member of an NIH study section and also regularly reviews T32 training grant applications. Former editor of the *Journal of Neuroscience*, she currently chairs the Scientific Publications Committee and served on the Ethics Committee for the Society for Neuroscience. Dr. Lipscombe has graduated a number of predoctoral and postdoctoral trainees from her own lab and has received several awards from Brown University for outstanding teaching and mentoring. She received her undergraduate and graduate degrees in pharmacology from University College London.

Brian Litt, M.D., obtained a degree in engineering and applied sciences from Harvard University in 1982 and his M.D. from Johns Hopkins University School of Medicine in 1986, where he stayed for an Osler Internship, postdoctoral fellowship in bioengineering, neurology residency, and fellowship in epilepsy and clinical neurophysiology. Dr. Litt stayed on the faculty at Johns Hopkins before moving to Emory University and Georgia Tech, with a joint appointment in neurology and biomedical engineering in 1996. In 2000, he was recruited to neurology and bioengineering at the University of Pennsylvania, where he is now a professor and divides his time equally between separate tenured appointments in the School of Medicine (neurology) and School of Engineering (bioengineering). He is director of the Penn Epilepsy Center at the Hospital of the University of Pennsylvania, and director of the Translational Neuroengineering Laboratory in Bioengineering, where he teaches a programming intensive graduate course on brain-computer interfaces.

Eve Marder, Ph.D., is the Victor and Gwendolyn Beinfield Professor of Neuroscience in the Biology Department of Brandeis University, where she also heads the Division of Science at Brandeis. Dr. Marder was president of the Society for Neuroscience in 2008, and is now a member of the NINDS Council. She is a member of the NAS, the IOM, and AAAS. She is a fellow of the Biophysical Society and a Fellow of AAAS. She received the Miriam Salpeter Memorial Award for Women in Neuroscience, the W. F. Gerard Prize from the Society for Neuroscience, the George A. Miller Award from the Cognitive Neuroscience Society, the Karl Spencer Lashley Prize from the American Philosophical Society, an Honorary Doctorate from Bowdoin College, and the Gruber Award in Neuroscience. Dr. Marder studies the dynamics of small neuronal networks, and her work was instrumental in demonstrating that neuronal circuits are not hard-wired, but can be reconfigured by neuromodulatory neurons and substances to produce a variety of outputs. For more than 20 years, Dr. Marder's lab has combined experimental work with insights from modeling and theoretical studies. Her lab pioneered studies of homeostatic regulation of intrinsic membrane properties, and stimulated work on the mechanisms by which brains remain stable while allowing for change during development and learning. Dr. Marder is now studying the extent to which similar network performance can arise from different sets of underlying network parameters, opening up rigorous studies of the variations in individual brains of normal healthy animals.

Maryann Martone, Ph.D., is co-director of the National Center for Microscopy and Imaging Research at the University of California, San Diego (UCSD). In 1993 she joined the Department of Neurosciences, where she is currently a professor in residence. Dr. Martone received her B.A. in biological psychology from Wellesley College and her Ph.D. in neuroscience from UCSD. She is the PI of the Neuroscience Information Framework project, a national project to establish a uniform resource description framework for neuroscience. Her recent work has focused on building ontologies for neuroscience for data integration. She recently finished her tenure as the U.S. scientific representative to the International Neuroinformatics Coordinating Facility (INCF), an international organization dedicated to developing tools and standards for neuroscience data exchange. Dr. Martone is a practicing neuroscientist, with expertise in neuroanatomy and light and electron microscopy. For the past decade, she has been working in the area of neuroinformatics to increase access to and use of neuroscience data. To further develop the framework, she heads the ontology development program for the INCF and the Data Standards Workstream for the newly launched One Mind for Research campaign. Through Neuroscience Information Framework and her neuroscience background, Dr. Martone has a unique global perspective on issues in data sharing and usage in the neurosciences and has gained considerable insight and expertise in working with diverse biomedical data. She has also continued to explore how these knowledge frameworks can be used to solve difficult problems in neurodegenerative disease through modeling of structural phenotypes in animal models of human neurodegenerative conditions.

Carol Mason, Ph.D., is a professor of pathology and cell biology, neuroscience, and ophthalmology at Columbia University, College of Physicians and Surgeons. Dr. Mason's research has addressed the dynamic structure of neurons and their processes in the context of the mature and developing cerebellum and visual system. In recent years, she has studied how the visual pathways are established from the retina through the optic chiasm to thalamic targets. Her work has revealed a molecular program of transcription and guidance factors that specify the ipsilateral and contralateral retinal ganglion cell pathways during the establishment of binocular circuitry. Current work applies these findings to the albino visual system, in which the lack of melanin leads to anatomical and functional perturbations of this circuit. Dr. Mason is a fellow of AAAS and the IOM. As co-director of the doctoral program in neurobiology and behavior at Columbia, and current president of the Society for Neuroscience, she has focused on training the next generation of neuroscientists, mentoring at all career stages, and promoting science communication to the public.

Marguerite Matthews, Ph.D., is a postdoctoral fellow in the Department of Behavioral Neuroscience at the Oregon Health & Science University (OHSU), where she uses functional connectivity MRI, along with computational approaches, to study typical and atypical brain organization in children and adolescents. She received a Ph.D. in neuroscience from the University of Pittsburgh, and a B.S. in biochemistry from Spelman College. In addition to her research at OHSU, Dr. Matthews directs a science education and outreach program, Youth Engaged in Science (YES!), developed with her research mentor, Damien Fair, PA-C, Ph.D. The YES! initiative aims to expose underrepresented minority youth in the Portland area to science, research, and STEM-related careers through in-class educational activities, laboratory tours, mentorship, and research internship opportunities. She has also worked closely with faculty and administrators to launch a research fellowship program aimed at increasing diversity at OHSU through the targeted recruitment of underrepresented minority postdocs and junior faculty to OHSU. Dr. Matthews is also an active member of the Society for Neuroscience and serves on the Society's Trainee Advisory Committee and the Advocacy Working Group. She is also a member of the Association of Underrepresented Minority Fellows.

Richard C. Mohs, Ph.D., is the vice president for Neuroscience Early Clinical Development and a Distinguished Research Fellow within Lilly Research Laboratories. He and his staff are responsible for phase I through phase II studies of molecules being developed for any neuroscience indication, with most molecules targeted for depression, schizophrenia, pain, Alzheimer's disease, or other neurodegenerative disease. Dr. Mohs joined Eli Lilly and Company in 2002, working in the early phase development group until 2006–2011, when he led the phase III development team for Eli Lilly's Alzheimer's disease compounds. He returned to lead the early phase development group in 2011. Dr. Mohs received his Ph.D. in psychology from Stanford University and completed postdoctoral training in pharmacology at the Stanford University Medical School. He holds a faculty appointment at the Mount Sinai School of Medicine in New York. Before joining Eli Lilly in 2002, Dr. Mohs spent 23 years with the Mount Sinai School of Medicine, where he was professor in the Department of Psychiatry and associate chief of staff for research at the Bronx Veterans Affairs Medical Center. The author or co-author of more than 300 scientific papers, Dr. Mohs has conducted research studies on aging, Alzheimer's disease, schizophrenia, and cognitive function. Among his studies are clinical trials that led to the approval, in the United States and other countries, of cholinergic drug treatments for Alzheimer's disease. Dr. Mohs has served as an adviser to many neuroscience research programs at universities and to several foundations supporting neuroscience research, including the John D. and Catherine T. MacArthur Foundation, the Charles A. Dana Foundation, and the Alzheimer's Drug Discovery Foundation.

John H. Morrison, Ph.D., is currently dean of Basic Sciences and the Graduate School of Biomedical Sciences, professor of neuroscience, and the Willard T. C. Johnson Professor of Geriatrics and Palliative Medicine (Neurobiology of Aging) at the Icahn School of Medicine at Mount Sinai. He served as chair of the Department of Neuroscience until 2006, when he stepped down as chair to become dean. Dr. Morrison earned his bachelor's and Ph.D. from Johns Hopkins University, and completed postdoctoral studies in the laboratory of Dr. Floyd E. Bloom at the Salk Institute for Biological Studies. He then served as a faculty member at The Scripps Research Institute, until he joined the faculty at Mount Sinai in 1989 to develop and lead a new Center for Neurobiology. Dr. Morrison's research program focuses primarily on the neurobiology of aging and neurodegenerative disorders, particularly as they relate to cellular and synaptic organization of the cerebral cortex. Within this broad arena, his lab works specifically on the interactions among endocrine factors (e.g., estrogen, stress steroids) and aging and the synaptic determinants of cognitive aging. His laboratory is particularly interested in age-related alterations in structural and molecular attributes of the synapse that compromise plasticity and lead to cognitive decline. Since 1985 NIH has funded Dr. Morrison's research without interruption, and he currently directs a large NIH-funded project on Estrogen and the Aging Brain, as well as one on the neurobiological basis of cognitive aging that has been designated as an NIH MERIT Award. Dr. Morrison has published over 300 articles on cortical organization, the cellular pathology of neurodegenerative disorders, the neurobiology of cognitive aging, and the effects of stress on cortical circuitry. He has also edited five books on related topics. He has served on numerous editorial boards, advisory boards, NIH committees, and the board of directors of the American Federation for Aging Research. Dr. Morrison has served as president of both The Harvey Society and The Cajal Club, and was elected to the Council of the Society for Neuroscience in 2010 and served in that capacity until 2013.

Atul Pande, M.D., is president of Verity BioConsulting, an independent drug development consulting firm. Previously he was senior vice president and senior adviser, Pharmaceutical R&D at GlaxoSmithKline. For more than two decades he has been active in the development of many important central nervous system drugs while holding various senior roles in Pfizer R&D, Parke-Davis/Warner-Lambert, and Lilly Research Laboratories. His experience includes pre-Investigational New Drug development; proof of concept to registration development; and launch and lifecycle management in the areas of anxiety, depression, epilepsy, neuropathic pain, schizophrenia, traumatic brain injury, and Alzheimer's and Parkinson's disease. Most recently he was also instrumental in the New Drug Application and Marketing Authorization Application submission and approval of medicines for asthma, chronic obstructive pulmonary disease, HIV, and cancer. Dr. Pande is a psychiatrist and fellow of several scientific societies. He began his career as a faculty member at the University of Michigan Medical School, where his research focused on mood disorders. He has published more than 50 peer-reviewed scientific papers and more than 100 abstracts, book chapters, and book reviews.

Katherine Prater is a Ph.D. candidate in the Neuroscience Graduate Program at the University of Michigan. Under the mentorship of Dr. Huda Akil, she is studying the brain mechanisms underlying individual differences in posttraumatic stress disorder acquisition. She is currently working in animal models and using molecular techniques to study the brain, but collaborates with other mentors who use fMRI to study human anxiety patients. Her main research interests involve a translational approach to anxiety research that allows a broader understanding of the underlying brain networks and cellular functioning in these debilitating disorders. Prater is also the co-founder of RELATE (Researchers Expanding Lay-Audience Teaching and Engagement), a combined training and service initiative to improve science, technology, engineering, and mathematics (STEM) graduate students' lay-audience communication skills. The inaugural RELATE workshop hosted 25 students from a variety of STEM disciplines. These trainees are currently engaging in lay-audience communication efforts around southeastern Michigan. Along with co-founder Elyse Aurbach, Prater hopes to influence STEM graduate education by providing professional development opportunities for candidate-level graduate students to positively impact the public's relationship with scientific research.

Indira M. Raman, Ph.D., is a professor in the Department of Neurobiology at Northwestern University, where she holds the Bill and Gayle Cook Chair in Biology. She completed her Ph.D. in neuroscience at the University of Wisconsin–Madison and postdoctoral training at the Vollum Institute and Harvard Medical School. Her research is in the areas of ion channel biophysics, synaptic transmission, and cerebellar physiology. From 2011–2014, she served as director of the Northwestern University Interdepartmental Neuroscience graduate training program, which unites about 150 faculty and 150 students in 20 departments in 7 schools of Northwestern. She has received awards for her teaching and scientific training of graduate and undergraduate students, including a Charles Deering McCormick Professorship of Teaching Excellence, the university's highest teaching honor.

Anthony Ricci, Ph.D., has a primary appointment in otolaryngology and a courtesy appointment in molecular and cellular physiology at Stanford University. He uses electrophysiological and optical tools to investigate the auditory periphery. He received a bachelor's degree in chemistry from Case Western Reserve University. He received his doctorate in neuroscience from Tulane University. Following a postdoctoral fellowship at the University of Texas and a second fellowship at the University of Wisconsin, he was hired to his first faculty position at the Louisiana State University (LSU) Medical School in New Orleans. As an undergraduate he taught STEM courses to underrepresented minorities in Cleveland. While in graduate school he similarly worked with both high school and college students, teaching STEM courses. At LSU he oversaw three basic neuroscience courses for incoming students while being a part of both the admissions and the curriculum committees. Since joining Stanford 8 years ago he has directed the neuroscience program boot camp course required of all incoming students, as a long-term member of the admissions committee, as a senior member of the program committee, as the programs representative to the Biosciences Committee on Graduate Admissions and Policy, as a first-year adviser, and most recently as the director of the training program. In addition to these efforts within the neuroscience program, Dr. Ricci has promoted science and education across socioeconomic groups by founding the Advance Summer Research Institute. It provides a transition time for incoming graduate students across all bioscience programs, enabling them to do an early research rotation, participate in workshops for professional development, and learn the skills needed to be a successful graduate student.

Jane Roskams, Ph.D., is executive director (strategy and alliances) at the Allen Institute. She previously directed the lab of brain repair at the University of British Columbia, is a professor in psychiatry and zoology, and is also serving as associate dean. Dr. Roskams previously completed fellowships in neuroscience and neuropathology at Johns Hopkins Medical Institutions and NIH. Her most recent research has focused on the contribution of stem-like cells to brain development and repair, and how DNA in the brain may be epigenetically rearranged to contribute to brain repair.

Terry Sejnowski, Ph.D., is a pioneer in computational neuroscience. His goal is to understand the principles that link brain to behavior. His laboratory uses both experimental and modeling techniques to study the biophysical properties of synapses and neurons and the population dynamics of large networks of neurons. New computational models and new analytical tools have been developed to understand how the brain represents the world and how new representations are formed through learning algorithms for changing the synaptic strengths of connections among neurons. He has published more than 300 scientific papers and 12 books, including *The Computational Brain*, with Patricia Churchland.

He received his Ph.D. in physics from Princeton University and was a postdoctoral fellow at Harvard Medical School. He was on the faculty at Johns Hopkins University and he now holds the Francis Crick Chair at The Salk Institute for Biological Studies. He is also a professor at UCSD, where he is co-director of the Institute for Neural Computation and co-director of the NSF Temporal Dynamics of Learning Center. He is president of the Neural Information Processing Systems Foundation, which organizes an annual conference attended by more than 1,000 researchers in machine learning and neural computation. He is also the founding editor-in-chief of *Neural Computation*, published by the MIT Press. An investigator with HHMI, he is also a fellow of AAAS and Institute of Electrical and Electronics Engineers. He has received many honors, including the Wright Prize for interdisciplinary research from Harvey Mudd College, the Neural Network Pioneer Award from IEEE, and the Hebb Prize from the International Neural Network Society. He was elected to the IOM and the NAS.

Michael Springer, Ph.D., is an assistant professor of systems biology at Harvard Medical School, where his research focuses on signal integration and evolution of signaling responses among yeast species. He has been heavily involved in teaching for over a decade. As a postdoctoral Fellow, Dr. Springer began teaching a short course on programming, image analysis, and modeling as part of the physiology course at Woods Hole Research Center (2004–2008). In 2010, professor of neurobiology Dr. Richard Born and Dr. Springer joined forces and expanded the course. The course is now a 5-day boot camp with four half-day review sessions. Ostensibly it is a programming course, but the programming component is designed as a foundation to discuss quantitative methods and reasoning and to introduce basic concepts in statistics, image analysis, and bioinformatics. Examples are focused around problems that students are likely to face in their own research. The course itself is taught using a number of active learning approaches. Dr. Springer received undergraduate degrees in biology and chemistry at Stanford University. He did his graduate work with Dr. Erin O'Shea at UCSF, integrating experiment and theory to study yeast phosphate homeostasis. During his postdoctoral work, conducted with Dr. Marc Kirschner at Harvard Medical School, he studied dosage compensation in yeast and developed high-throughput methodologies.

Oswald Steward, Ph.D., is known for his research on how nerve cells create and maintain their connections with each other, and how these synapses are modified after injury. He has also conducted research on how genes influence nerve cell regeneration, growth, and function and how physiological activity affects nerve cell connections. Dr. Steward is currently the chair and director of the Reeve-Irvine Research Center for Spinal Cord Injury at the University of California, Irvine (UCI), senior associate dean for research, and professor of anatomy and neurobiology. He serves on the board of the Christopher Reeve Paralysis Foundation and as the chair of its Science Advisory Council. Dr. Steward was also chair of an NIH neurobiology review group and served on NIH's Spinal Cord Injury Planning Committee. Prior to joining the faculty at UCI, he was a professor of neuroscience and neurosurgery at the University of Virginia, where he chaired the Department of Neuroscience.

Steward is a recipient of the NIH Research Career Development Award, the Jacob Javitz Neuroscience Investigator Award, and the Distinguished Investigator Award from the National Alliance for Research on Schizophrenia and Depression. He earned a doctorate in Psychobiology from UCI and a bachelor's in Psychology from the University of Colorado, Boulder.

Richard W. Tsien, D.Phil., is director of the Neuroscience Institute, Druckenmiller Professor of Neuroscience, and chair of the Neuroscience and Physiology Department at the New York University (NYU) School of Medicine. Prior to joining NYU in 2011, Dr. Tsien served as the George D. Smith Professor of Molecular Genetic Medicine at Stanford University. While there, Dr. Tsien founded and served as the inaugural chair of the Department of Molecular and Cellular Physiology. After a 6-year term as chair, in 1994 he co-led a successful Stanford-wide movement to establish an institute for neuroscience, the Stanford Brain Research Center, which he co-directed from 2000 through 2005. He served a 10-year term as the director and PI at Stanford's Silvio Conte Center for Neuroscience Research. As a scientist, Dr. Tsien is a world leader in the study of calcium channels and their signaling targets, particularly at pre- and postsynaptic sites. He studies how synapses contribute to neuronal computations and network function in both healthy and diseased brains. His research, generously supported by NIH and private foundations, has contributed substantially to understanding how neurotransmitters, drugs, and molecular alterations regulate calcium channels, and has implications for diverse clinical areas such as pain and autism. His research has been published in more than 200 peer-reviewed journal articles, and he has served on editorial boards for numerous journals. He has also served as section chair for AAAS (Neuroscience Section) and NAS (Neurobiology Section) and has been a member of scientific advisory boards for several institutes, including HHMI. In 2011, Dr. Tsien was awarded the Axelrod Prize by the Society for Neuroscience and was most recently awarded the 2013 Cartwright Prize by Columbia University Medical Center. Dr. Tsien received both an undergraduate and graduate degree in Electrical Engineering from MIT. He was a Rhodes Scholar, graduating with his doctorate in biophysics from Oxford University, England, after which he joined the faculty at Yale University School of Medicine and served for nearly two decades. He is a member of both the IOM and the NAS.

Douglas Weber, Ph.D., is a program manager in the Biological Technology Office at the Defense Advanced Research Projects Agency (DARPA). He is also an associate professor at the University of Pittsburgh in the Department of Bioengineering and the Department of Physical Medicine and Rehabilitation. At DARPA, Dr. Weber is currently managing the Reliable Neurotechnology (RE-NET), HAPTIX, and ElectRx programs. Dr. Weber received a B.S. in Biomedical Engineering from the Milwaukee School of Engineering and an M.S. and a Ph.D. in Bioengineering from Arizona State University. He completed postdoctoral training at the Centre for Neuroscience at the University of Alberta. He has published extensively in peer-reviewed journals and has mentored undergraduate and graduate students in bioengineering; medical students; and postdoctoral fellows. He is a member of the Society for Neuroscience and a senior member of IEEE.

Frank Yocca, Ph.D., is the vice president of Strategy and Externalization, and the Neuroscience Virtual Innovative Medicine Unit, at AstraZeneca R&D. He was formerly the vice president and head of CNS and pain drug discovery for AstraZeneca. Dr. Yocca received his Ph.D. in pharmacology from St. John's University in New York City. His work focused on the effect of antidepressants on circadian rhythms. Subsequently he was a postdoctoral fellow at Mt. Sinai Department of Pharmacology. Prior to joining AstraZeneca, he was executive director at the Bristol-Myers Squibb Pharmaceutical Research Institute. Dr. Yocca originally joined the Bristol-Myers Company in 1984 as a postdoctoral fellow in CNS research. Using techniques he learned from his academic postdoctoral position, he helped to elucidate the mechanism of action of the anxiolytic drug Buspar. He then joined Bristol-Myers and made significant advances in understanding the physiological role of the 5-HT1A receptor and its role in psychiatric disease states. During the 21 years Dr. Yocca spent with Bristol-Myers and then Bristol-Myers Squibb, he supported a number of psychiatric discovery programs, helping to discover and develop the antidepressant drug Serzone. Throughout his tenure, Dr. Yocca continued to work in the field of serotonin and advanced a number of agents to clinical trials, including several antimigraine agents (avitriptan) as well as antipsychotics and anxiolytics. In the latter stages of his career at Bristol-Myers Squibb, Dr. Yocca became involved in externalization and development. He contributed to the in-licensing and development of the antipsychotic agent Abilify. Additionally, Dr. Yocca was part of the externalization team that in-licensed to the recently approved antidepressant agent Emsam, the first antidepressant to be administered through a patch. In development, he was early development project leader for corticotropin-releasing hormone antagonists and was involved in phase IV clinical trials with Abilify. Dr. Yocca is a member of numerous scientific societies, including the Society for Neuroscience and American College of Neuropsychopharmacology.

Stevin Zorn, Ph.D., is executive vice president of neuroscience research for Lundbeck Research USA, for which he has been a board member since 2008. He is a member of Lundbeck's global research committee, development committee, R&D management group, and the R&D executive committee. His research focus is on discovering meaningful treatments to relieve suffering from both psychiatric and neurological diseases. He is currently leading Lundbeck's Disease Biology Unit on Neuroinflammation to discover breakthrough therapies for psychoneurological diseases. Dr. Zorn received a B.S. in chemistry from Lafayette College, and an M.S. and a Ph.D. in neurotoxicology and neuropharmacology, respectively, from the University of Texas Graduate School of Biomedical Sciences. Subsequent postdoctoral research studies centered on basic research of brain and intracellular neuronal signaling mechanisms at the Rockefeller University, New York, New York, in Paul Greengard's (Nobel Laureate) laboratory of molecular and cellular neuroscience. Prior to his current position, Dr. Zorn was with Pfizer Global Research and Development for nearly 20 years. His positions included head of General Pharmacology, Alzheimer's Disease Development Team leader, head of Psychotherapeutics Biology, head of Neuroscience Therapeutics, and co-chair of the global Neuroscience Therapeutic Area Leadership Team, with accountability for R&D as well as commercialization. In addition, he was vice president and Global Therapeutic Area Head for Central Nervous System Disorders Research at Pfizer. Dr. Zorn has extensive drug discovery and drug development experience across a broad range of neuro- and psychiatric disorders and across the whole value chain for drug discovery and development. He has co-authored more than 100 scientific research communications and patents and has contributed to the advancement of a wide variety of drug candidates. Several of these candidates, including the antipsychotic drug Geodon, which Dr. Zorn played a seminal role in discovering and developing, are now in clinical use.