Neuroscience Training for the 21st Century

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The field of neuroscience is enjoying a rapid expansion in scope, coupled with a remarkable broadening of conceptual approaches, scientific tools, and clinical applications. This growth poses new challenges for academic training programs as they prepare young neuroscientists for a more complex, competitive, and diverse career landscape. Multiple stakeholders, including academia, federal funding agencies, industry, scientific societies, private foundations, and other public and private sector contributors, need to be actively engaged in supporting this broad training effort. A renewed commitment to a more forward-looking, flexible yet integrative training vision offers opportunities for a bright future for young neuroscientists as they assume the role of vanguard of the enterprise that enriches our understanding of the brain.

Introduction

The brain is a remarkable piece of biological machinery that fascinates both scientists and the general public, while testing the limits of our ability to understand our own minds. Every facet of neural function requires intricate orchestration and ongoing fine-tuning and remodeling. Neural circuits exhibit an additional layer of integration that transcends the complexity of any given cell, with dynamic characteristics whose analysis requires sophisticated computation. It is not surprising that this machinery can malfunction in innumerable ways, leading to debilitating, sometimes devastating disorders across the lifespan. Thus, understanding the brain is both intrinsically fascinating and highly relevant to the well-being of humans and animals. It is often seen as the greatest challenge in the biosciences, possibly in all of modern science. Consequently, over the last two decades, the field of neuroscience has undergone a quiet revolution, redefining its boundaries beyond the biomedical sciences to incorporate knowledge and tools from physics, mathematics, and engineering, as well as the social sciences and the humanities.

The increasing integration between neuroscience and other scientific fields is having a major impact on the footprint of neuroscience both within and beyond the walls of academia. The influence of basic neuroscience research on biology and medicine continues to increase as advances in many areas are being translated into therapeutic approaches, including better tools for studying brain structure and function in health and disease; molecular analysis of receptors, ion channels, and broad molecular pathways; powerful approaches to examine and manipulate neural circuits; and more sophisticated electrophysiological strategies to monitor and modify neural function. Recently, there has been a trend to focus more resources in the pursuit of neuroscience research, as seen in a number of developments such as the Brain Research through Advancing Innovative Neurotechnologies (BRAIN) initiative (https://www.whitehouse.gov/share/brain-initiative) and research priorities seen in other countries (e.g., China Brain; Japan Brain/MINDS Project, http://brainminds.jp/en/; and the Human Brain Project in Europe, https://www.humanbrainproject.eu/). Moreover, there is an increasing need to communicate neuroscience information at all levels, from editing scholarly journals to educating the general public. On a national level, there is an ever-increasing need for informed regulators and policy makers.

The growth of the field, together with its commercialization of new products and services, will result in the expansion of career opportunities in the public and private sector, including bench scientists, entrepreneurs, analysts, consultants, and intellectual property experts. Given that the number of PhDs in neuroscience has risen much more rapidly than in any other field of biomedical research in the United States (see Figure 1), one challenge we must address is whether training programs are meeting the current and future workforce needs of the field. Clearly, we need to attract the best and the brightest from diverse backgrounds to take on the task of understanding the brain. The challenge before us is how to train and retain a talented work force to ensure a bright future both for neuroscience in general and for the individual young scientists entering the field. The discussion below focuses primarily on the landscape in the United States, although we would venture to guess that many of the same trends, challenges, and opportunities exist globally.

Developing the Expertise Needed to Advance Neuroscience in the 21st Century

In October 2014, the Forum on Neuroscience and Nervous System Disorders of the National Academies of Sciences,

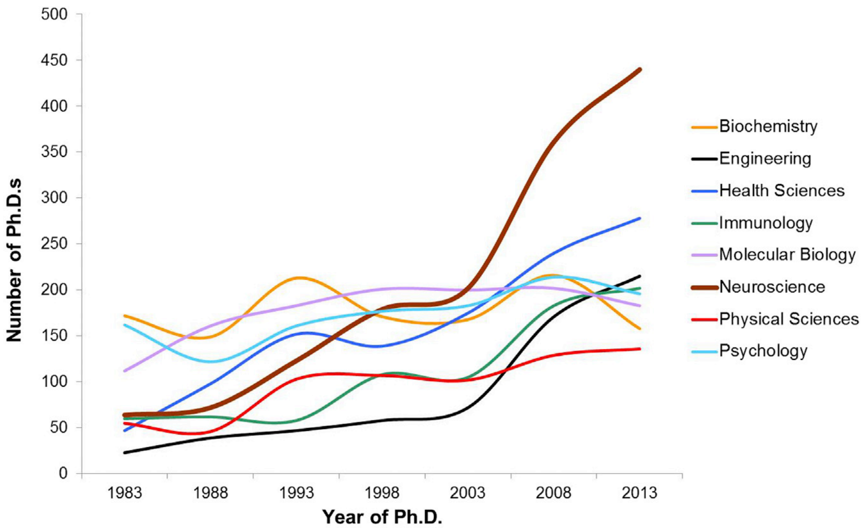

Figure 1. Trends in Fields of Study of Trainees and Fellows Receiving PhDs
Data taken from the NIH Office of Extramural Research (OER) Training and Advisory Committee June 2015 meeting on education and selected career outcomes of graduate trainees and fellows.

Engineering, and Medicine held a workshop on how best to develop the next generation of scientists to advance neuroscience (IOM, 2014). Neuroscience was characterized as fundamentally interdisciplinary and currently in a stage that requires greater incorporation of computational science, applied mathematics, and engineering. This raises two major challenges that are not new but are increasingly important: (1) how to best impart rigorous quantitative, analytic, and statistical skills required by emerging technologies among trainees in neuroscience, and (2) how to best integrate scientists from different disciplines into neuroscience.

Strengthening Experimental, Analytical, and Communication Skills

A challenge currently being addressed across the biomedical sciences is the need to improve the quality of published work. Improved training is probably the most important means to achieve this goal. A deep understanding of the statistical basis for interpreting experimental data needs to drive not only the analysis but also the design of experiments. Robust science requires rigorous experimental design, including blinded allocation to groups, blinded assessment of outcomes, prospective sample size calculations, and prospective accounting for exclusion of outliers. This is in particular true for animal experiments, but also applies to in vitro and cell-based experiments. Although a generic statistics course is commonly included in neuroscience graduate programs, very few programs include statisticians on their faculty. A more intensive and disciplined effort to improve the level of statistical reasoning and facility with statistical methods should be a high training priority for the future.

Data analytics have become increasingly complex, and to exploit these tools appropriately, training in areas such as programming, data management platforms, multi-dimensional cloud computing, data visualization and feature extraction, algorithm development, machine learning, and computer modeling may be valuable for neuroscience trainees. Current experimental approaches, such as gene expression arrays, deep sequencing, multi-electrode recordings, and image analysis, all produce large datasets that pose challenging analytical problems. The interpretation of these datasets demands more sophisticated quantitative skills to visualize complex, high-dimensional data and to perform appropriate statistical analyses. Moreover, many types of neuroscience data are not readily amenable to analysis by off-the-shelf software and thus require computational skills, including programming in high-level languages such as Python, "R," or MATLAB. The majority of our graduate students lack these skills, and it is essential that we revise our curricula to ensure that neuroscience students achieve competence in the area of computation and programming.

There are several potential points of intervention. Doctoral programs could require increased prerequisites in quantitative training on the part of applicants, especially in the area of statistics and programming. Additionally, individual programs should develop curricula to provide these necessary skills. Computational training can be jump-started by intensive instruction in a high-level programming language during pre-matriculation "boot camps," thus allowing subsequent core courses to incorporate quantitative exercises that build on and reinforce these skills. Students can also take advantage of a plethora of web-based resources, such as massive open online courses (MOOCs). It would be helpful to the neuroscience community if there were some level of coordination of such resources, for instance, through the Society for Neuroscience (SfN).

Students are coming to neuroscience graduate programs with ever more sophisticated science backgrounds. Though a major benefit, one casualty may be the communication and writing skills of the neuroscience trainees, in spite of the fact that these skills are critical for a successful career in science. As neuroscience coursework has become increasingly common in undergraduate curricula and more students are arriving in graduate school with experience in the field, the graduate course requirements are decreasing and students move on to laboratory work earlier in their graduate training. While a positive development, this may lead to students focusing on a specialized domain earlier and potentially lead to gaps in training. It will be important to track whether abbreviation of a broad-based neuroscience experience in graduate school adversely affects the ability of neuroscientists to interact across fields. Certainly, attention to key items such as grant-writing skills, laboratory and office management, ethics in science, fundamental neuroscience knowledge and its history, teaching, and mentoring are important for all neuroscience trainees. As important, however, is the ability to understand other scientific languages—for example, biologically trained neuroscientists should receive sufficient mathematical training to communicate with informaticians and

Box 1. NSF's Integrative Graduate Education and Research Traineeship Program

NSF's IGERT program was initiated in 1998 to address the need for a workforce of PhD scientists and engineers with interdisciplinary backgrounds. The IGERT program supported research-based graduate training programs that integrate research and education around an interdisciplinary theme and empower their trainees not only with deep knowledge and research skills in a major field but also with the ability, breadth, and depth of knowledge and skills to participate in cross-disciplinary collaborations that require teamwork. Since its inception, the IGERT program has made 278 awards and provided funding for approximately 6,500 graduate students. Studies of the impact of IGERT programs indicate that the dissertation research of IGERT trainees is more interdisciplinary than that of non-IGERT trainees in similar academic departments, and that over 75% of IGERT graduates report using two or more disciplines in their post-PhD positions (Carney and Neishi, 2010). Moreover, more IGERT graduates than non-IGERT PhD graduates were found to consider their graduate training programs as having prepared them well for research faculty positions at universities, and, in agreement with that perception, more IGERT graduates (75%) than non-IGERT graduates (63%) identified their primary job responsibility after graduation to be research (Carney et al., 2011). An added positive effect of IGERT programs is that they also foster interdisciplinary collaborative research and interdisciplinary teaching by participant faculty (Carney et al., 2006). Based on their analyses of past IGERT projects, Gamse et al. (2013) offer valuable insights about interdisciplinary graduate training programs in STEM (science, technology, engineering, and mathematics) fields, including core competencies for conducting interdisciplinary research, and the challenges faced by as well as the most successful aspects of interdisciplinary, team-science-promoting graduate training programs such as IGERT programs. The success of IGERT projects focused on neuroscience demonstrates that application of the IGERT concept to the field of neuroscience is not only feasible but also fruitful and may present a useful path for meeting emergent neuroscience workforce needs while both preserving academic rigor and offering trainees greater professional flexibility.

The IGERT program, whose last competition was held in 2013, helped lay the foundation for the NSF Research Traineeship (NRT) program, launched in 2014. Similar to the IGERT program, and as described in more detail below, the NRT program emphasizes interdisciplinary graduate research training.

computational scientists. In turn, computational neuroscientists must translate ideas conceptually as a means of communicating with colleagues with less mathematical training.

Fostering Transdisciplinary Training

The growth in neuroscience has necessarily led to the development of an ever-increasing number of subfields, e.g., molecular, cellular, systems, behavioral, and translational neuroscience. The deepening silos within neuroscience carry the risk of slowing scientific advancement. More deliberate attention to promote cross-fertilization and communication across neuroscience fields is necessary in the 21st century with teams of scientists with different types of expertise working together to attack problems that would never be solved with a single approach. Likewise, the tools available for neuroscience research have become increasingly sophisticated. There is a growing need to "demystify" these tools by imparting to trainees a working knowledge of the underlying principles of their operation. Students need to be required to think deeply about the limits and utility of new tools and analytical techniques, exploring outside their departments to learn from experts and developers of new technologies. Some graduate programs may choose to focus on promoting skills required for team science that promote cross-disciplinary approaches to addressing research questions (Stokols et al., 2008), with tracks that integrate trainees with backgrounds in the physical, engineering, and/or computational sciences with biologists, or that provide more intensive experiences in clinical neuroscience, technology development, data analytics, and other facets of neurobiology. These new directions pose challenges for neuroscience training programs, including (1) what additional disciplines to incorporate, (2) what level of competence in additional disciplines to train, and (3) how to teach these additional disciplinary competences as well as an understanding of and skill in team science. One potential solution would be for funding agencies that support graduate training programs, such as the NIH and the National Science Foundation (NSF), to encourage training programs in the neurosciences to incorporate in their curricula training in multiple disciplines. NSF's Integrative Graduate Education and Research Traineeship (IGERT) program may present a useful model (see Box 1).

Basic research is the foundation of the entire neuroscience enterprise. At the 2014 workshop hosted by the Forum on Neuroscience and Nervous System Disorders, several participants highlighted the importance of trainees who pursue careers in this area and for training programs to incorporate such training into their core courses. Equally important is enabling the process by which basic science discoveries add fundamental knowledge to the field and inform solutions for disabling neurological and psychiatric conditions. The process requires a cadre of investigators with a deep understanding of the complexity of the clinical disorders to engage in the very substantial research efforts on the neurobiology of disease. Building venues for mixing of basic neuroscience and clinical neuroscience training could promote translational potential of trainees from both the clinical and medical fields. The actual development of therapies or diagnostics that improve care of patients is as complex as any other field in neuroscience. For those interested in translation, special training is critical to avoid dedicating time and effort into "pseudo translation." Training in teams that include biotechnology or industry partners, clinicians, patient advocates, experts in regulatory affairs, and bioethicists, among others, would foster more successful translation from the bench than in the past. The increasingly transdisciplinary future of neuroscience makes it difficult for any given program to excel in all these facets of training, and programs need to build their curricula to take

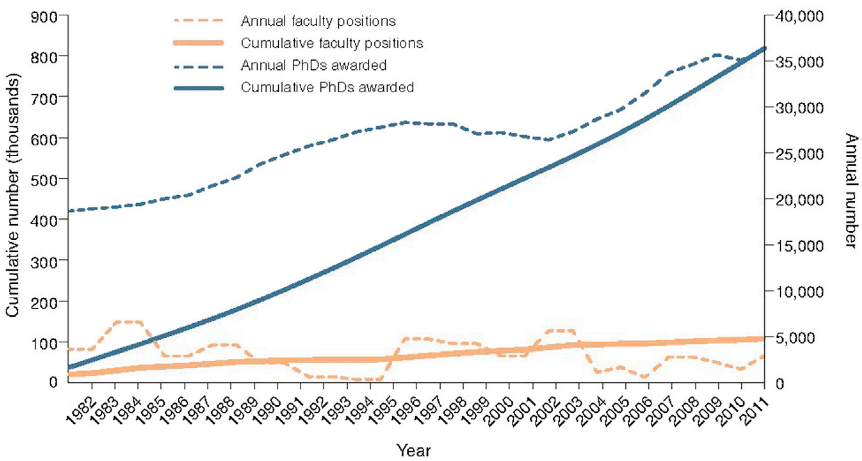

Figure 2. New Faculty Positions versus New PhDs
Since 1982, almost 800,000 PhDs were awarded in science and engineering (S&E) fields, whereas only about 100,000 academic faculty positions were created in those fields within the same time frame. The number of S&E PhDs awarded annually has also increased over this time frame, from ~19,000 in 1982 to ~36,000 in 2011. The number of faculty positions created each year, however, has not changed, with roughly 3,000 new positions created annually. Reprinted by permission from Macmillan Publishers Ltd (Schillebeeckx et al., 2013).

optimal advantage of the strengths within their institutions and in the surrounding environment. There may be value in considering the existence of two major types of training programs: those that are geared toward the more traditional training "of neuroscientists," and new programs that train people from a variety of backgrounds "in neuroscience," an approach seen in other disciplines (see Gould, 2015).

Training for Different Career Opportunities

Students entering neuroscience have become increasingly aware of the challenging academic job market and the wide range of opportunities outside of academia. Whereas in the past, a non-academic career was viewed as "plan B," many students now entering graduate school are very receptive to the wide variety of available opportunities both within and outside of academia. It is the responsibility of neuroscience training programs to provide trainees with the tools, skills, and knowledge that enable the trainees to make effective contributions to the workforce. This includes informing students about the range of careers available to them, establishing supplementary curricular offerings tailored to different career paths, and providing internship opportunities. Equally important is the need to ensure that the academic enterprise continues to flourish and that young neuroscientists will have an opportunity to make critical future discoveries about the brain. A critical part of this effort should include appropriate mentoring; however, there is a concern that appropriate mentoring has suffered as competition for funding has become more acute and the demands of laboratory management have burgeoned (Barres, 2013).

Trends in Training Neuroscientists versus Available Future Academic Positions

Research at United States academic institutions is a primary engine that drives most innovation in the neuroscience space. Data and concepts derived from academia provide the backbone for private sector advances. However, the rapid increase in numbers of neuroscientists in training is not balanced by any such expected increase in future positions (see Figure 2 from Schillebeeckx et al., 2013, for science and engineering fields). In addition, academia has been slow to adjust its model for career advancement and employee satisfaction. Graduate students often express concern around pursuing an academic career path, a concern reinforced by many mentors frustrated by the funding situation and the challenging criteria for promotions and tenure. As a result of this sense of uncertainty, we are likely losing promising scientists from the academic career path.

Since 1983, a decreasing percentage of neuroscience PhD students planned to pursue postdoctoral training—training that is seen as a necessary step in securing an academic research position (see Figure 3). According to data in 2013 from NSF's National Center for Science and Engineering Statistics, 55% of neuroscience PhDs were in careers in academia 6–10 years post-doctorate, compared to 42% of those 11–15 years post-doctorate (see Figure 4). These numbers suggest that an increasing percentage of PhD students are working toward careers outside traditional academia. Two factors seem to underlie this trend: one is that these students recognize that future prospects for academic careers are declining, and the other is that non-academic careers (e.g., in publishing, public policy, and industry) are becoming more attractive and available. However, funders, academic institutions, and prospective PhD students need much better numbers regarding trends for both the demand (for example, the future availability of academic research positions or positions in the pharmaceutical industry) and supply (i.e., the "pipeline").

As a whole, academia needs to take a step back and understand what forces may be pushing people away from the academic career path and work proactively to address these issues in order to maintain the best and brightest scientists in the workforce. The vitality and research opportunities in neuroscience are enormous, and it is critical to ensure that other sources of funding are identified to compensate for some of the loss in federal funding. As in other industries, issues like employee engagement and empowerment should be seriously addressed, and changes implemented. Greater departmental and institutional support of promising scientists is needed to bolster early career advancement. There are many advantages to an academic career, including intellectual freedom, collaborations, access to world-class facilities, interactions with ambitious and talented colleagues, flexible schedules, and the ongoing thrill of creating new knowledge while continuing to learn and contribute to the greater good. These values should be preserved and supported, and trainees should be exposed to their existence and encouraged to contemplate them even in the face of some risk.

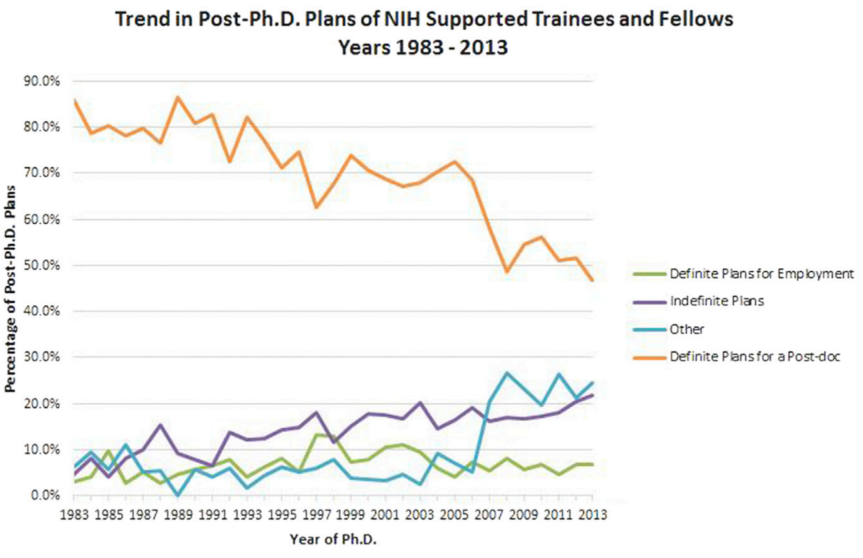

Figure 3. Trend in Post-PhD Plans of NIH-Supported Trainees and Fellows Receiving PhDs in Neuroscience from 1983 to 2013
Data taken from the NIH Office of Extramural Research (OER) Training and Advisory Committee June 2015 meeting on education and selected career outcomes of graduate trainees and fellows.

Opportunities for Careers outside Academia

The increasing number of neuroscience PhD students opting for careers not involving postdoctoral training (Figure 3) indicates that these students, now representing the majority, are preparing for careers outside of academic research. The depicted numbers do not include the subset of students who pursue postdoctoral training and still opt for non-academic careers. This shift in students' post-PhD plans raises the question as to whether current training programs are equipped and organized to provide adequate training for non-academic careers.

One problem is that current PhD training programs are operated by faculty scientists who typically have no experience in the non-academic careers to which many of their students aspire. An informal survey of chairs of medical neuroscience departments (this was run through the Association of Medical School Neuroscience Department Chairs, http://www.amsndc.org/) shows that the vast majority of neuroscience PhD programs have either already begun to expand their training scope to incorporate non-academic curricula or are discussing ways to do so. There are many examples of such efforts, including at institutions that have been recipients of NIH's Broadening Experiences in Scientific Training (BEST) award program (see Box 2), designed to expose students to research-related career options. Although graduate programs are taking a diversity of approaches to this challenge, there are common themes. Some of the salient elements of a non-academic career training program are as follows: (1) institutional legitimization of the students' pursuit of non-academic careers, (2) educating students about the range of career options, (3) preparing and mentoring students for their chosen career paths, and (4) tracking career outcomes.

These points can be illustrated using one example (among many) from Harvard's Division of Medical Sciences Paths program, which was established in 2011 to expose and mentor students seeking non-traditional academic careers (see Box 3).

The nation benefits from the PhD training of neuroscientists, both those in academic and non-academic roles. The experience students receive by successfully navigating a rigorous PhD program provides them with a deep understanding and critical perspective of research that cannot be obtained in any other way. Future PhD candidates who pursue careers outside of academia without such training will be without the basic foundation for evaluating and understanding research and the accompanying literature. And it can be argued that as neuroscience knowledge becomes more complex, we need to find the right balance between those who generate it and those who help translate it and apply it to many facets of life. We thus suggest that as training programs evolve mechanisms to incorporate non-academic career paths (e.g., training in neuroscience), they not abandon the core research training that currently characterizes PhD programs.

Career-focused curriculum offerings are going to continue to increase in importance in neuroscience training programs. These are still early times, and it is likely that many approaches will be tested before the most successful are identified. It will be important for programs to have a mechanism to facilitate the sharing of resources and reporting on best practices. It will be even more important for the neuroscience community to achieve a reasonable perspective concerning the future career landscape, including the types of available careers and the projected numbers of jobs. This information will be critical for career training and for considerations concerning the number of trainees who should be entering the field.

Addressing Diversity Challenges in Neuroscience

Importantly, we must also consider ways to improve the representation of women and diverse groups in neuroscience careers. In neuroscience and in other biomedical sciences, women outnumber men in graduate school programs but remain underrepresented in faculty positions. Clearly, the system is losing talented women neuroscientists who could be leading us into the next innovations. There is work underway to address this gender imbalance at NIH, NSF, and SfN, including the NIH's Working Group on Women in Biomedical Careers (https://womeninscience.nih.gov/), NSF's ADVANCE: Increasing the Participation and Advancement of Women in Academic Science and Engineering Careers program (http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5383), and SfN's Increasing Women in Neuroscience (iWiN) program. The NIH Working Group on Women in Biomedical Careers was formed in 2007 and serves

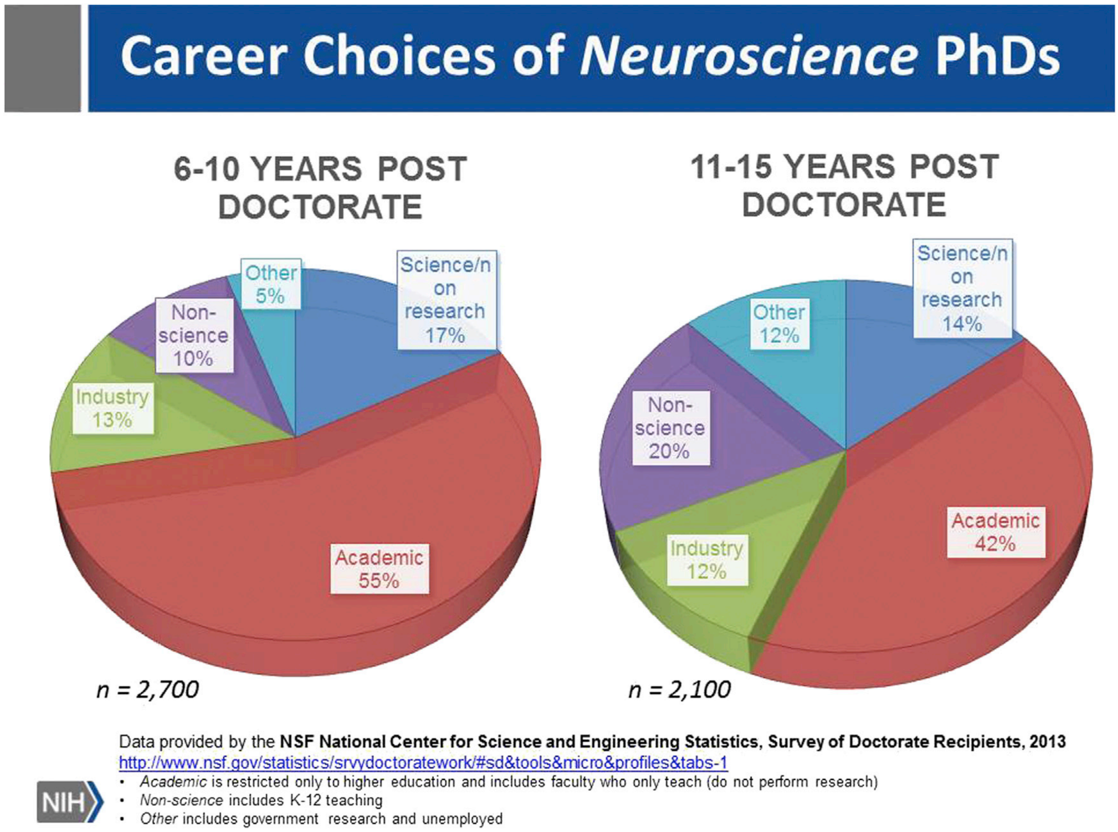

Figure 4. Career Choices of Neuroscience PhDs
"Academic" is restricted only to higher education and includes faculty who only teach (do not perform research), "non-science" includes K–12 teaching, and "other" includes government research and unemployed. Data provided by the National Science Foundation Center for Science and Engineering Statistics 2013 Survey of Doctorate Recipients (http://www.nsf.gov/statistics/srvydoctoratework/#sd&tools&micro&profiles&tabs-1).

as a trans-NIH effort that considers barriers for women in science and develops innovative strategies to promote entry, recruitment, retention, and sustained advancement of women in biomedical and research careers. Derived from recognition of the intellectual strength and value of a diverse workforce, the goal of NSF's ADVANCE program is to increase representation and advancement of women in academic science and engineering by supporting efforts aimed at transforming academic culture and institutional practices, policies, and structure. SfN's iWiN program is an example of one type of project supported by the ADVANCE program to provide opportunities for women neuroscientists and address challenges they may confront in the field. NIH and NSF also have underway various efforts to diversify the workforce by increasing the representation and advancement of underrepresented minorities in biomedical science. The National Institute of Neurological Disorders and Stroke (NINDS) "supports diverse individuals through general training programs as well as with targeted efforts to increase the number of scientists from diverse population groups who are prepared to pursue careers in neuroscience research" (http://www.ninds.nih.gov/diversity_programs/index.htm). Some examples include the Individual NRSA for Diversity PhD Students (http://www.ninds.nih.gov/funding/areas/training_and_career_development/pre-doctoral-fellowship.htm#f31c), the NINDS Faculty Development Award to Promote Diversity in Neuroscience Research (http://www.ninds.nih.gov/funding/areas/training_and_career_development/mentored-research-scientist.htm#k01), the NINDS Advanced Postdoctoral Career Transition Award to Promote Diversity in Neuroscience Research (http://www.ninds.nih.gov/funding/areas/training_and_career_development/mentored-research-scientist.htm#k22), and the NINDS Neuroscience Development for Advancing the Careers of a Diverse Research Workforce (R25) (http://www.ninds.nih.gov/funding/areas/training_and_career_development/institutional-programs.htm#r25). NSF encourages efforts that broaden participation in all of its training and core funding mechanisms through the agency's merit review criteria, and it promotes efforts at the institutional level through programs such as the Louis Stokes Alliances for Minority Participation (https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=13646), the Alliances of Graduate Education and the Professoriate (https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5474), and the recently launched Inclusion across the Nation of Communities of Learners and Underrepresented Discoverers in Engineering and Science (http://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsf16544). However, continued comprehensive and coordinated efforts with long-term impact are needed to address the systemic issue of insufficient diversity in academic science.

Box 2. NIH's Broadening Experiences in Scientific Training Awards Program

In March 2013, the NIH Common Fund program issued a funding opportunity entitled ''NIH Director's Biomedical Research Workforce Innovation Award: Broadening Experiences in Scientific Training (BEST)'' (http://grants.nih.gov/grants/guide/rfa-files/RFA-RM-12-022.html).The purpose of this funding opportunity is to ''seek, identify, and support bold and innovative approaches to broaden graduate and postdoctoral training, such that training programs reflect the range of career options that trainees (regardless of funding source) ultimately may pursue and that are required for a robust biomedical, behavioral, social, and clinical research enterprise.'' Currently, 17 institutions across the country have been awarded a 5-year, one-time NIH BEST grant, aimed at identifying and implementing bold and innovative approaches to broaden career and professional development for graduate and postdoctoral training. Each institution employs a unique programmatic approach—some include voluntary workshops for trainees, some are integrated into the core curricula as courses, while others are customized as ''BESTernships'' that offer full- or part-time experiences for trainees at industry labs, as well as in federal STEM policy and advocacy, regulatory, legal, government, and public affairs; innovation; and academia (http://www.nihbest.org/about-best/). Some examples include:

(1) Track-based training: Entrepreneurship and Business, Science Communication and Public Policy, Education and Outreach, Tech Transfer and Intellectual Property, Government and Nonprofit Research and Research Administration, and Biotech/Pharma Industry Research and Management.
(2) Education/course work: Science Policy Bootcamp, business as a second language, pre-seed workshop (identifies potential paths to commercialization of high-tech ideas), team building and leadership development, scientific and technical writing, drug discovery, networking, grant writing, time management, responsible conduct of research, regulatory science, clinical innovations, and communication to broad audiences such as policymakers, K–12 educators, and the general public.
(3) Internships/externships: experience available to graduate students and postdocs includes 160 hr internships that can take place as a 1 month full-time effort or part time over 2–3 months (at this point mostly paid by the institution), mostly at industry labs (Merck, Bristol Myers Squibb, Allergen, etc.) but also in Federal Stem Policy and Advocacy, Regulatory, Legal, Government and Public Affairs, Innovation, and Academia.

There are roughly 100 career development experts among the 17 sites, and the NIH BEST Coordinating Center works to develop, evaluate, and share challenges and best practices (Meyers et al., 2016).

Identifying the Roles of Each Sector for Supporting the Future Neuroscience Workforce

Academic Institutions

The vitality and future of neuroscience depends on the ability of the field to continue to attract, train, and nurture the brightest and most capable graduate students and postdoctoral fellows. In addition to representing the future of the field, this group forms the bulk of the laboratory workforce, which is the backbone of the research enterprise. It is therefore incumbent on academic institutions to develop alternative or complementary strategies for funding graduate training in the biosciences, as well as supporting the early careers of young scientists to include securing private funds and providing other opportunities for work relevant to career development. Besides these additional contributions from academia and the need for more robust and stable federal funding to support academic faculty positions in neuroscience, there are other changes that can be made to improve the allure of academic research careers.

One issue is the narrowness of options for students interested in academic research options. Currently, the only real model in the United States is to obtain a tenure-track faculty position depending largely upon being head of a laboratory. However, many students are vitally interested in research careers but find some of the negative features of running a laboratory, including dealing with constant funding pressures and an increased bureaucratic load, to be severely off-putting. A more attractive career option for these individuals would be one that encouraged them to do research in a role that supports an ongoing program run by others (e.g., a staff scientist; see Box 4). Such a career track, which is available in other scientific cultures (e.g., many European countries), would need to be developed, respected, and stably supported by United States academic research institutions. Overall, it is important for academia to correct the pessimistic view that many young scientists have developed toward a career path in academic scientific research. What is offered here are just a few ideas of what might be done to improve the attractiveness of research careers for forthcoming neuroscientists. The lack of clear options within an academic research career is already being discussed and confronted by many, if not most, neuroscience training programs, so it seems likely that many other potential solutions to this issue will be found. It is thus imperative that we find a means to track and evaluate various potential solutions and make such data available to the neuroscience community.

Another issue that poses a barrier for young investigators is the ''two-body problem.'' It is much more common now than in past decades for beginning investigators to be in a relationship with another career-minded individual, often another hopeful academic, which means that many such aspiring neuroscientists must find two positions, often leading to significant compromise or failure in career development. The two-body problem may be a particular challenge for women and may contribute to the leaky pipeline for female trainees. The challenge of dual-career couples may make it more difficult for women to secure their first faculty position and seems likely to be a major contributor to the large exodus of women from the pipeline between their postdoctoral and faculty levels. However, even for men, the two-body problem poses a barrier to career development. Academic institutions have been slow to recognize, much less address, this problem.

Box 3. Program Highlight: Harvard's Division of Medical Sciences Paths Program

Harvard's Division of Medical Sciences Paths program includes individual paths centered on career interests such as biotechnology, writing and editing, intellectual property, science policy, and consulting. Each path includes a student interest group, an associated set of courses, internship opportunities, and alumni mentors. Legitimization was achieved by making Paths an integral part of graduate education. This included giving the program official status, listing it on all program webpages, and awarding academic credit for career courses and internships. Faculty rapidly became supportive of these efforts, especially as they observed their students and postdocs struggle with an increasingly challenging academic job market. Students are exposed to career options through courses that survey the career landscape and through informational sessions sponsored by individual paths. Once a student has identified a career path, he/she engages in a variety of activities designed to position the student for a successful transition following graduation. This includes career-specific enrichment courses, focused extracurricular activities, alumni mentoring, and internship opportunities. Finally, career outcomes are tracked by maintaining close contact with alumni who have pursued these paths.

Career programs do not necessarily require a large influx of new institutional resources as there are economies that can be achieved by harnessing or repurposing current resources. Existing student organizations such as biotechnology and consulting clubs can be incorporated into the program. Enrichment course offerings are typically available from allied institutions including business, education, government, and public health institutions. The Paths program has experienced an exceptional level of involvement from alumni and local private enterprises. There is a genuine enthusiasm on the part of alumni to re-engage with the institution and to mentor students who wish to follow in their paths. They have been willing partners in offering career courses and networking events, and providing internship opportunities at minimal or no cost to the institution. Not surprisingly, the graduate students are the single greatest driving force behind these programs, and it is essential that they have a strong voice in directing these endeavors. The students are highly motivated to explore different career options and bring nearly limitless creativity and energy to the enterprise. For example, students in the biotechnology path established a course in healthcare innovation that is taught by biotechnology leaders, and students in the writing path created an open access journal, the Journal of Emerging Investigators, that encourages middle and high school students to pursue science through publication of their science fair projects.

The Private Sector

After a several-year period of decline, there has been renewed investment in neuroscience from pharmaceutical companies, startup biotechnology companies, and the technology sector (Google, Apple, etc.). Even though neuroscience research and development remains a risky proposition compared to other therapeutic areas, including oncology, cardiovascular disease, and metabolism, more than three billion dollars was invested in 2014 in companies developing drugs for neurodegenerative and psychiatric disease, more than in any of the last 10 years (Tracy, 2015). Although the unmet medical need for these and other CNS disorders remains high and is a strong commercial driver, ongoing investment is built on a foundation of advances in understanding of brain circuit function, disease genetics and pathophysiology, and the rapid development of technologies to monitor the brain and behavior in real time. Across the private sector, there is real promise of developing new, impactful treatments for patients who desperately need them.

Realizing the commercial potential of these investments requires a well-trained neuroscience workforce able to interact collaboratively in multi-disciplinary teams focused on advancing projects through the drug discovery pipeline, including in the many attendant areas of specialization that are a hallmark of end-to-end drug development (clinical, regulatory, commercial, partnerships, external opportunities, policy, etc.). Investment in training for neuroscientists by the private sector has increased in recent years. Many small, mid-sized, and big pharma have summer internship programs for undergraduates and offer lab rotation opportunities to graduate master's and PhD degree students, sometimes as part of a broader collaborative platform with individual academic institutions. Some companies offer postdoctoral training programs that recruit individuals that have met similar metrics of success as do academic principal investigators (PIs). During their training, industry postdocs typically pursue discovery work that is readily publishable, joining large collaborative teams that are a sine qua non of drug discovery. Whereas historically, molecular, cellular, and behavioral expertise were highly valued in neuroscientists applying for industry positions, the imperative to successfully translate findings to the clinic has seen increased recruitment of neuroscientists with circuits and systems, electrophysiology, and human biology and clinical expertise. Across the private sector, concerns with rigor, reproducibility, and robustness of research findings have raised awareness of the importance of training in experimental design, statistics and data analytics, responsible conduct, and research ethics. Postdocs that complete an industry training program are highly recruited for opportunities across the private sector, and there is a small but growing trend for neuroscientists who have completed industry postdocs to pursue positions in academia, where their drug discovery and translational experience makes them valuable future collaborators and external advisors for the industry, and valuable to academic institutions with burgeoning target validation, assay development/screening, and other drug discovery-relevant efforts. Because the private sector continually looks to partner with academia through pre-competitive consortia and other models, understanding how neuroscience is advanced in both arenas becomes a particularly valuable professional credential.

Societies and Patient-Advocacy Organizations

Well-funded and active philanthropic organizations, such as the Cure Huntington's Disease Initiative and the Michael J.

Box 4. A New Class of Academic Biomedical Scientists: The "Staff Scientist"

A new type of academic researcher, one that often is referred to as a ''staff scientist,'' would be a well-trained researcher who serves as a vital team member in a laboratory. Currently, the personnel of most laboratories are dominated by trainees: PhD students and postdoctoral fellows. Such trainees represent the bulk of the biomedical research enterprise in the United States. The faculty head of the laboratory thus oversees numerous trainees, and this is emblematic of the imbalance between the large training pipeline and the small endpoint of positions for those trainees. Another problem with this arrangement is lack of stability: trainees are involved with a given laboratory for only 4 years or so, meaning that long-range research programs must constantly deal with the upheaval of personnel changes. Alberts et al. (2014) deal with this issue as follows:

''We believe that staff scientists can and should play increasingly important roles in the biomedical workforce. Within individual laboratories, they can oversee the day-to-day work of the laboratory, taking on some of the administrative burdens that now tend to fall on the shoulders of the laboratory head; orient and train new members of the laboratory; manage large equipment and common facilities; and perform scientific projects independently or in collaboration with other members of the group. Within institutions, they can serve as leaders and technical experts in core laboratories serving multiple investigators and even multiple institutions.''

The creation of such positions would provide many more career opportunities for PhD students for academic research careers and thereby partially ameliorate the concern that too many PhDs are being trained given the predicted availability of future tenure-track faculty positions in institutions. To be attractive, such positions would need to be seen as reasonably stable and not, for instance, dependent on a given laboratory maintaining continuous NIH funding. This would require institutions to support such positions. As noted by Alberts et al. (2014), ''To succeed, universities will need employment policies that provide these individuals with attractive career paths, short of guaranteed employment.'' Funding and support for such positions already exist within the NIH intramural research program and are currently being explored by several institutions.

Fox Foundation for Parkinson's Research, and nonprofit organizations such as the Simons Foundation, have entered the arena and require individuals with high levels of neuroscience expertise and skill to advance their work. Such individuals hold senior leadership positions within those organizations and are critical players in helping to identify and manage potential research priorities. In addition, the Society for Neuroscience's Neuroscience Training Committee (https://www.sfn.org/About/Volunteer-Leadership/Committees/Neuroscience-Training-Committee) brings together individuals from many sectors to discuss topics and plan activities around neuroscience education, life-long learning, and workforce policy.

Funding Agencies: NIH and NSF

NIH institutes vary in the percentage of their budget devoted to training. The National Institute of Mental Health assigns approximately 7%–8% (http://www.nimh.nih.gov/about/budget/fy-2016-budget-congressional-justification.shtml), and NINDS 4%–5% (http://www.ninds.nih.gov/funding/ninds_funding_strategy.htm) to training, which includes Research Career Development Awards. NIH funds graduate and post-graduate neuroscience training with its traditional National Research Service Awards (NRSAs). However, the vast majority of neuroscience trainees are funded on R01s or other funding sources, and NIH has exercised very little influence on this training. The NRSA programs include fellowship awards to individual trainees at the predoctoral graduate school level or the postdoctoral level. NIH also funds two major types of institutional training awards: (1) multi-institute sponsored programs for broad-based neuroscience training in the early years of graduate school, and (2) institute-specific training programs usually for thematic neuroscience training of graduate students or fellows in specific areas of neuroscience. The latter would provide the flexibility to include creative solutions for the future of neuroscience training. For instance, the NIH Blueprint for Neuroscience (http://neuroscienceblueprint.nih.gov/) funds a number of training programs in computational neuroscience, and short courses in computational neuroscience are funded as part of the BRAIN Initiative.

NIH is also concerned with the growing and long training times before becoming independent scientists, and a number of programs, e.g., Pathway to Independence Award and Director's Early Independence Award, were created to shorten that time. In addition, NIH funds specific programs to promote diversity in the neuroscience workforce at the college, graduate, postdoctoral, and early-career stage. The neuroscience institutes and centers are currently planning to promote greater quantitative and experimental skill training in their jointly sponsored, broad-based institutional training award. The neuroscience institutes are also examining timing the award of fellowship grants to better empower trainees with their own funding to choose labs based on their interests as opposed to the funding situation of the PIs.

One of NSF's approaches to advancing the frontiers of science and technology is to invest in training of the next generation of scientists and engineers. Among the agency's current priority goals is STEM graduate student preparedness for entering the STEM workforce and pursuing productive careers in- and outside academia. NSF funds training at the graduate student level through its Graduate Research Fellowship Program (GRFP) (https://www.nsfgrfp.org/) and the NSF Research Traineeship (NRT) program (https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=505015). The GRFP provides fellowship support for individual master's and PhD students in science and engineering in the early stages of their graduate training and offers fellowship recipients the freedom to conduct research at any accredited United States institution of graduate education of their choosing. Additionally, the program provides mechanisms for fellows to enhance their professional development through international research collaborations and/or research internships at federal facilities and national laboratories. Different from the GRFP, the NRT program provides support for cohorts of graduate students by funding STEM education programs that emphasize innovative, evidence-based traineeship approaches in interdisciplinary research areas (Traineeship Track) and projects that test and validate innovative and potentially transformative graduate STEM education strategies (Innovations in Graduate Education Track). Similar to the IGERT program (see Box 1), the Traineeship Track promotes training and collaborative research that transcend traditional disciplinary boundaries, to enable trainees to bridge research areas and engage in cross-disciplinary team science. Furthermore, it encourages the development and implementation of training curricula that prepare students for multiple career pathways. As part of NSF's engagement in the BRAIN Initiative and in recognition of the need for investigators skilled in developing and applying new technologies, complex data analytics, and theoretical frameworks to reveal the fundamental principles of nervous system function and complex behavior, a current priority area of the NRT Traineeship Track is "Understanding the Brain." NSF also funds Research Experiences for Undergraduates (REU) (http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5517&from=fund) by supporting REU Sites, programs that offer mentored participation in research for groups of undergraduate students through a single department and discipline or multiple departments that coalesce around a coherent intellectual theme, and by making REU supplements to an individual-investigator research award. In addition to these targeted programs, NSF invests in workforce preparation by supporting trainees at all levels, including the postdoctoral level, through a core research award made to individual investigators. Although the educational and research experiences embedded in core research grants are not organized around specific, strategic training goals, their quality and potential impact on trainee professional development are evaluated as part of NSF's merit review criteria.

Conclusions

The future of neuroscience rests in the hands of a new generation of scientists who are willing to confront and overcome the great challenges of the field. This new generation has grown in the midst of an unprecedented explosion in knowledge, technologies, data, and tools. These young scientists begin their training with great talent, know-how, curiosity, and enthusiasm. Moreover, our field is vibrant, exciting, and in the midst of a revolution that aims to integrate human knowledge across many levels of analysis. This should be the best of times for both the scientists and the field. The shared task of all the stakeholders—academia, government, industry, scientific societies, foundations, and other components of the private and public sectors—is to ensure that we do not kill this hope. Rather, we should work collaboratively to offer the thoughtfulness, flexibility, nimbleness, and necessary support that will ensure the success of this next generation of neuroscientists.

The rewards for a better understanding of the brain are difficult to overstate. Such knowledge will not only inform how we treat devastating brain disorders, but it will also alter our self-concept as humans and inform how we see and treat each other. The key step is to train and support the talented neuroscientists of the 21st century who will continue this exciting journey of discovery.

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