BURROUGHS WELLCOME FUND

EARLY CAREER OUTCOMES

from the Burroughs Wellcome Fund's
Institutional Awards at the Scientific Interface

ADVANCING BIOMEDICAL SCIENCE BY SUPPORTING RESEARCH & EDUCATION

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BURROUGHS WELLCOME FUND

ABSTRACT

Purpose

In 1996, the Burroughs Wellcome Fund (BWF), an independent private foundation, identified the interface between biology and the physical, mathematical, computational, and engineering sciences as an area ripe for innovation and in need of unique talent. BWF has addressed this need in two ways: first, by investing in 10 interdisciplinary training programs based in U.S. academic institutions, in three rounds of awards between 1996 and 2000, called Institutional Awards at the Scientific Interface (IASI). Next, once the establishment of these 'habitats' was conceptualized and catalyzed, the Fund shifted its ongoing investment to individual awards targeted at the postdoc-to-faculty transition, Career Awards at the Scientific Interface (CASI), which has supported 123 individuals from 2002 through the present. This report measures the impact of the IASI training programs, as of 2007, on the early careers of the recipients whom the programs supported as graduate students or postdoctoral fellows.

Methods

In 2007 and 2008, we asked program alumni to submit curricula vitae (CVs) with full training, employment, publication, and funding details. We also collected demographic data on program participants and on institutional changes during the funding period from annual progress reports for the years 1997 until 2008.

Results

Based on a 60% response rate, we were able to evaluate early career outcomes for 152 program alumni who had received a Ph.D. by August 2007. Of the 92 who had entered the workforce by 2007, 75 (82%) were employed in academia. Of those 75, 60 (80%) had tenure-track faculty positions, and 34 (45%) were primary or co-investigator on at least one National Institutes of Health (NIH) grant. In addition, 67 (96%) of the 70 whose publications the authors could evaluate had at least one interdisciplinary publication among their five most recent. Program participants who had received their Ph.D. in 2001-2003 were more likely than the earlier cohorts to enter the workforce without postdoctoral training. Funded institutions reported institutional changes including new curricular emphases in graduate programs, interdisciplinary faculty hires, and acquiring support from other funding sources.

Conclusions

There are few other data on outcomes of intentionally interdisciplinary training programs, thus these results present an early baseline rather than a comparative evaluation. The data suggest that interdisciplinary training can produce scientists who are competitive in their ability to move into tenure-track faculty positions.

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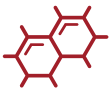
INTRODUCTION



Providing individual, high-prestige awards to promising young scientists has long been BWF's trademark strategy.

In the mid 1990s, the interface between biology and the physical, mathematical, and computational sciences was an area ripe for advance, as the flood of genomic, protein, and cell signaling data into biology and the concurrent development of new technologies created unprecedented opportunities to model, measure, and understand cellular phenomena and biological systems. At the time, very few institutions offered cross-disciplinary training that intentionally brought physical scientists, mathematicians, and engineers into biology. The language and culture barriers separating these disciplines were significant, and a concern persisted that 'interdisciplinary' scientists would be at a competitive disadvantage in establishing academic careers and procuring research funding. Furthermore, the need to provide adequate depth of training in multiple disciplines[1, 2] seemed at odds with calls to shorten the path to scientific independence by limiting the time spent in training.[3-7]

The Burroughs Wellcome Fund (BWF),[8] an independent, private foundation whose mission is to support the advancement of biomedical science, identified the interface between biology and the physical, mathematical, computational, and engineering sciences as an area in need of innovation and unique talent. BWF has addressed this need in two ways: first, by investing in 10 interdisciplinary training programs based in U.S. academic institutions, in three rounds of awards between 1996 and 2000 called Institutional Awards at the Scientific Interface (IASI). Next, once the establishment of these 'habitats' was conceptualized and catalyzed, the Fund shifted its ongoing investment to individual awards targeted at the postdoc-to-faculty transition; these Career Awards at the Scientific Interface (CASI) have supported 123 individuals from 2002 through the present. Indeed, providing individual, high-prestige awards to promising young scientists has long been BWF's trademark strategy.

This report measures the impact of the IASI training programs, as of 2007, on the early careers of the recipients whom the programs supported as graduate students or postdocs. The Fund viewed the 10 IASI programs as 'social experiments' that took students and fellows with backgrounds in physical sciences, mathematics, or engineering, and helped train them to tackle biological questions. The Fund required IASI programs to have two co-directors, one from the biological sciences, and one from physics, mathematics, chemistry, or engineering. Funds were intended to primarily support stipends for graduate students and postdoctoral fellows, but could also be used for faculty

seed grants, community-building events such as retreats and seminar series, and program administration. Trainee stipend funding was not tied to one department but meant to promote trainee independence and the ability to belong to more than one research group. Dual mentors were strongly encouraged. The Fund expected programs to provide opportunities for trainees to present their work to mixed audiences to hone their communications skills. With no other prescribed structure, the BWF asked programs to invent ways of addressing the significant language and cultural barriers among these fields, creating 'habitats' in which young scientists could flourish and grow comfortable working through interdisciplinary barriers.

Through the IASI program investment, BWF aimed to achieve two goals: First, to create a cadre of young scientists who would launch careers in interdisciplinary research; second, to promote institutional change, as measured by the sustainability of the interdisciplinary 'ecosystem' within the funded institutions. Here we describe the progress of the IASI program toward these two goals, at the point in time at which the BWF funding for these programs ended.

There is little evidence on the outcomes of intentionally interdisciplinary training, measured by the length of time spent in training, movement of program alumni into permanent positions and research careers, their success in obtaining federal funding, and the nature of their early career publications.

This report measures the impact of the IASI training programs, as of 2007, on the early careers of the recipients whom the programs supported as graduate students or postdocs.

METHODS

The Institutional Awards at the Scientific Interface (IASI) funded 10 training programs across the U.S.: four beginning in 1996, two in 1998, and four in 2000 (Table 1). The duration of funding was five years, Each program was granted five years' funding, with two of the programs receiving supplements for an additional two years. Each program submitted an annual progress report during the funding period, which included a narrative and data on institutional changes compiled by each program director. The reporting process also requested trainees to submit information on their training backgrounds and scientific accomplishments, via a web-based questionnaire. We informed all participants that their responses would be used in outcome evaluations, and that all data would be presented in aggregate; their individual identities would not be disclosed in any dissemination of results.

The Institutional Awards at the Scientific Interface (IASI) funded 10 training programs across the U.S.

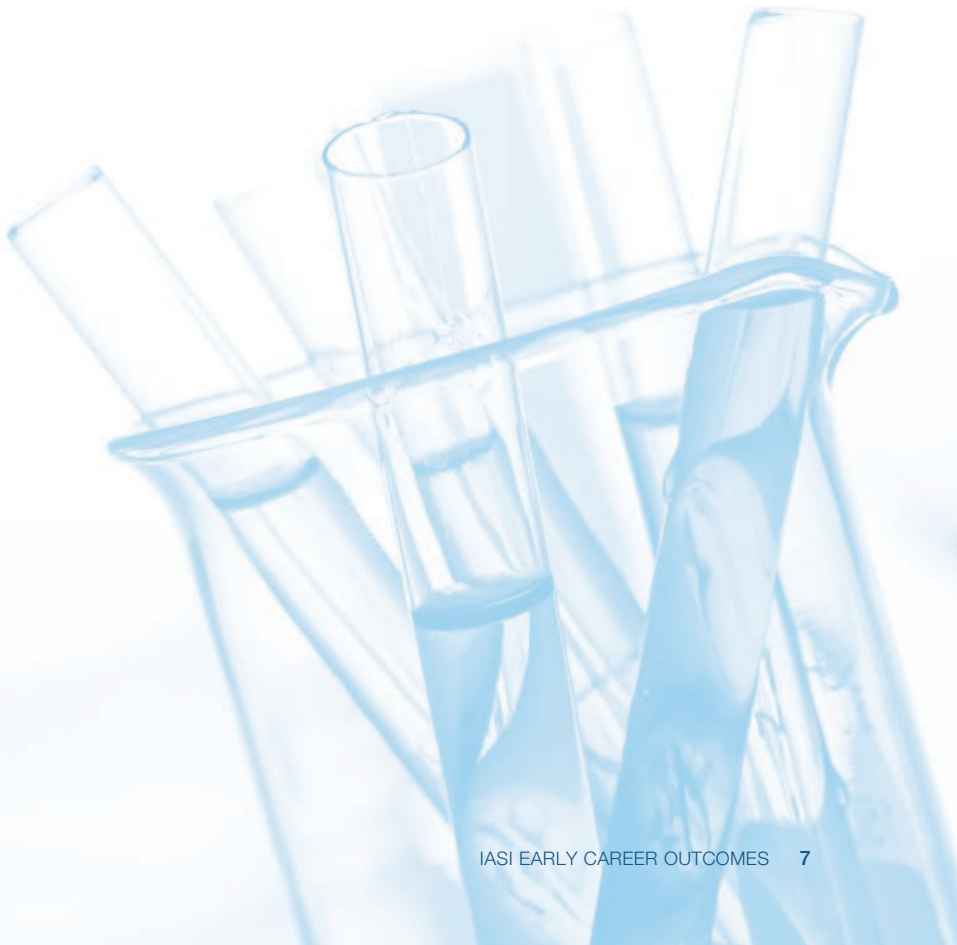
TABLE 1

Institutions and programs with recipients of Institutional Awards at the Scientific Interface (IASI) from the Burroughs Wellcome Fund (BWF) in 1996, 1998 and 2000

Institution(s)	Program Name	Number and Fraction of Respondents (152=100%)	Years of BWF Funding
Awarded in 1996			
Rockefeller University	Interdisciplinary Graduate and Postdoctoral Training Program in Physics, Chemistry, and Biology	15 (10%)	1997-2001
University of California-San Diego Scripps Research Institute Salk Institute San Diego Supercomputer Center	La Jolla Interfaces in Science	21 (14%)	1997-2007
California Institute of Technology	Program in Computational Molecular Biology	17 (11%)	1997-2001
Florida State University (consortium of laboratories at 12 institutions across the US)	Program in Mathematics and Molecular Biology (PMMB)	40 (26%)	1997-2007
Awarded in 1998			
Brown University	Interdisciplinary Training Program in Brain Science	7 (5%)	1999-2005
Johns Hopkins University	Program in Computational Biology	6 (4%)	1999-2007
Awarded in 2000			
Princeton University	Burroughs Wellcome Fund Training Program in Biological Dynamics	9 (6%)	2001-2009
Boston University	Burroughs Wellcome Fund Training Program in Mathematical and Computational Neuroscience	16 (11%)	2001-2008
University of Chicago	Cross-Disciplinary Program in Biophysical Dynamics and Biocomplexity	8 (5%)	2001-2007
University of California-San Francisco	Graduate Program in Quantitative Biology	13 (9%)	2001-2006

A total of 426 unique program participants were reported through the online system. Among these, 35 had participated as undergraduates and were excluded from the analysis. The program directors provided the contact information (as of August 2007) for 367 of the remaining program alumni; in 2007-2008 we contacted them (please refer to the methods section for survey questions) via email and phone, and asked them to submit current curriculum vitae (CV) with full training, employment, publication, and funding details, to evaluate outcomes of the program in which they had participated. We also asked them to respond to a short survey (three questions) about their training experience under the program. At this time we reiterated that data would be presented only in aggregate. A total of 221 individuals responded; a rate of 60%. Non-respondents include those for whom the email address provided by the program directors may have been invalid. 69 respondents indicated that they had not yet obtained a Ph.D. as of August 2007, and were also excluded from the analysis, leaving 152 respondents. We extracted gender and citizenship information from the BWF progress report database, while the information on length of time in training, current employment category, grant support, and publications came from the self-reported CVs.

For 70 of the 75 program alumni who held academic positions in 2007, we also reviewed the five most recent peer-reviewed publications as reported on the CVs: An external rater with expertise in biological sciences categorized them as "purely biological", "non-biological," or "interdisciplinary." For example, the rater scored all papers in journals such as *Bioinformatics, Biophysical Journal, Journal of Mathematical Biology*, etc., as interdisciplinary. Papers published in other journals were considered interdisciplinary if the title of the paper reflected use of physical, computational, or mathematical approaches within a biological system. If a paper's title indicated a physical or mathematical analysis of a non-biological system, the rater scored it as "non-biological."



RESULTS

From 1997-2007, 391 individuals participated in the 10 BWF-funded training programs.

Characteristics of Respondents

From 1997-2007, 391 individuals participated in the 10 BWF-funded training programs as graduate students or postdoctoral fellows. In August 2007, the program directors provided contact information for 367, all of whom we contacted to request a current CV. Responses were received from 221 individuals (60%); we excluded 69 from the analysis who had not obtained a Ph.D. as of 2007.

Detailed CVs from the remaining 152 respondents who had earned a Ph.D. degree as of August 2007 were included in this analysis. Table 2 shows the distribution of this group, by field of Ph.D. training: The vast majority (n=134; 88%) had Ph.D training in a non-biological or interdisciplinary field, with the remainder (n=18; 12%) having Ph.D. training in biology or biochemistry departments. In order to be eligible to participate in the programs, students from traditional biological science departments were required to demonstrate a background in a non-biological scientific field (physics, mathematics, chemistry, computer science, engineering), evidenced by a baccalaureate or masters degree in one of those fields. Table 2 also shows that more trainees received their degrees in later years; this is because it took time for the programs to recruit students and reach steady state, and because the programs funded after 1998 tended to support more predoctoral students than postdoctoral fellows.

The 152 respondents included 105 (69%) men and 46 (30%) women (the gender of one respondent was undetermined), which roughly reflects the gender distribution among all 426 unique participants (including ones that participated as undergraduates) from the 10 programs (67.0% men, 32.5% women, and 0.5% unknown gender). Overall, the IASI programs included women at or above the levels of their representation among those earning U.S. doctoral degrees in physical science, mathematics, and engineering fields.[9]

TABLE 2

Doctoral training background and year Ph.D. degree was awarded among the 152 respondents who had obtained a Ph.D. degree by August 2007

Ph.D. Field	Number of Respondents (% of total)
Chemistry	21
Computer Science	10
Engineering	4
Mathematics/Applied Mathematics	23
Physics	25
Statistics	9
Other	2
Subtotal Physical /Mathematical	**94 (62%)**
Bioengineering	4
Biophysics	18
Computational bio/bioinformatics	9
Neuroscience	9
Subtotal Interdisciplinary	**40 (26%)**
Biochemistry	11
Biology	7
Subtotal Biological	**18 (12%)**
Total	**152**

Ph.D. Year Range	Number of Respondents
1991-1997	19
1998-2000	31
2001-2003	48
2004-2007	54
Total	**152**

Unlike federally-funded training programs, the BWF-funded programs were permitted to provide support to temporary residents of the United States in addition to citizens and permanent residents. Of the 152 respondents, 75 (49 %) identified themselves as US citizens, 8 (5%) as permanent residents, and 65 (43%) as temporary residents of the United States at the time of their participation in the BWF program. Four (3%) did not identify their citizenship status.

The 152 respondents included alumni from each of the 10 training programs (Table 1). The Program in Mathematics and Molecular Biology (PMMB) was overrepresented among the respondents, accounting for 40 (26%) of the 152, while the other nine programs each accounted for between six (4%) and 21 (14%) of the respondents. Because PMMB was a geographically distributed program (administered through Florida State University), the overrepresentation of its trainees increases the institutional diversity of the respondent pool.

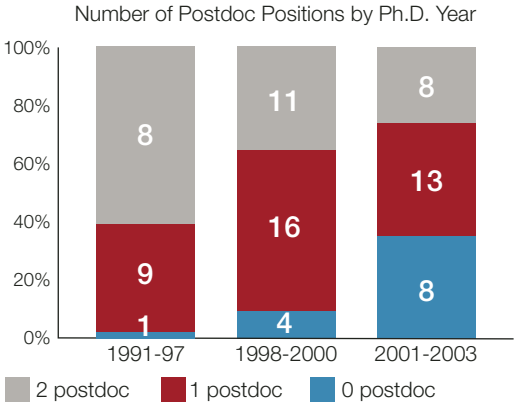
The 152 respondents received their doctoral training from 51 different institutions, and pursued postdoctoral training at 52 different institutions. For the purpose of this analysis, we did not identify outcomes from individual institutions, but treated the respondents as one cohort, distinguished by having trained in an intentionally interdisciplinary context for a portion of their education.

Extent of Postdoctoral Training

The length of time required for scientists to achieve independence has been an ongoing concern in U.S. science policy,[5] and becomes even more of an issue when trainees are expected to reach a level of competence in multiple disciplines. Therefore, we counted the number of postdoctoral positions held by the 78 program alumni who had received their Ph.D.s in 2003 or earlier and moved into permanent positions by 2007 (Figure 1). We found that the more recent graduates were more likely to enter the workforce directly after the Ph.D. than were the earlier cohorts: For example, of the 18 respondents receiving doctoral degrees between 1991 and 1997 who had entered the workforce, only one had entered the workforce without any postdoctoral training post; in contrast, 8 of the 29 (28%) employed respondents who had received Ph.D.s between 2001 and 2003 did not pursue postdoctoral training before entering the workforce.

FIGURE 1

Number of postdoctoral training posts for the 78 respondents who had earned their Ph.D. degree by 2003 and reported holding a permanent position by 2007, by date range of Ph.D. completion.



We found that the more recent graduates were more likely to enter the workforce directly after the Ph.D. than were the earlier cohorts.

RESULTS CONTINUED

As of 2007, five of the 12 (41%) respondents who had attained the rank of associate professor were women.

Early Career Development

We examined the early career outcomes of all 92 respondents who had completed their training and moved into a permanent position by 2007, regardless of when they received their Ph.D. degree (Table 3). We found that some were still in their first non-training posts, while others had been in the workforce for several years and moved on to another position. An overwhelming majority (75, or 82%) were employed in academic positions, which included the titles of assistant professor, associate professor, research faculty, instructor, adjunct or visiting professor, or independent fellow. Of the 75 individuals in academia, 46 (61%) were appointed as tenure-track assistant professors, and 14 (19%) had been promoted to associate or full professor, so that the proportion of academics in tenured or tenure-track positions was 80% (60 of the 75).

Women accounted for 14 of the 46 (30%) respondents appointed as assistant professor. This is similar to the proportion of women (46 of 152; 30%) in the respondent group as a whole, indicating that women were not underrepresented among program alumni entering the tenure track. As of 2007, five of the 12 (41%) respondents who had attained the rank of associate professor were women. While the total number is too small to determine any significant gender-specific trends, there was no obvious trend toward attrition of women from the faculty ranks among the program alumni.

TABLE 3

Type of positions reported in 2007 by all 92 IASI program alumni with a permanent position, regardless of when they earned their Ph.D. degree

All Positions (Number and % of total)

	Industry	Government Research	Research Institute	Other	Academia	Total
Men	5 (8%)	2 (3%)	4 (6%)	0 (0%)	51* (82%)	**62* (100%)**
Women	2 (7%)	3 (10%)	0 (0%)	1 (3%)	24 (80%)	**30 (100%)**
Both	7 (8%)	5 (5%)	4 (4%)	1 (1%)	75 (82%)	**92 (100%)**

Academic Positions (Number and % of total)

		Academic Tenure Track				
	All	Assistant	Associate	Professor	Other acad.	Total
Men	41 (80%)	32* (63%)	7 (14%)	2 (4%)	10 (20%)	**51* (100%)**
Women	19 (79%)	14 (58%)	5 (21%)	0 (0%)	5 (21%)	**24 (100%)**
Both	60 (80%)	46 (61%)	12 (16%)	2 (3%)	15 (20%)	**75* (100%)**

*includes one academic assistant professor with unknown gender

Early Academic Career Activity: Funding and Publications

We assessed success in obtaining federal funding—a key outcome for early academic careers—among the 75 respondents who were employed in academia (tenure track and other academic positions) as of 2007. They reported working in a wide variety of departments, some as research faculty or lecturers, while others had been promoted to associate professor; 34 (45%) were listed as primary or co-investigator on at least one NIH grant, and 27 (36%) were serving as primary or co-investigator on at least one NSF grant. Most of those receiving NIH grants were appointed in non-biological departments including statistics, physics, mathematics, engineering, chemistry, and computer science (data not shown). 66 (29%) of the 227 grant awards listed on the CVs of this group came from private foundations (see Table 4), indicating the importance of such foundations in establishing early careers.

TABLE 4

Success in obtaining funding among the 75 IASI alumni in the study employed in academia as of 2007. Grants received are listed by source.

Funding Agency Type	Number of Grants
Private Foundation	66
National Institutes of Health	65
National Science Foundation	40
Institutional (University)	19
International	15
Other Government	14
Canadian Government	8
Total	**227**

To ascertain whether IASI trainees pursued interdisciplinary science as they launched their early careers, we asked an external rater to examine the five most recent publications of 70 of the 75 respondents who held academic positions as of 2007. The rater coded each of 345 papers for 'interdisciplinarity,' based on the paper's title as well as the title of the journal in which each was published. For example, the rater scored all papers published in the *Journal of Mathematical Biology* as interdisciplinary. Papers published in other journals were considered interdisciplinary if the paper title reflected use of physical, computational, or mathematical approaches within a biological system. Among the 345 papers included in the analysis, the rater scored 245 (71%) as interdisciplinary. Of the 70 program alumni whose papers were assessed, 67 (96%) had at least one interdisciplinary publication among the five most recent, and 54 (77%) had at least three interdisciplinary publications among their five most recent.

Among the 345 papers included in the analysis, the rater scored 245 (71%) as interdisciplinary.

RESULTS CONTINUED

While many trainees indicated that gaining ‘wet lab’ skills was very important, most listed “soft skills”as being most valuable to their career development.

Survey Results

At the time we asked program alumni to submit a current CV, we also asked them to answer three questions about their training experience, to assess program effectiveness in creating and sustaining interdisciplinary research, and to identify qualitative factors that may have contributed to a trainee’s sustained involvement in interdisciplinary research.

The three survey questions were:

- Which aspects of your training have been most important to you in your current work?
- In what ways did your mentor assist in your career development?
- Do you consider your current work ‘interdisciplinary’—at the interface with biology? If so, have you faced any obstacles as you’ve pursued your career?

The responses to these questions tended to be consistent across disciplines and institutions. While many trainees indicated that gaining ‘wet lab’ skills was very important, most listed “soft skills”—learning to communicate and work effectively across disciplines—as being most valuable to their career development. Several respondents noted that this was fostered effectively through meetings of trainees from all of the programs. Others emphasized that mentors played important roles in shaping their careers, by encouraging them to think independently, and by giving them due credit for their work. Almost all (90%, or 136) of the 152 respondents characterized their current work as “interdisciplinary.” The most common obstacle cited by respondents was that funding agencies and academic departments tend to expect applicants to be experts in one field, so applicants tend to be judged by their contributions to only one discipline when they are evaluated for career advancement or grant funding; their interdisciplinary skills may not be fully appreciated.

Evidence of Institutional Change

The second goal of the program was to promote institutional change, as measured by the sustainability of the interdisciplinary ‘ecosystem’ within the funded institutions. For their final progress reports, we asked program directors to identify institutional changes that had occurred as a result of the IASI program. The surveyed institutions reported a significant lowering of the barriers between disciplines, departments, and institutions, evidenced by a marked increase in the level of interdisciplinary faculty interaction. This increase was reported in terms of steady and continued growth in cross-disciplinary

collaborations, both within and outside institutions, as well as the observation that whenever individuals or groups successfully overcame interdisciplinary barriers to research, they 'never went back' to their traditional mode of operation.

The second unanimously reported transformation was a shift in the emphasis of graduate programs, demonstrated by the development of new interdisciplinary courses. At institutions representing half of the programs, these courses became part of a revised core curriculum; in addition, half of the BWF-funded programs reported the launch of new permanent institutional programs of graduate or undergraduate study to sustain what had been started, and half reported hiring new interdisciplinary faculty. Six of the 10 programs reported success in acquiring additional funding from inside or outside the institution, resulting in the development of a new program, center, or building designed to foster cross-disciplinary research and training. Funding sources included the Howard Hughes Medical Institute, the National Institutes of Health, and the National Science Foundation.

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DISCUSSION

We expected that the alumni of the BWF programs would have postdoc tenures well below the 5-year term limits recommended by the National Academies.

This analysis of early careers presents a small but unique cohort: those whose training was intentionally interdisciplinary during Ph.D. or postdoctoral study or both. The individuals in the group trained from 1998-2007 at more than 50 institutions. Program participants came from backgrounds in physics, mathematics, chemistry, and engineering, using approaches from these disciplines to address research questions in biological systems.

At the time, there was a perception within the physical science and mathematics areas that working at the interface with biology was not adequately rigorous, and thus not recommended for the "best" trainees. Likewise, within biology the potential intellectual contributions from physical scientists and mathematicians were not fully appreciated, beyond their serving as technical problem solvers or statisticians. Therefore, an important value of the program was true intellectual collaboration; physical scientists and mathematicians were viewed as full partners with biologists in framing the scientific questions and in interpreting the results, with the expectation that scientific benefits would accrue to the fields of mathematics and physics as well as to biology. As a result, the program succeeded in attracting top faculty and top students from these non-biological fields.

Studies examining the biomedical research workforce at the time the program began noted that the time biomedical scientists spent in postdoctoral training had grown longer, and recommended a shorter path to independence.[3;4;10-13] One key reason for the lengthening time spent in training is that the supply of doctorally-trained biomedical scientists has for decades outstripped the number of available tenure-track faculty positions they can occupy.[6;12-15] Other factors include the increasing complexity of biomedical science, and the expectation that extensive postdoctoral training is a necessary prerequisite to be considered for a faculty position. For interdisciplinary scientists seeking to enter biology after initially training in a non-biological discipline, the length of time required to gain adequate depth in biology to launch a career as an independent scientist would seem to be even longer.

We expected that the alumni of the BWF programs would have postdoc tenures well below the 5-year term limits recommended by the National Academies.[13] We believed there would be increasing demand for their interdisciplinary skills as the flood of genomic and proteomic data made mainstream biology more quantitative, creating opportunities for modeling and

development of theory, and because advances in imaging and other technologies have opened up productive new lines of inquiry for research in biological systems. Second, the BWF funding was not tied to a department or to a mentor's research grant, thus encouraging trainees to be entrepreneurial, seek out collaborators and, in many cases, be part of two research groups, accelerating their acquisition of the important skills necessary for success as independent scientists.

We found that the trainees supported by the IASI programs were more likely than average Ph.D. graduates in physical sciences to enter into postdoctoral training: overall, among all 78 respondents who were employed by 2007 and had received their Ph.D. by 2003, only 13 (17%) entered the workforce directly without any postdoctoral training (Figure 1). That is far less than the national average at the time: According to the 2005 Survey of Earned Doctorates,[16] nearly half of all physical science Ph.D.s and nearly two-thirds of mathematics Ph.D.s bypassed postdoctoral training to enter the workforce. We interpret this as a reflection of the culture of the BWF-supported programs, which steered graduates toward careers in academia as opposed to industry.

As for how many of the Ph.D. holders moved on to tenure track positions in academia, an appropriate comparison group for our cohort is difficult to identify. Since 1998, the National Science Foundation has funded almost 6,500 interdisciplinary graduate students through its IGERT (Integrative Graduate Education and Research Traineeship) program.[17] Early career outcomes of IGERT trainees funded between 1998 and 2007 have been reported,[18] but the IGERT programs supported predoctoral students only, while the BWF programs supported both pre- and postdoctoral trainees, making comparison difficult. Nevertheless, compared with non-interdisciplinary graduate students in similar departments, IGERT students took less time to complete their degrees, and in 2008 62% of the trainees funded by IGERT between 1998 and 2007 reported working in academia (colleges or universities).[18]

DISCUSSION CONTINUED

While not an explicitly interdisciplinary program, the NIH-funded National Research Service Award (Kirschstein-NRSA) may provide the best comparison, although also with limitations: Kirschstein-NRSA supported trainees with backgrounds in biomedical science and not physical science and mathematics; the Kirschstein-NRSA study population about whom data were available were funded prior to 1993, while all of the BWF programs received funding after 1996; and the Kirschstein-NRSA program only supports postdocs in the form of either individual fellowships or traineeships.

Of these two, the traineeships are the most comparable to the BWF program, as candidates are appointed through discrete institutional training programs rather than by applying independently to NIH. According to a 2006 report on early career outcomes of the Kirschstein-NRSA program,[19] 59% of Kirschstein-NRSA trainees held positions in academia four years after receiving the Ph.D. degree, 69% of them in tenure-track positions.

Based on our results, the IASI cohort alumni were more likely than either the NSF-funded IGERT trainees or the NIH-funded NRSA trainees to pursue positions within academia at 82% (75 of the 92 respondents with a permanent position in 2007; see Table 3), and fell in between them in their likelihood, if employed within academia, to be on the tenure track, at 80% (60 of the 75 with a permanent academic position in 2007; see Table 3). The average postdoc length for the 92 respondents that entered into a postdoc was 3.06 years, and 3.13 years for those that chose an academic position.

As previously reported,[20] a number of principles emerged from the experience of the co-directors of the funded programs. Requiring dual mentors for trainees—one from quantitative and one from biological sciences—proved to be an important element for success. Participating in group meetings with both mentors greatly facilitated the necessary immersion in the culture, language, technology, literature, and key players in the two fields. Shared trainees, whose funding transcended departmental lines, proved to be the catalysts for bringing research groups together. The co-directors felt that the interdisciplinary culture should be as influential to the trainees as their departmental culture, and that a variety of social events, retreats, symposia, and internet resources could be deployed to create these interdisciplinary cultures, in addition to courses that integrate theory and application. In short, creating a cadre of scientists who will ask new questions in new ways depends on the adaptability of their mentors, their institutions, and the funding agencies that support their education and research.

This analysis establishes a baseline for early career outcomes of participants in what was, at the time, a novel training environment. The early indicators suggested that the participants in this 'social experiment' experienced no disadvantage in competing for tenure-track positions, securing federal funding, and they continued to pursue interdisciplinary work well after their training was completed. A follow-up study, which would track the continued career progression of the IASI cohort reported here, as well as the 123 recipients of BWF's Career Awards at the Scientific Interface (CASI; awarded from 2002-present) is warranted, and would further inform the efforts of federal agencies and other foundations in designing interdisciplinary training programs to prepare future generations of innovators.

Two decades after the BWF IASI program was conceived, the notion that the future of biology will unfold at its boundaries with the physical and mathematical sciences has become mainstream,[21,22] and has been re-conceptualized as 'convergence science:' an "approach to problem solving that cuts across disciplinary boundaries."[23] Importantly, many of the areas in which convergence is expected to lead to breakthroughs biomanufacturing, cell-based therapeutics, health care information technology, imaging, microbiome engineering, precision medicine, and theoretical biology are embodied in the portfolio of BWF awards, including both the IASI and CASI programs.

Thus the issue is not new, and since BWF's early, initiating efforts, federal agencies have launched programs to support this kind of research.[24,25] Recently however[23], increasing attention has been paid to the local 'ecosystems' that are necessary for fostering convergence science, underscoring many of the findings in our previous report,[20] notably, the attention to social and cultural issues that can impede collaboration across disciplines and the need to provide incentives in terms of promotion and tenure. Other recent recommendations call for a problem-based approach to identifying research priorities, and involving industry experts in academic programs to accelerate innovation.

Indeed, the vision that BWF began to flesh out by creating ecosystems for young interdisciplinary scientists with its Institutional Awards at the Scientific Interface is now embraced as a national priority calling for concerted and coordinated effort across a broad range of stakeholders. While BWF will continue to contribute to this national conversation from our experience, we recognize that our core strength is our flexible, generous support for the bold ideas of individual young scientists early in their careers and we expect to continue to help launch this next generation of innovators well into the future.

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DISCLOSURES

Acknowledgements

The authors wish to thank the directors of the BWF-supported IASI programs, as well as the program coordinators, who worked closely with the BWF to track the progress of the supported trainees. We also wish to thank Dr. Maryrose Franko for rating the interdisciplinarity of the peer-reviewed manuscripts from the IASI trainees surveyed and to Dr. Andreas von Bubnoff who contributed to the editorial review of the manuscript. We are also grateful to Dr. Queta Bond, former BWF President, under whose leadership IASI was conceptualized and launched, and also Dr. John Burris, current BWF President, who contributed helpful comments to this manuscript and encouraged its preparation.

Funding/support

None

Other disclosures

None

Ethical approval

Burroughs Wellcome Fund (BWF) awardees agree in writing that in the interest of transparency and public accountability regarding foundation-supported research, BWF may share information about its awardees in a variety of venues, including its Web site, annual report, and other publications. Awardee CVs and the data used here are maintained in BWF's secure awardee grants servers. These data and the conclusions of this paper have not been used to evaluate individual awardees, and collection and analysis of these data does not put any awardee's funding at risk. Risk to the awardees whose data are presented in aggregate here is minimized by focusing on quantifiable known information. Selection of participants was equitable: All of those funded by a well-defined subset of BWF grant programs were asked to participate, but there was no penalty for not complying with this request.

REFERENCES

1 Committee on Strengthening the Linkages between the Sciences and the Mathematical Sciences. Strengthening the Linkages between the Sciences and the Mathematical Sciences. Washington, DC: National Academies Press; 2000.

2 Committee on Facilitating Interdisciplinary Research and Committee on Science, Engineering, and Public Policy. Facilitating Interdisciplinary Research. Washington, DC: National Academies Press; 2005.

3 Committee on Science, Engineering, and Public Policy, National Academy of Sciences. Reshaping the graduate education of scientists and engineers. Washington, DC: National Academies Press; 1995.

4 Committee on Dimensions, Causes, and Implications of Recent Trends in Careers of Life Scientists, National Research Council. Trends in the Early Careers of Life Scientists. Washington, DC: National Academies Press; 1998.

5 Committee on Bridges to Independence, Board on Life Sciences, National Research Council of the National Academies. Bridges to Independence: Fostering the Independence of New Investigators in Biomedical Research. Washington, DC: National Academies Press; 2005.

6 Committee on Science, Engineering, and Public Policy (COSEPUP). Enhancing the Postdoctoral Experience for Scientists and Engineers. Washington, DC: National Academies Press; 2000.

7 Committee on National Needs for Biomedical and Behavioral Scientists. Addressing the Nation's Changing Needs for Biomedical and Behavioral Scientists. Washington, DC: National Academies Press; 2000.

8 Burroughs Wellcome Fund. *www.bwfund.org*

9 National Science Board Subcommittee on Science and Engineering Indicators. Science and Engineering Indicators 2006. Arlington, VA: National Science Foundation; 2006.

10 Freeman R, Weinstein E, Marincola E, Rosenbaum J, and Solomon F. Competition and careers in biosciences. Science 2001;294:2293-2294.

11 Nerad M, Cerny J. Postdoctoral Patterns, Career Advancement, and Problems. Science 1999;285:1533-1535.

12 Committee to Review the State of Postdoctoral Experience in Scientists and Engineers. The postdoctoral Experience Revisited. Washington, DC: National Academies Press; 2014.

13 Powell K. The Future of the Postdoc. Nature 2015;520:144-147.

14 National Science Foundation Directorate for Social, Behavioral and Economic Sciences, Issue Brief NSF 99-310. Has the use of postdocs changed? *http://www.nsf.gov/statistics/issuebrf/sib99310.htm.* Published December 2, 1998. Accessed October 14, 2010.

15 President's Council of Advisors on Science and Technology, 2012: Report to the President. Transformation and Opportunity: The Future of the U.S. Research Enterprise. [Page 95]

16 Hoffer TB, Welch V Jr, Webber K, Williams K, Lisek B, Hess M, et al. Doctorate Recipients from United States Universities: Summary Report 2005. Chicago: National Opinion Research Center, 2006.

17 The Integrative Graduate Education and Research Traineeship (IGERT): Mission and History. *http://www.igert.org/public/about/history-and-mission*. Accessed May 27, 2015.

18 Evaluation of the National Science Foundation's Integrative Graduate Education and Research Traineeship Program (IGERT): Follow-up Study of IGERT Graduates. Abt Associates 2011. http://www.igert.org/system/content_item_assets/files/1535/ES_IGERT_FOLLOWUP_STUDY_FULLREPORT_May_2011.pdf?1340382040. Accessed May 27, 2015. [Pages E-5; 76; Exhibit 5.8]

19 Mantovi R, Look MV, Wuerker E. Career Achievements of National Research Service Award Postdoctoral Trainees and Fellows: 1975-2004. Bethesda, Md: Office of Extramural Programs, Office of the Director, National Institutes of Health, 2006.

20 Sung NS, Gordon JI, Rose GD, Getzoff ED, Kron SJ, Mumford D et al. Educating Future Scientists. Science 2003;301:1485.

21 Committee on Forefronts of Science at the Interface of Physical and Life Sciences. Research at the Intersection of the Physical and Life Sciences. Washington, DC: National Academies Press; 2009.

22 Committee on A New Biology for the 21st Century: Ensuring the United States Leads the Coming Biology Revolution. A New Biology for the 21st Century. Washington, DC: National Academies Press; 2009.

23 Committee on Key Challenge Areas for Convergence and Health, Board on Life Sciences, National Research Council of the National Academies. Convergence: Facilitating Transdisciplinary Integration of Life Sciences, Physical Sciences, Engineering, and Beyond. Washington, DC: National Academies Press; 2014.

24 *https://commonfund.nih.gov/Interdisciplinary*

25 National Science Foundation Innovation Corps. *https://www.nsf.gov/news/special_reports/i-corps/*

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