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The Traditional Training of PhDs Threatens the Technology Transfer and Entrepreneurship Pipeline While Innovative Programs Provide Unique Recovery Opportunities

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Abstract: The flaws in the training of PhDs in life science disciplines are impacting the state of academic biomedical science in the United States (U.S.) as well as the fate of PhD students and postdoctoral fellows. In the absence of sweeping changes to the U.S. graduate training model, these circumstances will degrade the pipeline of highly educated scientific innovators and entrepreneurs. To counter this, a wide range of unique programs are emerging with the objective of providing opportunities for PhDs to more easily transition into the job market, where they will be able to sustain and build innovation within the marketplace.

In this article, we describe the current challenges faced by emerging PhDs in the life sciences, address the negative implications of the existing training paradigm, and introduce some of the unique programs that will help PhD trainees be better prepared for the non-academic career paths that they are likely to follow. PhDs from all disciplines are key contributors to the innovations that drive technology transfer and entrepreneurship. As such, graduate programs should serve as the common training grounds for these individuals to gain the subject matter expertise, research experience, and vision needed to develop scientific advancements for the benefit of society.

Keywords: Careers, entrepreneurship, Innovative training programs, Jobs, PhD training, Research funding, Science PhD, Skill development.

INTRODUCTION

The current graduate training system in the U.S. continues to produce greater numbers of highly educated PhDs than there are faculty positions for which they have been trained [1]. The gulf between numbers of PhDs produced and the number of tenure-track positions available in any given year is widening; currently less than 10% of PhDs graduating each year will eventually find a tenure-track position [2, 3], and the trend is only worsening [4]. In the absence of available positions along the traditional academic path, these PhDs must then compete for a wide range of non-academic positions that often require a combination of capabilities, skills, and experience that they have not acquired through their graduate training programs. This problem is compounded by the often unspoken stigma against highly educated early career scientists who have not yet demonstrated that their academic credentials will translate into high performance and a good fit in a non-academic role.

Unless PhD training is transformed so that PhDs emerge well prepared and competitive for the positions available to them, we propose that the future of the research enterprise is in danger. In the absence of transformative change to the graduate training paradigm, the current situation will worsen and its impacts will become more far reaching. Emerging postgraduates will continue to struggle to find employment in their professional disciplines, while employers will face greater challenges in finding the talent they need. If left unchecked, this disconnect will damage our country's knowledge economy and could greatly decrease academic-based technology transfer and entrepreneurship activities. For example, suboptimal employment of PhDs could reduce the productivity of academic-based innovation, which in 2012 and in the U.S. alone led to the formation of 705 startup companies, produced over 5,000 new patents, executed over 5,000 licensing agreements, and generated $2.6 billion in licensing income [5].

Solutions must include providing professional development training to equip PhDs with transferable skills (e.g., communication, leadership, business acumen, project management) in addition to the technical skills that are in high demand by employers in biotechnology and pharmaceutical job sectors. Importantly, professional development activities must enable emerging postgraduates to obtain the broader perspective (e.g., the economic and social context of scientific research) that is generally lacking in their graduate training environment. To achieve this, several barriers faced by PhD trainees must be overcome.

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Science PhD trainees typically don't have access to the kinds of opportunities that are commonly used in other career tracks to provide trainees with applied learning experiences that will be directly relevant to their future employers. And even if they were available, many trainees would face tough obstacles to participation—to include resistance from university administrators and faculty, many of whom still carry the misperception that non-academic careers still represent an "alternative" path for PhDs. They will be further limited by the more understandable expectation that students and postdoctoral fellows will not have time for external training opportunities due to their full-time obligations under traditional research and training grants.

PROFESSIONAL COSTS BORNE BY EARLY CAREER SCIENTISTS

Universities rely on the labor of graduate students and postdoctoral fellows to conduct research, publish manuscripts, win grants, and teach. Although they serve a critical role in the mission of the university, they are sometimes used in ways that do not benefit their education and training. For example, we have seen trainees perform experiments for faculty and other researchers without the hope of sharing authorship on publications; write/co-write and obtain major grant applications without the ability of being listed as co-investigators, thus not receiving intellectual/academic credit for such activity; train other students only to have a faculty advisor take credit for the training; and be forced to be all-around laboratory managers, technicians, and administrative assistants. Additionally, expectations for completion of graduate programs and fellowships are often nebulous, and this uncertainty hinders trainees' ability to make the most of their PhD education and training.

More disturbingly, recent studies have revealed that academic science is set up as a winner-takes-all system, where a select few scientists dominate the publishing landscape, monopolize funding, and influence science labor policy [6, 7]. For example, Ioannidis and co-authors [8] found that only a small, elite fraction of scientists—usually the heads of laboratories or research groups—dominate publications in research journals, and concluded from their analysis that "the research system may be exploiting the work of millions of young scientists". Similarly, new faculty members disproportionately come from a small group of elite labs—labs where women are often under-represented—which suggests a very uneven landscape in an already hypercompetitive job market [9, 10]. These studies highlight the fact that the current system incentivizes universities and faculty members to use cheap trainee labor in order to sustain the research enterprise, and indicate that the system only "offers" career success to a select group. This situation is unacceptable and unethical.

FINANCIAL AND PERSONAL COSTS BORNE BY EARLY CAREER SCIENTISTS

PhDs coming through the current graduate training system are suffering tremendous financial and personal costs. Financially, trainees are expected to work long, hard hours for little pay. Because their positions are not permanent, PhD students and postdoctoral fellows often have to move every few years—with all the costs that moving entails [11, 12]. Trainees have poor benefits (e.g., minimal health insurance and no retirement plan). They sink themselves deeper into debt [13] under the erroneous belief that they are investing in their future, and that once they land a tenure-track position, they will be able to repay the debt. But the truth is that the vast majority of PhDs will *never* land a tenure-track position. Yet for many, the sunk financial and emotional costs of leaving the system after years of investment are too much to bear, and because their sense of success and self-worth is so inextricably tied to the goal of a tenure-track job, trainees remain trapped in this system [14]. We can only conclude that going to graduate school and pursuing a research career is becoming not an investment in one's future, but rather, a luxury—one that may be financially unaffordable to most.

In addition to the financial burden, trainees also bear tremendous personal costs [15]. Because they move so frequently—and to the few places where the scarce jobs happen to be—academics must often find partners who are willing to move with them to remote locations. Dual-academic couples face the two-body problem. Even if an academic is lucky enough to find a partner who is willing to follow them to the next job (while accumulating debt in the process, and without the prospect of ever making a large salary comparable to that of a lawyer or medical doctor), the struggles do not end there. Women delay starting families and having children until they have more stable employment (i.e., tenure-track positions), which sometimes comes too late. However, if women opt to have children during their trainee years, they have little money to support themselves—let alone a dependent—and pay a high "baby penalty" which harms their career prospects [16]. Last but not least, many trainees suffer culturally-accepted damage to their physical and mental health [17].

So we ask, how can early career PhDs be better prepared for the job market in a way that is not as costly—both personally and professionally—as the current PhD education and training system?

What if PhD training was better aligned with the skills most sought after by employers? What if institutions offered courses that trained students with both "hard" and "soft" skills much needed by employers outside of academia? And what if these institutions did a better job of connecting students with early work opportunities (e.g., internships, externships, fellowships)?

RESOURCES FOR PHD TRAINEES

A number of career-related websites and other resources have been developed over the past few years to more broadly share information about non-academic career paths and opportunities for new PhDs, and to support their professional development while they are still completing their academic training. In addition to the various PhD career-oriented informational websites that have been established by individuals and groups with related interests (e.g., www.phdcareerguide.com, www.versatilephd.com, www.phds.org, to name just a few), there has been some progress in

establishing more standardized career planning tools and processes for PhD trainees. A key example is the Individual Development Plan (IDP), and specifically the myIDP career planning tool on the *ScienceCareers* website, which is based on the Federation of American Societies for Experimental Biology's (FASEB) IDP for postdoctoral fellows. Many academic institutions now require their National Institutes of Health (NIH)-supported biomedical PhD trainees to complete an IDP, under the direction and guidance of their faculty advisors. Similarly, the National Science Foundation (NSF) requires that grant proposals requesting funds to support postdoctoral fellows include a "postdoctoral mentoring plan" to outline the career development activities for the trainee.

The IDP initiative is a valuable first step in prompting and enabling biomedical science trainees to proactively evaluate their skills, interests, and career objectives, and to develop specific goals for career planning and preparation while they are still in graduate school. And the NIH deserves credit for helping to drive it, by strongly encouraging funded institutions first to develop policies employing IDPs for all NIH-supported trainees, and then to report on their progress as part of their annual Research Performance Progress Reports. But there are obvious limitations to both the overall effort and the utility of IDPs to trainees. Many of these limitations are introduced elsewhere in this article, but two of the most prominent are as follows: [1] university faculty are generally ill-equipped to provide guidance, through the IDP process, on professional development for career paths with which they have little to no experience, and [2] once trainees develop an IDP, they are still left largely on their own to acquire the additional training and perspective they will likely need to enter (and succeed) in those career paths.

Both of these limitations rest squarely in the sights of SciPhD (www.sciphd.com), a Maryland-based company which offers a number of professional development services to individuals and universities. Founded by executives who have spent their careers successfully navigating the intersection of business and science, SciPhD helps prepare scientists for non-academic careers through self-assessments, resume and interview prep programs, group workshops and bootcamps, and custom certificate programs. The company's workshops and programs have been delivered at dozens of universities, medical schools, and science academies across the country. SciPhD's array of services can support individuals and academic programs in developing the training, skills, and perspective needed for success in industry. They provide course work and training in critical areas such as communications, leadership, negotiation, team building, networking, and project management—all of which are essential to technology commercialization and entrepreneurship but are not directly emphasized through the traditional academic training model.

The unique professional development and training opportunities available through organizations such as SciPhD are undoubtedly valuable to PhD students and postdoctoral fellows, filling key gaps in their training experience and helping to prepare them for the challenging transition from academia to other job sectors. But how does all this preparation address what many say is the key ingredient for obtaining a non-academic position—real, live industry experience—along with the broader perspective that comes with it? Most new PhDs seeking to transition out of academia now face this unfortunate Catch-22: they aren't marketable for non-academic positions unless and until they have work experience, and they cannot get the work experience that will make them marketable for non-academic positions. One of the unique aspects of SciPhD's programs is how they relate industry's business process to the scientific method, which helps to demonstrate how many "industry-obtained skills" are actually experienced during PhD trainees' academic training. The bigger issue is that scientists are not trained to recognize or emphasize these "business" skills (e.g., collaborating across labs, leadership, teaching and mentoring students, supervising, managing budgets, and using essential project management skills), and are therefore left only to emphasize their excellent scientific accomplishments. This limitation just perpetuates the myth to potential hiring managers that PhD trainees don't have these skills, resulting in their looking elsewhere for new talent. By recognizing the importance of business and soft skills early in their graduate and post-graduate education, trainees are encouraged to look for opportunities to further develop these skills through real experiences and accomplishments that demonstrate a level of mastery. This is the final critical piece. Without accomplishments, an otherwise impressive resume will likely be rejected in favor of candidates who have proven through experience that they have all the required skills; not just scientific, but business and social skills as well.

INDUSTRY-FOCUSED GRADUATE PROGRAMS AS POTENTIAL MODELS FOR PHD TRAINING

Advancements in the biotechnology, pharmaceutical, and health care sectors are increasingly cross-disciplinary in nature. The path to commercialization and societal benefit typically involves extensive, long-term research and development collaborations among multiple organizations, as well as complex business strategies for navigating the challenging funding and regulatory environments that surround the innovation pipeline. These circumstances further diminish the relevance of the traditional academic research paradigm and the silos that typically exist within graduate and medical schools. They also make the graduate training model—with its focus on discipline-specific course work followed by several years of narrowly focused research—increasingly obsolete in the context of today's job market for PhDs.

Industry-specific and cross-disciplinary training needs have contributed to the rapid growth of the Professional Science Master's (PSM) degree, now available in numerous fields at universities across the country. The PSM is a relatively new but increasingly popular graduate degree that typically combines two years of academic training in an emerging or interdisciplinary scientific area with professional development opportunities such as internships and industry-focused team projects. PSM programs have been developed through collaborations between universities and employers to better prepare graduates with the workplace skills and perspectives that will be needed in their targeted career paths and industries. These programs clearly meet an important need, and a key component of their value

proposition is the fact that the PSM courses and professional development experiences are directly informed and supported by industry.

Although PSM programs do not address the academic-industry gap at the level of advanced PhD training in scientific research and innovation, they do provide some ideas that could translate into more relevant training approaches for PhD students and postdoctoral fellows. For example, one popular element of PSM programs is the use of an industry-driven case study model that allows students to work on collaborative team-based projects that will help them better understand the problems their future employers will need them to solve. Whereas internships, case studies, and team-based projects are the norm for students in advanced degree fields such as business, law, and medicine, they are completely absent from the typical academic training experience of PhD students and postdoctoral fellows in the life sciences. In addition to providing "real-world" project experience and perspective to PSM students, these activities also provide an opportunity for those potential employers to get to know the students and evaluate their capabilities and performance—and candidacy for future positions—while they are still training. And they can pave the way for students to obtain and excel in more substantive professional development experiences with partner companies, such as summer internships. Importantly, PSM programs help position graduates to more immediately and directly contribute to technology development and commercialization, by providing a wide range of meaningful training opportunities that merge scientific innovation and business needs.

The industry-focused courses, projects, and work experiences that are part of most PSM programs also serve the more basic purpose of making students aware of the various career paths and options that may be available to them when they graduate. This perspective is often completely absent for PhD students and postdoctoral fellows, who typically lack such visibility themselves and must rely on the narrowly focused training, guidance, and insights provided by faculty members who also have little to no experience outside academia. Unfortunately, these same circumstances also foster a lack of awareness about the significant challenges that postgraduates will face as they attempt to transition from academia. Many trainees do not recognize the implications of a tough job market, the continued decline of tenure-track positions, and the unspoken stigma against hiring scientists without industry experience until they are either unemployed or trapped in a "terminal" postdoctoral position.

INNOVATIVE PROGRAMS ARE RETOOLING PHDS FOR THE JOB MARKET

Several programs—from grassroots efforts organized by students to industry-focused initiatives and top-down efforts from federal agencies—are helping students and postdoctoral fellows transition to the non-academic job market.

Grassroots efforts to build connections and skills to the non-academic job market include a student-created nonprofit consulting firm, the Biotechnology and Life Sciences Advising Group (BALSA), aimed at providing industry experience to trainees [3]. In this program, trainees provide consulting services to their local university's technology transfer office and area companies and in return build real-world work experience and network connections while they are still in training. Similar programs have formed at the Medical College of Wisconsin (Postdoc Industry Consultants), the University of Pittsburg (Fourth River Solutions) and at the University of Michigan (Michigan Life Sciences Engineering Advising and Development). Students sometimes face resistance from faculty members and administrators for participating in these organizations, which is perhaps to be expected during a period of culture change in PhD training.

Some biotechnology companies have also capitalized on the opportunity to retrain and hire PhDs seeking careers in industry. One example is a course organized by the American Society for Cell Biology and the Keck Graduate Institute, sponsored by EMD Millipore [18]. The course trains interested postdoctoral fellows in the competencies scientists need to thrive in industry, and also serves as a recruitment tool for biotechnology companies. Unfortunately, most graduate students and postdoctoral fellows will likely still face obstacles to accessing and completing such courses in parallel with their core academic training requirements.

One of the founding objectives of Sciversify—a scientific recruiting firm based in the Research Triangle area of North Carolina—is to help create and facilitate internship and work opportunities for students and postgraduates. In addition to its traditional recruiting and staffing services, Sciversify works on a pro bono basis with local companies and other non-academic organizations to develop internships and externships, recruit and select candidates for these training experiences, and provide as-needed mentoring and support throughout the process. Although the opportunities are not restricted to PhD students and postdoctoral fellows, most of the individuals placed in internships and externships to date have either been recent postgraduates or students who are within two years of completing their graduate work. They have worked on projects ranging from a Small Business Innovation Research (SBIR) grant application for a biotechnology company's clinical diagnostic platform to a career resource database for a non-profit organization's science and technology business unit. The feedback from participants and host organizations about the value of these kinds of experiences has been very positive thus far, and Sciversify is continuing to explore ways to expand their reach and impact—for both trainees and industry partners.

As might be expected, progress in these efforts has been constrained by many of the same obstacles previously described for PhD trainees seeking to gain more industry-relevant experience. Although numerous advocates can be found on the university side—among both faculty and administrators—who recognize the unmet need for this experience, there have been mixed reactions to the prospect of students and postdoctoral fellows actually being able to participate in a part-time internship or externship without impacting their academic research projects. The question of whether and to what extent the trainees' grant funding dictates their ability to participate, even on their "own time" through flexible and remote work arrangements, also

continues to go largely unresolved. And despite the high level of interest that has been informally communicated by students and postdoctoral fellows, many are often still reluctant to talk with their advisors about specific opportunities to gain experience outside the lab. As such, the advisor's letter of support—which Sciversify typically requests from trainees who are selected for internships and externships—can dramatically reduce the number of individuals who are willing and/or able to apply.

The group is further narrowed to those who are also willing to sacrifice their own time to find, apply for, and participate in available opportunities while continuing to spend the long hours in the lab—often more than "full time" even without outside obligations—that are expected by their advisors and required to advance their research projects. Another factor that further limits the pool of eligible candidates is the need to select individuals who not only have the scientific expertise required for a specific project, but who also possess the non-technical skills and competencies to hit the ground running and get results for the host organization. This factor goes back to the unspoken stigma against PhD trainees who lack work experience, and to the Catch-22 they face in trying to acquire such experience. These and other challenges have limited participation to a small subset of trainees who both recognize the value of gaining additional experience beyond their academic training, and have open-minded advisors and relationships that enable direct conversations about their career paths and preparations. For initiatives like Sciversify's to be successful, they need to do more than just provide opportunities for trainees to gain this experience. Arguably just as important is the need to start changing the often-negative views held by potential employers about the capabilities, fit, and value of new PhDs in the non-academic workplace.

Initiatives such as BALSA and the internship efforts of Sciversify are relatively new, and the data on their overall impact is therefore limited. As such as data becomes available, it has the potential to help trainees, as well as federal agencies that fund biomedical research and training, to better understand and overcome the career development hurdles described in this paper.

THE NEED FOR GOVERNMENT LEADERSHIP TO CREATE FUNDING INCENTIVES ALIGNED WITH TRAINING GOALS

At a larger scale, the NIH has recognized that it is imperative to train students and postdoctoral fellows for non-academic careers. To this end, the NIH has created a grant program called Broadening Experiences in Scientific Training, or BEST. The program supports innovative approaches designed to broaden graduate and postdoctoral training to better prepare PhDs for a range of career options. Some have criticized the BEST program as a timid first step; the budget for the program is only $11 million over two years, out of the NIH's approximately $30 billion budget [19]. And although the program is intended to support the development of innovative training initiatives that can be shared across the university system, only 17 universities have received grants through the 2013 and 2014 award cycles. In spite of this additional funding incentive, universities are struggling to implement more broadly relevant training initiatives while continuing to operate within the constraints of their traditional grant frameworks. Additional guidance from the NIH and other federal funding authorities is needed to help university administrators and faculty create such opportunities and to establish policies that will avoid conflicts with their primary funding sources. Nevertheless, the existence of the BEST program indicates that federal agencies recognize the need to reform PhD education and training to ensure a solid future for biomedical research and innovation.

At the core of the challenges emerging from the NIH BEST Program and related initiatives is the as-yet unaddressed conflict between the traditional funding mandate of the academic research system and the need for fundamental change in the system's core training objectives. Traditional NIH grant funding to universities is primarily designed to support [1] basic research programs for the advancement of biomedical knowledge and [2] the training and development of the next generation of academic scientists. These two drivers are no longer aligned with either the current state of biomedical innovation or the career paths that are actually available to emerging postgraduates. This fundamental conflict must be addressed at the federal level by the NIH and other major funding agencies if universities stand a chance of making the dramatic cultural and structural changes needed to re-align their training programs with the realities of today's job market, which is increasingly driven by the rapidly evolving, cross-disciplinary landscape of biomedical innovation and commercialization.

Further, the Funding Opportunity Announcement for BEST grant applications notes that the program is not intended to fully train participants for new career options but rather to "prepare them for the next steps in their career development." So even for the small subset of PhDs who will have the opportunity to participate in unique programs like those developed under BEST grant funding, the question remains: how are they going to fully prepare for the career options that will actually be available to them? How will they obtain this preparation while surrounded by faculty with no experience in those career paths, and while completing their full-time research obligations under their advisors' traditional grant funding?

In addition to providing better guidance to universities on how to implement more broadly relevant training programs while working within the constraints of their traditional funding sources, federal funding agencies also need to explore ways to better engage the private sector in these programs. Federal agencies such as NSF, NIH, and others have clearly recognized the central role of universities in providing the foundation for scientific innovations—and the need to develop a pipeline to bring basic research findings to commercialization—as evidenced by their support of grant programs such as the Small Business Innovation Research, Small Business Technology Transfer, and Accelerating Innovation Research-Technology Transfer. These programs, however, do not have a training component, and could be augmented with training to help early career scientists develop the necessary expertise in entrepreneurship and commercialization.

The absence of industry engagement is one of the many limitations of the BEST Program, as universities receiving grant funding through the program are left to their own means and insights (or lack thereof) in building relevant training experiences and seeking inputs from the non-academic job sector. As such, they are again constrained by the fact that most faculty members and many university administrators have very limited non-academic experience, connections, or perspective. Some of the aforementioned efforts, such as Sciversify's facilitation of industry internships and externships for PhD trainees, can help to bridge this gap on a smaller scale and in specific geographic areas. But to make a significant impact across the academic training enterprise, the federal government should look for ways to more directly support and incentivize collaboration between academia and the private sector in the development of more relevant university-based training programs.

As anyone who has worked in or around Washington, D.C., knows all too well, driving change at the federal level is never fast or easy. A logical first step is to look for existing models that might provide ideas and lessons learned on government-funded and partnership-based approaches for enhancing the academic training paradigm. Along those lines, the United Kingdom's (UK) Cogent Group can serve as an interesting case study and a potential model for future programs in the U.S. Cogent is a private organization that receives funding through the Employer Investment Fund (EIF), managed by the UK Commission for Employment and Skills (UKCES), to operate the Cogent Sector Skills Council (SSC) as an employer-led, strategic skills body for the science industries. The Cogent SSC website outlines the following strategic objectives: [1] to have a pipeline of young people with the capability, drive and ambition to build a globally competitive science based industry in the UK, and [2] to support the development of the existing workforce to acquire the skills needed to adopt new technologies and innovate new products and services.

Cogent SSC implements several services to achieve these objectives, including a Technical Apprentice Service (TAS), the National Skills Academy for the Process Industries (NSAPI), and a Life Science Placement Service. The latter provides a unique and potentially valuable model for both enhancing the effectiveness of existing efforts—such as the BEST Program—and developing new initiatives that more directly focus on bridging the gap between academia and industry. Cogent's Life Science Placements Service aims to help universities and private organizations "develop tomorrow's scientists today" by facilitating the placement of undergraduates, graduates, and postgraduates in both short-term and extended work-training experiences with industry employers. It provides an array of services to both universities and employers, to include developing relationships and placement opportunities as well as managing the recruitment, selection, and placement processes. These services are provided at no-cost to universities and are subsidized to the employers through the UKCES-managed Growth and Innovation Fund.

Similar programs have been developed in the U.S. but they have generally been on a much smaller scale, with funding often coming through industry partnerships or, in at least one case, state government. For example, the North Carolina Biotechnology Center established an Industrial Fellowship Program (IFP) in 2008 to provide opportunities for emerging PhD scientists to obtain industry experience. The IFP provided 2 years of funding for selected participants to work as employees of North Carolina-based biotechnology companies, with their salaries and benefits being subsidized through the Biotechnology Center's funding from the North Carolina General Assembly. In addition to its unique funding source and cost-sharing structure, the IFP had a number of other elements that differentiated it from a typical postdoctoral fellowship program in government or industry. The program leveraged the Biotechnology Center's unique capabilities to deliver training programs in collaboration with its industry partners, providing a comprehensive support framework for the training, preparation, and future success of fellowship participants. The IFP Director served as a co-mentor for the fellows, providing guidance and assistance throughout the two-year experience and helping them prepare for their post-fellowship career searches. The IFP team at the Biotechnology Center also held numerous workshops and networking and coaching events that provided additional opportunities for fellows to gain industry exposure and perspective.

The IFP was quite successful by all measures: 23 companies participated in just the first five years, with 100% industry employment rates among fellows completing the program—often at the same companies that had hosted their fellowships. Despite this success, the program eventually fell victim to state budget cuts and was cancelled in 2013, although one final IFP participant is continuing in an industry fellowship that was established prior to the cuts and will extend through this year. The Biotechnology Center continues to operate an Industrial Internship Program for undergraduate and graduate students, with the participants to date being a mix of graduate students in business and the life sciences. These and other programs have attempted to chip at the problem at the state and local levels, but they will continue to struggle in the absence of expanded leadership, guidance, and funding at the federal level—all of which are needed to drive critical changes in the academic culture and university-based training paradigm.

CONCLUSION

The circumstances described in this article are not new [4, 20]. The disconnect between the expanding number of emerging PhDs and the rapidly declining number of tenure-track positions has been extensively documented, across a diverse range of disciplines, over the past several decades. And the key premise that PhD students and postdoctoral fellows are trained too narrowly has been just as widely promulgated. The associated shortcomings in their preparedness and competitiveness for non-academic careers have been made increasingly apparent over the past several years, largely as a result of the constrained funding environment and the challenging overall job market. There is no longer a basis for debate on whether these problems exist; the important questions relate to what is being done to address them, and how we can drive more rapid and significant change in the doctoral training system. The emergence of programs such as the NIH BEST grant

initiative provide signs of recognition at the federal level that the system is broken. And this article has described a number of other initiatives—at the grassroots and university levels and through private sector collaborations—that are specifically designed to make the PhD training experience more relevant and valuable to the next generation of scientists, innovators, thought leaders, and entrepreneurs.

So how do we reinforce and expand these efforts, and what will happen if we are not more successful in the next ten years than in the past decade? First, it is important to have a clear understanding of the scope and severity of the situation, as well as its broader implications. The reality is that tens of thousands of PhD students and postdoctoral fellows are being trained for career paths that are on the verge of extinction, and most are left unprepared for the paths they will ultimately take. The academic tenure-track—long viewed as the "traditional" career path for PhDs—is now restricted to a very small subset of the large postdoctoral pipeline, whereas non-academic careers—historically viewed and criticized as "alternative" paths—are now the only options available to most new PhDs. And unfortunately, new PhDs are forced to fight what is often a long and difficult battle for obtaining non-academic jobs, as they lack not only industry-relevant training and skills but the non-academic work experience that many employers require. New PhDs find themselves in unfortunate circumstances that will prove increasingly detrimental not only to themselves but to the overall advancement of science, technology, and innovation for the benefit of our society. Many early career PhDs will continue to push through several years of postdoctoral training, with the hopes of either building up their CVs and publication lists to the point of potentially becoming competitive for tenure-track faculty positions or eventually gaining enough relevant experience to land a non-academic position. Some will be forced to follow the jobs one way or another, by changing fields, relocating to areas with stronger job markets, or for international trainees, returning to their home countries. Each of these scenarios will contribute to a growing "brain drain" and the associated losses in knowledge, human capital, and opportunity for the areas where they have completed their doctoral training.

Meaningful efforts to reverse these trends also require careful analysis of the various contributing factors to the flaws in the current system. Although it is an oversimplification to say that, "it all comes down to money", funding is unarguably a core issue, and its roles in sustaining a broken graduate training system are particularly evident in the biological and biomedical sciences. The NIH is the source of the vast majority of academic training and research grant funding across the life science disciplines. This funding is explicitly intended to support the education and/or the research efforts of the next generation of academic scientists. And it creates an inherent conflict between the mandate for grant-supported trainees to conduct full-time academic research and the rising need for those trainees to gain skills and experience that are relevant to the non-academic career paths that they will likely have to pursue. Even the NIH BEST Program—which is designed to promote non-academic career development—does not directly address this conflict, other than to provide the direction that BEST grant-supported training opportunities and experiences should not increase the participants' time to degree or postdoctoral period.

The grassroots, university-driven, and partnership-based approaches introduced in this article are great first steps, but a more comprehensive solution will require strong leadership and fundamental change at the federal level. Federal and state governments should actively engage employers in non-academic sectors and incentivize them to provide opportunities for work experience to trainees in graduate programs. For the long term future state of the technology transfer and entrepreneurship pipeline, we hope that federal agencies responsible for research funding policy will address the issues in scientific research and graduate training before it is too late. It would be a shame—and a waste of the federal money currently used to train young scientists—to lose countless talented PhDs to employment that does not make the best use of their skills and training.

CONFLICT OF INTEREST

Steve Greenbaum is a Managing Partner at Sciversify.

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