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Article

Collaborative Co-Mentored Dissertations Spanning Institutions: Influences on Student Development

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The Graduate Partnerships Program (GPP), established in 2000, links universities with National Institutes of Health (NIH) laboratories for predoctoral training. Several partnerships required that students create collaborative dissertations between at least one NIH and one university research mentor. More than 60 students have entered into these co-mentored research collaborations, and many others established them even though not required. Much was learned about the experiences of these and other GPP students by using structured interviews as part of a formal self-study of the GPP in 2005. Complications of trying to work with two mentors are managed through careful program design and mentor selection. In the collaborative model, students develop a complex set of scientific and interpersonal skills. They lead their own independent research projects, drawing on the expertise of multiple mentors and acquiring skills at negotiating everyone's interests. They develop high levels of independence, maturity, flexibility, and the ability to see research questions from different perspectives. No evidence was found that co-mentoring diminishes the normally expected accomplishments of a student during the Ph.D. Multi-mentored dissertations require skills not all graduate students may possess this early in training, but for those who do, they can promote rapid and extensive development of skills needed for collaborative, interdisciplinary research.

INTRODUCTION: THE FRAMEWORK FOR TRAINING OF SCIENTISTS

The methods for guiding the education and training of scientists have a long-standing tradition that has changed very little over time. Typically, undergraduate students begin by learning fundamental scientific knowledge and principles in their discipline, which lays the foundation for subsequent training in research methods and experimental design. Experience with the excitement of discovering new knowledge is provided through undergraduate research, which, not uncommonly, is the stimulus for certain students to head toward research careers versus careers applying scientific knowledge. At the same time, students are taught to recognize that scientific knowledge is always changing as new discoveries are made, and how to ask and answer questions to both challenge and build upon scientific theories.

Discussions with established scientists guide the process for building skills in scientific reasoning and thinking, but the single most important activity in the training of scientists is the learning and modeling of scientific behavior through student–mentor relationships. Creating the opportunity for "students" to learn from a sequence of mentors is the central dogma of the training of scientists. Science and research, however, are rapidly evolving from a largely individual endeavor to a highly collaborative and interdisciplinary activity. Over the past decade or more, intense interest has focused on these changes in research. The level of importance attached to this issue is exemplified by the launch in 2003 of the National Academies Keck *Futures Initiative*, a 15-year project of the National Academy of Science funded by a $40 million grant from the W. M. Keck Foundation

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(National Academies, 2003). At the same time, the Committee on Facilitating Interdisciplinary Research of the National Academy of Science was established, and its work led to a major study, the results of which were released in November 2004 (Committee on Facilitating Interdisciplinary Research, 2004). That report extolled the value of interdisciplinary training, and identified the many barriers to it, but it did not address in any detail the impacts of such training beyond scientific expertise. If one hopes to train young scientists toward interdisciplinary science, several questions arise: How will they become comfortable with principles, methods, and languages of different disciplines? When and how will young scientists start learning how to collaborate so they are well prepared for the research of the future? Should alternatives to the time-honored practice of students learning from one primary mentor at a time be reconsidered, allowing them to study under multiple mentors with different approaches to research at the same time?

A few reports on individual programs introducing new models or approaches to research training have been published. For example, at the University of Washington (Seattle, WA), the fusing of two departments led to the creation of a new interdisciplinary graduate program (Fields *et al.*, 2006). Although too new to show any outcomes from this program, they report that it has attracted outstanding students who are eager and able to work collaboratively. At Texas A&M (College Station, TX), a new interdisciplinary graduate program was created spanning biomedical engineering, mathematics, medical physiology, and veterinary physiology and pharmacology (Humphrey *et al.*, 2005). The program's Steering Committee ". . . ensures that all dissertations embrace close interactions between multiple students/faculty from allied disciplines." Again, no outcomes or students' perspectives were reported. One of the more complete descriptions of an alternative approach comes from the Computational and Systems Biology Initiative (CSBi) at Massachusetts Institute of Technology (Cambridge, MA) (Tadmor and Tidor, 2005). The emphasis of CSBi has been to create a framework and activities that promote informal interactions among students and faculty across a wide array of departments and programs around the theme of systems biology. The goal is to stimulate interactions that lead to collaborations, familiarity with new technologies, and scientific interactions across previously unconnected units. The initial focus has been on graduate courses and students. Like the experiences at the University of Washington, the leaders of this program reported that students ". . . are well-suited to and interested in joint mentorship of their Ph.D. research by two faculty members from different backgrounds." They feel this approach uniquely prepares students for "nontraditional interdisciplinary research," although they describe a number of challenges these students face.

By far the most systematized effort to promote interdisciplinary research has been the National Science Foundation Integrative Graduate Education and Research Traineeship (NSF IGERT) Program. Created in 1997, it has funded 125 institutional training programs specifically focused on providing formal and informal opportunities for faculty to create new interdisciplinary training programs. Very recently, an extensive evaluation of the IGERT program was published (Carney *et al.*, 2006). This study showed that these programs have provided a markedly different graduate experience and substantially increased the students' contacts across disciplines. Almost twice as many IGERT students reported working on research projects including multiple disciplines as a comparison group of students (76 vs. 42%). The study did not report any details on the degree to which these projects involved multiple formal mentors and/or the degree of collaboration involved. Most published reports about IGERT programs have emphasized their structures and characteristics important to their success, but they have not yet reported on systematic differences between their graduates and other students (e.g., Martin and Umberger, 2003). Individual IGERT websites usually described and promoted interactions among students and faculty across departments in an organized manner, but most students ultimately became part of an existing Ph.D. program with a single primary mentor. Most encouraged students to have at least a secondary mentor but formal establishment of comentored dissertations did not seem to be a common feature. Because so many programs are promoting the concept of broader exposure and mentorship, it would seem especially critical to study the impacts, both positive and negative, of these new training paradigms.

BACKGROUND CONTEXT: NATIONAL INSTITUTES OF HEALTH GRADUATE PARTNERSHIPS PROGRAM

In the mid-1990s, the decision was made by National Institutes of Health (NIH) leadership to open the wealth of research resources in the NIH intramural laboratories to Ph.D. students for dissertation research. The goal was to create a graduate student experience that would take advantage of the unique mission of the NIH Intramural Research Program (IRP) and its laboratories. Rather than create a separate graduate school at NIH, efforts were focused on the formation of partnerships with existing Ph.D. programs by the creation of the Graduate Partnerships Program (GPP; http://gpp.nih.gov). A few partnerships with local universities already were in existence at the NIH, but they were relatively informal, and there was little infrastructure at NIH to support them. Additionally, a modest number of Ph.D. students from U.S. and international universities annually found their way to NIH labs for dissertation research through arrangements that they had established on an individual basis. Thus, Ph.D. students were not foreign to NIH, but they were largely on their own to accomplish their goals. Since 2000, the GPP has grown to include 16 formal NIH–university partnerships. To be eligible for these formal partnerships, students must be U.S. citizens or permanent residents. Along with students being admitted into the partnership graduate programs, the number of U.S. and international students at NIH through individual agreements also continued to grow. By fall 2006, >400 Ph.D. students were doing all or part of their dissertation research with NIH investigators, with students distributed about equally between the formal university partnerships and individual arrangements.

In 2003, while the GPP was growing, the NIH Roadmap identified several specific objectives for enhancing biomedical research in the twenty-first century (NIH Roadmap Initiatives, 2003). One of the three key themes of the NIH Roadmap focused on research teams of the future, including high-risk research, interdisciplinary research, and reengineering the clinical research enterprise. The first two of these themes are especially germane to Ph.D. training and research in the IRP. Specifically, the IRP was charged to serve as a ". . . laboratory to demonstrate the feasibility, benefits, and successes to establishing interdisciplinary research teams." The GPP, as part of the IRP, was given the opportunity to test different models of graduate training for their potential to provide research skills critical for interdisciplinary research.

The first partnerships established were with universities and programs with a history of students doing research at NIH (e.g., the Johns Hopkins University Biology Department and the George Washington University Genetics Program) and with other programs interested in exploring new partnerships (e.g., The University of Pennsylvania Immunology Program and the New York University Structural Biology Program). These and the other partnerships with U.S. universities tended to follow a model where students spent the first year or two in university classes and lab rotations (at NIH and the university) before choosing a dissertation mentor at NIH or the university.

Additionally, three of the early (2001 and 2002) NIH–university partnerships were created with the University of Oxford (OX) and the University of Cambridge (CAM) in the United Kingdom (U.K.), and the Karolinska Institutet (KI) in Stockholm, Sweden. The initial idea of students doing collaborative dissertations working with both NIH and university mentors came about through discussions between Dr. Michael Lenardo of NIH and Professor Andrew McMichael of the University of Oxford in 2000. Students in the United Kingdom and Swedish partnerships followed the European model in which students identify a primary research mentor at the start of their degree program, not after doing lab rotations as in most U.S. biomedical Ph.D. programs. Thus, students who were sufficiently advanced to have defined research interests were selected for the U.K. and Swedish partnerships. Because the program was a partnership, students had to choose both an NIH research mentor and a university faculty mentor, and they had to create a dissertation research project that bridged the two laboratories and institutions. Students spent about half of their research time in each laboratory, but in all cases they were required to spend at least half of their time at NIH. The partnerships with Cambridge, Oxford, and the Karolinska offered an opportunity to observe student development when the traditional single-mentor model was replaced by dissertation research spanning mentors, institutions, and, in this case, continents. All NIH–university partnerships have active faculty/scientist partnerships directors at NIH and the university. Additional administrative structures vary among the partnerships depending on the numbers of students in them.

DESIGN OF PARTNERSHIPS WITH CO-MENTORED DISSERTATION RESEARCH

NIH–OX/CAM Partnerships

The design of the NIH–university partnerships with Oxford and Cambridge universities, and the Karolinska Institutet, are described in detail because they are very different from U.S. Ph.D. programs, and they are the source of the greatest number of students in the study doing dual-mentored dissertations. The degree requirements of the Oxford and Cambridge programs are similar and modeled after the British degree where students are not required to complete formal coursework. Instead, students are expected to have already acquired the formal academic training needed before they begin the Ph.D. program. This same expectation is applied to U.S. students accepted into these partnerships. Students are welcome to audit classes, however, to expand their knowledge base as they wish. Similarly, students in the NIH–OX/CAM partnerships can audit or formally register for courses offered at NIH through the Foundation for the Advanced Education in the Sciences. Students also frequently take part in specialized training courses in Europe and the United States. The partnerships are broad based, allowing students to do their Ph.D. in almost any science department. Traditionally, Oxford and Cambridge Ph.D. students are expected to complete the degree in 3 yr. With the added complexity of the collaborative dissertation, however, most students in the NIH–OX/CAM partnerships require 4 yr. Twenty-five students had been admitted to each of the Oxford and Cambridge partnerships between 2001 and 2005. At the time of the self-study, through which the data were gathered, none had completed their Ph.D. or D.Phil., although several were nearing completion.

The application and admissions process for the NIH–OX/CAM partnerships is similar to that of other Ph.D. programs. Applications are reviewed by an admissions committee largely composed of NIH investigators, and approximately 40 candidates are invited to interview at NIH. Most students apply for both Oxford and Cambridge partnerships. Criteria for acceptance into the programs are the same as for most biomedical Ph.D. programs, including academic abilities, substantial prior research, and strong letters of recommendation. Additionally, substantial weight is placed on maturity, independence, sufficient scientific background to be able to learn independently outside of formal courses, and evidence that the applicant is likely to be able to establish a dissertation research plan at the start of the program while working with co-mentors. Students who meet these criteria come from many different backgrounds, some right out of a baccalaureate degree and some after having done full-time research for a year or more after graduation. Students are interviewed by members of the Committee at NIH, and they are given the opportunity to meet with potential mentors during the interview. Students who are accepted must accept or decline by the same April 15 deadline of U.S. Ph.D. programs. Those who accept the offer of admission immediately begin identifying potential NIH and Oxford or Cambridge mentors. Some have already done so based on prior NIH research experience, or, occasionally, some have spent time at Oxford or Cambridge. To facilitate the co-mentor selection process, new students spend a week at NIH and a week at their U.K. university in June, talking with potential mentors. Program leaders provide students with extensive guidance on choosing co-mentors through conversations by phone, e-mail, and in-person. Some students choose an established mentor pair that already has an ongoing collaboration, but many choose a U.K. or NIH mentor first and then work with that investigator to identify a research collaborator. Mentors are expected to talk with each other to ensure that the collaboration is viable and that they are willing to enter into it. Students must identify their pair, or more, of mentors by the time they come to NIH on August 1.

During August and September, students are taught how to construct an NIH-style research proposal through a formal workshop provided by the GPP leadership. Students then work with their mentors, and often each other, to create and refine their written proposal. Before starting their research at NIH or the university, the proposal must be approved by both co-mentors and the partnership director. The proposal is shorter and less complete than a typical dissertation proposal (~5–10 pages), because it is recognized that the actual direction of the work may change as initial studies are carried out, but it does include a tentative timeline of when work will be conducted in each lab. This preliminary proposal focuses students on the work of their mentors, requiring them to think critically about new questions of interest to them and to delineate in writing expectations for students and mentors.

In early years of the programs, most students started their research at the U.K. universities, often spending the first 2 yr there with infrequent visits back to NIH. More recently, students are not following any set pattern, some starting at NIH and some going back and forth at shorter intervals. The intent is to let the research dictate the distribution of time. An annual $3000 travel budget allows and encourages students to keep in contact with both mentors and laboratories throughout the duration of their training.

The Karolinska Institutet Neuroscience Partnership Program

The NIH–KI partnership is very similar to the NIH–OX/CAM partnership. Students choose a pair of investigators between NIH and Karolinska at the start of the program, although the distribution of time spent at each location is more flexible (as long as at least half is at NIH). There are, however, some differences. Unlike the very broad research foci that students can pursue in the NIH–OX/CAM partnership, the NIH–KI partnership focuses on the neurosciences, a major strength of both Karolinska and NIH. Unlike students in the NIH–OX/CAM partnership who have no required course work, NIH–KI partnership students must complete several course credits, about half of which are required of all students and half of student choice. The elective credits can come from university courses or other educational activities such as extended workshops or seminar series. The NIH–KI partnership places greater emphasis on existing collaborations between NIH and Karolinska investigators than the NIH–OX/CAM partnerships, although students can still create their own collaborations. To receive their degrees, students in the NIH–KI partnership program (as well as all other Karolinska Ph.D. students) must have at least four publications, including at least two as first author. This requirement tends to focus students and mentors on concrete publishable units of work. The final difference in the NIH–KI program is the participation of Karolinska students, originating from Sweden and funded completely by Karolinska, as exchange students. This part of the program begins with a Karolinska and NIH mentor pair submitting a research proposal for competitive review by a selection committee at Karolinska. If the project is selected, its availability is advertised in Sweden and the best candidate chosen from among those who apply. At the time of the self-study, 12 U.S. students had joined the NIH–KI partnership from the U.S. direction, and nine non-U.S. students (not all Swedish) had joined the partnership from the Karolinska direction.

Monitoring and Guiding Student Progress

Both the British and Swedish systems of graduate education place more reliance on students and mentors to ensure student progress than on dissertation committees that are standard at U.S. Ph.D. programs. Both programs have a milestone that students must pass that is similar to the U.S. qualifying or candidacy exams; this formal exam is called the half-time review at Karolinska (usually after about 2 yr) and the transfer report (after 1 yr) at Oxford and Cambridge. Given the complex nature of these programs, however, the partnership directors and faculty have established requirements for more frequent review and monitoring of student progress than is normally provided in these European systems. Student progress is carefully monitored by the leadership of the programs, including an NIH investigator who assumes a primary advising and monitoring role for each yearly cohort of Oxford and Cambridge students. As is described below, regular communication among the student and all mentors is even more important than in a traditional single-mentor Ph.D. program. This communication is accomplished through conference calls, meetings of the students and mentors at scientific meetings, visits of mentors between the collaborator's labs, and so on. The cohort advisor takes care to ensure that students and mentors all start out with the same understanding of what they hope to accomplish and the likely role played by each lab. Periodic discussions among all of those involved also are essential, so that students do not have to play the role of interpreting one mentor's ideas to the other mentor.

Other Students Engaged in Collaborative Dissertations

Many GPP students in other partnerships or individual agreements were identified as having more than one mentor during the self-study. The nature and degree of formality varied, but many students reached the same level of true co-mentoring as those in the NIH–OX/CAM and NIH–KI partnerships. Thus, GPP students fall into three broad categories—those with required collaborative dissertations, those with self-initiated collaborations, and those working predominantly with a single mentor.

PURPOSE OF THE STUDY

The data provided in this report address one potential element of training toward interdisciplinary science—purposeful co-mentoring of young scientists by two or more mentors. The data come from a year-long self-study of the GPP. The self-study, conducted in 2005, was a formative evaluation of the GPP since its inception in 2000. As noted above, the structure and design of the NIH–university partnerships are varied, and they evolved substantially between 2000 and 2005 as problems and successful approaches were identified.

Thus, the self-study was designed to examine the evolution of the partnerships and what could be learned from their different designs. The requirement for some students to create and complete a collaborative dissertation between a university professor and an NIH faculty-equivalent investigator was one big difference among the partnerships.

One could hypothesize that collaboration and interdisciplinary thinking are best learned by working with a sequence of mentors, each an expert in his or her field, enabling students to eventually integrate what is learned when they begin their own independent scientific career. An alternative hypothesis could be that working with more than one mentor at the same time could promote a more rapidly integrated base of knowledge and expertise. Some graduate students have historically been involved with collaborations, but few if any reports of the impacts of formal co-mentored projects have been documented. This study focused on students' perceptions and observations of their experiences, and it provided initial insight on the potential impacts on their development as scientists.

METHODS OF THE STUDY

As noted above, early in 2005 a year-long formal self-study of the GPP and its partnerships was initiated. It was too early to do an evaluation of the outcomes of the program, because only two students had graduated from the formal partnerships. Rather, the focus of the self-study was a formative or process evaluation of the evolution of the program, with a strong emphasis on understanding GPP student experiences. As part of the self-study, systematic semistructured interviews were conducted with 109 students, including 50 students doing collaborative dissertations, 30 through the NIH–OX/CAM and NIH–KI partnerships, and 20 through other formal partnerships (5 students) or individual agreements (15 students). Data describing the overall student experience at NIH are drawn from the entire sample of 109 students, whereas most of the data on the co-mentored experience are drawn from the subset of 50 students.

Students who had been doing research for at least 1 yr were invited to voluntarily participate in interviews. Approximately 40% of the eligible students volunteered and were interviewed. Anyone who volunteered was interviewed. Efforts were made to include a similar number of independent and partnership students, but somewhat fewer independent students volunteered. The characteristics of the students interviewed are shown in Table 1.

Table 1. Distribution of students interviewed across partnerships

	No. of students	% of Interview group	No. of women (%)
Total	109		65 (60)
Oxford/Cambridge	21	19	18 (62)
Karolinska	10	9	5 (50)
Other formal partnerships	40	37	20 (50)
Independent agreement	38	35	24 (63)
Two mentors	41	38	26 (63)
Three or more mentors	9	8	4 (44)
International	20	18	14 (70)

The interviews were carried out to better understand the student experience at NIH and within the partnerships. Consistent with this goal, interview questions were open ended, giving no indication of any specific response that was being sought. For example, "List the greatest benefits (challenges) you see for doing dissertation research at NIH" allowed for independent answers compared with guiding students toward certain choices like rating a list of possibilities. Students were given the questions 24–48 h in advance of the interview and asked to respond with initial answers and send them in advance or bring them to the interview (see Appendix I in Supplemental Material). We felt that providing the questions in advance allowed students to provide more reflective responses. Students usually gave one or two pieces of information for each question on paper but often would talk for a long time and reveal much more during the interview when asked questions such as "Tell me more about how you got your two mentors to agree." The first author took notes during the interview to capture the essence of students' responses. These notes were transcribed into a single document, distinguishing them from the comments students provided before the interview. All quotations in the *Results* were selected from the initial written comments to eliminate interviewer interpretation. Quotes provided in the *Results* were chosen because they were representative of both written and verbal comments made by students.

To manage and analyze the interview data, a software program was used that is designed for qualitative research and management of text-based data (NVivo; QSR International, Doncaster, Victoria, Australia). The program also allows assignment of a document to multiple groups, facilitating comparisons between them (e.g., different partnerships, individual vs. partnership students, one mentor vs. two, international vs. U.S. student, and so on). On the basis of the interview questions, major thematic areas were established, and then subcategories were created from answers provided by students. For example, under Benefits to Research at NIH, categories such as Resources, Access to outstanding scientists, NIH library, and so on were created from student responses. The analysis software enabled the creation of virtual links from the text of each student's responses to that category even if the student mentioned it while discussing other questions. This linkage allowed display and comparison of words defining a theme and frequency analysis. More than 200 themes were initially identified with respect to program evaluation and overall student experience. As is common in this type of study, a much smaller number of themes emerged as common to many individuals. A full listing of the interview analysis themes that emerged is provided in Appendix II in Supplemental Material, and a more detailed description of the collection and analysis of interview and other text-based data is provided in Appendix III in Supplemental Material.

Because this study was purely an evaluation of an educational program, it was determined by the NIH Office of Human Subjects Research to be exempt from IRB approval. However, participation was voluntary, and assurance of confidentiality was given and respected. Despite the assurance of confidentiality, the possibility existed that some students would not feel comfortable providing negative feedback or revealing unpleasant situations during the interviews. To determine whether this was the case, after the interviews students were given the opportunity to complete an anonymous survey with discrete items and scaled responses and to provide additional comments about their experiences. All students completed the survey, but only four students added any additional comments. Neither the surveys nor those comments revealed anything new that was not mentioned during interviews. Those surveys are not described in this report, because they do not provide the same level of insight into student experience provided by the interviews. Responses in the interviews also were very consistent with what students said about their experiences in the GPP during day-to-day conversations.

RESULTS

Demographics of the Students and Differences between Groups

As seen by the data in Table 1, the students interviewed were drawn from all of the different types of Ph.D. programs within the GPP. The sample was very representative of the overall GPP population with the exception of a lower number of individual agreement students. Because the self-study was focused somewhat more on the formal partnerships, efforts were made to ensure good representation from each of them. The relatively higher number of women than men in the interview population is close to the percentage in the overall GPP student body. Although the percentage of women and international students is provided (Table 1), no evidence was found for any systematic differences between men and women or U.S. and international students. Thus, results are not broken down between these groups.

Dissertation Research at NIH

To place the impact of collaborative dissertations and comentoring into context, it was important to first understand the students' perceptions of doing research at NIH in general. These observations are based on the total sample of 109 students. Most students had previously participated in research at U.S. universities as undergraduates, all spent part of their time in graduate school at their universities, and they had friends doing their dissertations there. Thus, they often described their experience at NIH by contrasting it to a university environment.

When asked to identify the most important benefits to doing dissertation research at NIH, the highest frequencies of responses related to the availability of resources at NIH, with responses ranging from unspecified "resources" to responses that focused on specifics such as access to high technology, money for supplies, and so on (Table 2). Perhaps less predictable was the high frequency (2/3 of the students) with which they mentioned access to many talented scientists. One-third of the students also mentioned the ease with which they received help from other labs and the openness of NIH principal investigators (PIs) to collaboration. One-third of the students also mentioned the value of the many seminars they could attend at NIH. Their comments indicated they viewed the seminars as expanding their access to other scientists and an important way to learn about science beyond their own research. Taking these themes together, a clear picture emerged in which most students perceived NIH as a cooperative and collaborative environment where they had easy access to a large cadre of talented scientists. A variety of other benefits to being at NIH were mentioned by students, all of which contributed to a positive impression expressed by a majority of them.

Table 2. Advantages to research at NIH mentioned by 10% or more of students

	Response frequency (%)		
	All students	Partnership students	Independent students
Access to many talented scientists	69 (67)	51 (72)	18 (49)
Resources (no specified details)	67 (62)	49 (69)	18 (49)
Money for supplies	40 (37)	27 (38)	13 (35)
High technology	39 (36)	22 (31)	17 (46)
Access to outside scientists–seminars	37 (34)	23 (32)	14 (38)
Help from other labs	33 (31)	21 (30)	12 (32)
NIH PIs open to collaborations	33 (31)	18 (25)	15 (40)
Breadth of experience	23 (21)	18 (25)	5 (14)
Travel to meetings	13 (12)	6 (8)	7 (19)
Focused on getting work done	13 (12)	8 (11)	5 (14)
Networking	12 (11)	8 (11)	4 (11)
Excellent mentors at NIH	11 (10)	6 (8)	5 (14)

Students also identified some challenges or negative aspects of being a graduate student at NIH (Table 3). By far the most frequent response was missing the academic and social elements associated with being on a university campus with many other graduate students. Many students commented on how this issue was becoming less evident as the number of students rose and the efforts to bring them together expanded between 2000 and 2005. The second most common comment (19%) related to the high expectations they felt they had to live up to given the caliber of research and the many postdocs in their labs. However, few expressed the opinion that these high expectations were bad, but rather, a challenge that many appreciated. Only six students indicated they thought the expectations of their mentors were too high. Although noting that they were present, none of the challenges to being at NIH rose to the level of a major concern to students. Independent students mentioned missing an academic or student environment less frequently than partnership students and seemed less bothered by the bureaucracy at NIH.

When asked whether the benefits of doing research at NIH outweighed the challenges, 92% responded with an unqualified "yes," 6% responded with a qualified yes (sometimes saying "It depends on the day"), whereas only 2% said the challenges outweighed the benefits. In summary, the

Table 3. Challenges or disadvantages to research at NIH mentioned by 10% or more of students

	Responses frequency (%)		
	All students	Partnership students	Independent students
Missing academic/student environment	46 (43)	38 (54)	8 (22)
High expectations	21 (19)	12 (17)	9 (24)
Bureaucracy	15 (14)	13 (18)	2 (5)
Mentoring limited/PIs busy	15 (14)	10 (14)	5 (14)
PIs don't appreciate demands of being a student	14 (13)	11 (15)	4 (11)
Treated like a postdoc–not enough guidance	11 (10)	7 (10)	3 (8)
Too many options to choose from	11 (10)	11 (15)	0 (0)

majority of the students saw great benefit to being at NIH and any challenges as minor in comparison.

Potential Impacts of Collaborative Co-Mentored Dissertation Research

During interviews with the students doing collaborative dissertations, it became quickly apparent that the nature of their experience and the words they chose to describe these experiences were very different from students who were not engaged in co-mentored dissertations. They also described very different experiences from students in traditional Ph.D. programs. (This comparison is based on the prior experiences of the authors who have each trained Ph.D. students and led biomedical Ph.D. programs for >25 yr, including four major biomedical research institutions.) Some students had thought about these differences and could articulate them clearly. Others described what they were going through, but they had not drawn broad meaning or implications. The most sophisticated responses came from students who had actually joined one of the three international partnerships because they thought it would be different, and, thus, they tended to compare their expectations with their experiences. The following results will capture both the variations across students and mentors, and, most importantly, the commonalities that begin to define the potential impacts of this approach to dissertation research.

Insight into the Differences between University and NIH Research Environments. When asked about the benefits of having experiences at both a university and the NIH, the most common responses related to the broader exposure students received. Some talked about it as learning how to work in both environments, often indicating they were very aware of the differences. Many saw this broader experience as an important benefit by helping them determine where they would like to work in the future. Many students acquired insight into the difference between research that was constrained by tighter resource boundaries and relatively short peer-review cycles in a university, and research with greater latitude to explore a tangent or try a high-risk/high-payoff project at NIH. Whether this experience will better prepare them for high-risk, boundary-expanding research in the future, or lead to frustrations with what they can do in a grant-driven university, remains to be determined. As students discussed this dichotomy, however, it was less with concern for future frustration and more with awareness and insight. Quotes from students from which this observation arose include the following:

> "They are two completely different scientific worlds which is a great experience by itself."

> "Working in two different labs gives you a really good experience for how research is done in different places."

Broader Exposure to Scientific Knowledge, Approaches to Research, and Scientific Colleagues. Students who experience in-depth inclusion within two different research teams are automatically imbued with a broader scientific experience. Students often spontaneously articulated contrasting approaches to research in their two labs. They were seeing and learning about two distinct processes of science and discovery by working within two contrasting research approaches. For example, students offered the following comments:

> ". . . when you work in one lab for a long period of time, you start to think that that's the only way things are done. Then you switch to another lab and it can be a shock. If you've already got lab experience, then I suppose you already know that, but it seems some people don't, and in that case I would think it's a great thing to do your training in two labs, so you see right away how differently things can be done."

> "I have a total of 4 advisors, which gives me access to 4 different areas of expertise. I have advice on papers, directions for research, and methodologies from physics, psychiatry, biology, etc. I am able to use the data from one place, and the novel methods from another."

Many also commented on the great advantage and enjoyment of acquiring two complete sets of professional colleagues to learn from and build their professional network of colleagues for the future.

> "I will have a larger and more diverse cohort of colleagues."

> "Generating connections with research leaders and those that are themselves well networked in the research community early in one's career."

Seeing Approaches to Research Questions from Different Perspectives. When asked about the benefits of working with more than one mentor, the overwhelming number of students commented on the broader experience (44 of 50 students in the study with more than one mentor). The words of the students went much farther to describe what they meant by "broader experience." Representative quotes include the following:

> "This component [multiple mentors] is integral, and broadens the training experience by allowing for dif-

> ferent perspectives, by giving the opportunity to conduct research in very different settings, and by fostering a collaborative mentality to research."

> "I am learning from two great scientists: two ways of thinking, two scientific views, two personalities, two role models."

> ". . . benefits are primarily the opportunity to have access to senior scientists in different fields and gain knowledge, experience, training from multiple perspectives."

> "I have chosen 3 mentors. Each mentor is an expert in a given field that will encompass my thesis. I will rely on each mentor to provide their expert knowledge and guide me in a promising direction."

> "By having to relate data to several people you get to look at it many different ways and by the time you have convinced everyone it is stronger and better."

> "I feel having two mentors is much better than one. You can get a different perspective on the research plans and insight into projects that could possibly tap the strong points from both advisors, which you could miss if you had only one perspective on things."

Working with more than one mentor at the same time allowed students to compare and contrast their different perspectives in real time, and their words describe their active comparisons. The broader perspective came not just in knowledge but also in approaches to questions. This suggested that acquisition of comparative perspectives on scientific questions is likely to be achieved when a student is working with more than one mentor.

Independence. One of the most common expressions from students about what they appreciate about being in the GPP, having co-mentors, or both was the independence that it allowed them. Many saw this as one of the attractions to their program from the start. For example, when asked what they got out of the co-mentoring or how they will be different from being in the program, many commented such as follows:

> "I will be much more independent."

> ". . . being able to take charge of your work and not have to follow confined guidelines."

> "I know how to work within an interdisciplinary team, and in making international collaborations work! I feel more confident as an independent scientific thinker as I've had to be that from the beginning."

Those students who engaged most actively with their projects and mentors recognized the opportunity to create their own projects that drew on the expertise of both or sometimes multiple mentors. Some students in traditional Ph.D. programs are given the freedom to design autonomous research questions, but in collaborations it seemed to be frequent. The most advanced students saw this as a critical skill that will position them for future research.

> "Not feeling completely beholden to one supervisor. I have much more flexibility to have input into the direction of my Ph.D. studies."

> "I've been able to design and execute my own thesis project."

> "So far, there have been no problems between mentors or between me and my mentors. All of them give me their opinions and then I do the work that I decide is best. I will be extremely self-taught as my research experience, although helped, has been heavily self-organized and self-imposed."

Many students saw their experience as being beyond that of a Ph.D. dissertation, likening it more to a postdoctoral experience.

> "This program is very much like doing a postdoc fellowship; in some ways you have to be very independent throughout the graduate years."

> "I also tend to feel like I've been treated much more like a postdoc when it comes to the freedom and responsibilities I've been accorded with my research."

> "I think my training will surpass the average graduate student. My experience has actually been more along the lines of a postdoc."

Development of Interpersonal Skills for Managing Relationships. Several students commented on how much they believed they learned about managing people and interpersonal relationships through their dual-mentored experience. Although this could be considered under the category of professional skills, for some it went beyond this into a broader context of improving their skills at managing interpersonal relationships. This skill is likely to be invaluable in whatever career path students choose.

> "Having more than one supervisor can be a lot of work trying to get them all to agree on an issue. Requires lots of patience and at times an obstinate PhD student!"

> "Communication is the biggest problem. I write weekly (or biweekly) updates by email to keep both informed of what I am doing. If there is a difference of opinion about results, writing papers (author order, which journal, etc) or future directions (how much time spent at NIH vs. University) this could be a problem. Thankfully, not a problem with my mentors."

Preparation for Interdisciplinary Research. No conscious effort was focused on asking students to choose mentors from different disciplines, but many of them did so, driven by their own unique interests. What students talked most about is the immersion in these different environments and their ability to bring insights from one lab to the other.

> "Obviously, having two mentors allows you to get two perspectives on your work that can be quite different. My two mentors are in very different fields (behavioral work vs. electrophysiology) and so it gives great exposure to two different fields and a very different perspective than if I were working in either one of those labs exclusively."

> "Each of my advisors has a different area of expertise but they are able to contribute to the ideas of one another."

> "When I go to the University I learn fundamental biophysics and chemical physics but here at the NIH I learn neuroscience. Keeping these two learning fronts strictly separate allows me to look at neuroscience problems from a chemical physicist's or biophysicist's perspective and vice versa."

> "I know how to work within an interdisciplinary team, and in making international collaborations work! I feel more confident as an independent scientific thinker as I've had to be that from the beginning."

> "It allows me to begin approaching my research questions from a multi-disciplinary approach, which will be a key factor in future research endeavors in my field."

> "I will be extremely self-taught as my research experience, although helped, has been heavily self-organized and self-imposed. I also have the skills of working with many leaders in separate fields at the same time, and making an interdisciplinary research topic move successfully forward."

Ability to Do Collaborative Research. About half of the students working with more than one mentor also expressed how this helped them learn to collaborate. Representative quotes include the following:

> "As navigating a collaboration is one of the most important experiences and skills to have in research today, it does not mean that it is always easy. Thus, the biggest challenge in my experience has also been the navigation of the collaboration such as keeping both sides satisfied and yet directing the research toward my own interests. This has been no easy task and often I have failed miserably, but again the ability to learn these skills in an environment where one is protected as a student is extremely beneficial and priceless."

> "Again the benefit of learning to navigate a collaboration and get one's own interests accomplished is one of the best skills to learn early in one's professional career."

> "Having the opinions and advice of two advisors on your project increases collaborations and future scientific connections in the field."

The following quote from a student responding to a question of how they think they might be different as a result of their experience seemed to synthesize many of the individual themes that arose from the interviews.

> "Again, and perhaps I cannot stress this point enough, the advantage of the NIH program is that it affords students who are strongly self-motivated and sure of their interests in research to grow up quickly. That is, they are exposed to situations/experience during their PhD that other students may not be exposed to until they are even the head of their own lab. The largest of these experiences is the integral involvement of a collaboration to one's PhD. The skills needed not only to complete but to thrive in these PhD programs are priceless skills in a world of research that is requiring more and more collaboration between groups, not only within the US but overseas as well."

Challenges Created by Having Multiple Mentors

Virtually all of the challenges of working with two mentors identified by the students fell into one of two categories: meeting the expectations of both mentors and communication among everyone involved. It should be noted that use of the word "challenge" rather than "problem" or "negative" gave students the option of identifying either positive or negative challenges, as well as ones they had overcome or were still facing. Of the challenges they identified, none were described as challenges they could not handle. Some expressed that learning how to deal with the challenges would, in the long run, be beneficial. Representative quotes included:

> "Bridging the expertise of the two labs at the same time satisfying the interest of both labs. This is a scientific challenge."

> "One of the problems that I have encountered was deciding at what places the various topic of my research would be carried-out. One advisor was strongly against carrying out research in parallel, while the other thought that parallel research would be good idea. The problem was resolved over telephone conference, in which it was decided that parallel research would not be a good idea. "

> "The most difficult situations that I have come across with my two mentors have been issues of trust and maintaining a collegial atmosphere. The solutions to these issues have consisted of a large variety of choices, some were very successful and others failed miserably. The major theme of the successful solutions has been to ensure a constant dialog both between advisors and between student and both advisors. This has proven to be tricky at times with proprietary information, but nonetheless is consistently one of the best solutions."

Not all of the potential problems of serving two mentors were worked out at the time of the interviews. See the following examples:

> "At first I found it difficult to juggle having two mentors, finally I came to understand, or rather we came to understand that my NIH mentor, who I saw on a daily basis was the one who should direct me on a daily basis and my (university) mentor would serve in an advisory capacity. I still foresee potential problems during my thesis defense. I could end up doing twice the work to please two people. I will do my best to deal with this potential problem when the time comes."

> "The biggest problem for me is getting my advisors to see that there are problems, and to address them. One is extremely laid back and hands off while the other is the complete opposite and not necessarily in a good way."

The skills that students developed to overcome the challenges of multiple mentors were many, but the one mentioned most frequently was learning how to achieve effective communication that led to resolution of issues rather than letting them languish. This skill obviously overlaps with the high levels of independence described above. One of the best expressions of this was as follows:

> "I had 5 advisors in my first 1½ years, now I have 4. Communication between all of them was the hardest to achieve. They all had differing points-of-view on how I should proceed with my PhD project. I overcame this obstacle by being more involved in the decision-making; rather than allowing the dissenting opinions to languish I made sure that after each meeting/discussion we all reached a reasonable agreement as to the project details etc."

The overarching observation is that students feel they get many benefits from having multiple mentors but they can encounter some challenges. The challenges are usually surmountable and students often see overcoming them as leading to acquisition of important skills.

Potential Concerns About and Problems for Collaborative Dissertations

We also looked for evidence of common concerns that could be raised for collaborative versus traditional dissertation research models. Collaborative dissertations are likely to require more energy and time to manage and may introduce pitfalls that are less likely to occur working with a single mentor. Some problems were encountered by the first students in the programs that were addressed by program design changes, e.g., the need for a written preproposal before starting work in the lab. Observations made during the course of the first 5 years of the GPP and the extensive data gathered during the self-study provided insights into some of the potential problems one might suspect could occur.

Not achieving the level of academic preparation or scholarly contribution expected of the Ph.D. Although this is an issue that will have to be followed closely as more students graduate, so far, there do not seem to be any differences in the performance of students in candidacy exams and the number of abstracts/publications of the students doing collaborative dissertations compared with those with single mentors.

Risk of failing to achieve scientific depth of maturity as a result of not spending enough time with either mentor. Some students commented on this concern and it will be hard to judge until more students have completed their dissertations and their depth and breadth of knowledge is assessed. Some students also talked about a greater sense of urgency and need to focus, knowing they did not have the luxury of multiple years with a single mentor. The assumption is that if the two portions of the project are closely linked, then the student will acquire the same depth of expertise but from two mentors rather than one.

Out of sight, out of mind when working in the "other" lab. This was one of the biggest complications that occurred with the first students in the co-mentored partnerships. Students, mentors, and program leaders failed to recognize the frequency and depth of communication needed to ensure that both mentors kept fully engaged with the work. Without this purposeful communication, some students would move to "the other lab" after 2 yr and encounter a long and steep re-engagement process with the lab and mentor. This problem was solved by students with good communication strategies and "buy-in" to the project by both mentors from the start of the project.

Conflicts with establishment of intellectual property and authorship. These issues are realities of all research collaborations. After some early difficulties with this issue, students are now alerted to it better and given guidance on how to proactively manage any potential conflicts. The importance of openly discussing these topics with everyone involved is stressed. So far, no unresolvable conflicts have been encountered.

Students not feeling like they are an integral part of either the NIH or the university community. In many ways, this lack of community is unavoidable. It was a bigger or smaller issue for different students. Those who are outgoing and engage with new settings quickly, or have less of a need to be part of a community beyond their lab or small social group, were not bothered. The most important outcome of talking with the students was the recognition of the need to help potential students understand this reality so they can factor it into their decisions of whether or not a collaboration between a university and NIH is a good fit for them.

Conflicts trying to serve two mentors. As noted above from the student interviews, and experiences during the first 5 years of the GPP, students could and did encounter some conflicts trying to meet the expectations of two different mentors. The frequency of the conflicts greatly declined with the introduction of the preliminary dissertation proposal; the proposal made it clear to mentors from the start what they were entering into. The preliminary proposal defined the plan from the start, and open, frequent communication kept everyone on the same page. We also discovered that this requirement made it possible to select for those mentors who were open to the dual-mentored process. Mentors who were not comfortable with it realized what was expected and declined to participate. From the interviews, it seemed that most mentors worked hard to keep students from being buffeted by conflicts, taking their mentoring responsibilities very seriously. This was expressed very well by one student as follows:

> "As navigating a collaboration is one of the most important experiences and skills to have in research today, it does not mean that it is always easy. Thus, the biggest challenge in my experience has also been the navigation of the collaboration such as keeping both sides satisfied and yet directing the research toward my own interests. This has been no easy task and often I have failed miserably, but again the ability to learn these skills in an *environment where one is protected* as a student is extremely beneficial and priceless." (emphasis added)

For the process to be successful and enable rapid development, mentors must recognize that the students should be "protected" from situations that could impair their success. They must agree to the unique responsibility they are accepting at this critical stage of student development. When difficulties arose, they almost invariably were the result of mentors placing their needs first, not unlike a cause of problems in some single-mentored dissertations. To date, only one instance of conflicts between mentors that could not be resolved has occurred. The GPP leadership intervened in this instance to prevent it from negatively affecting the student.

DISCUSSION

Much of what is required to evolve from a beginning student, who is simply fascinated with science, to expert scientist, deeply engaged in discovering new knowledge, cannot be provided by classes. One has to experience for oneself the trial and error processes involved with proposing and testing hypotheses. Historically, the most formative element of this evolution has been the very close relationship between one student and one mentor. The results presented here, however, suggest that there may be benefits to extending this intense first phase of predoctoral scientific training to include concurrent multiple mentors and even institutions.

From a practical standpoint, the student experiences reported here demonstrate that it is feasible to purposefully create a co- or multi-mentored Ph.D. training experience, even across institutions. To succeed, this training experience must include faculty who are willing to provide the structures needed to facilitate collaborative projects, and students who seek breadth of scientific experience and possess the needed independence and maturity. Students can be protected from the risks of conflicting scientific views of mentors by proper research planning at the beginning of the training experience and the usual academic oversight provided by Ph.D. programs.

As observed by this study, there are a number of potential benefits to co-mentored dissertations. One benefit is the broader exposure to scientific questions, and how to approach them, that occurs when students are simultaneously mentored by two or more scientists. Equally important is the apparent rapid development of communication and research project management skills that this approach requires. What was perhaps most striking about all of the interviews was the apparent ease with which most students adapted to and took control of their situations. They all saw it as challenging to create the collaborations and manage their project across several mentors, but, with only a few exceptions, they saw it as a positive, growth-producing process they mastered within the relatively short time of their first year or two. The level of independence and maturity many students displayed after even 2 years of graduate school (e.g., negotiating between distinguished scientists, designing and leading a complex project, sophisticated knowledge and expertise related to both labs, scheduling research activities across multiple sites, and so on) exceeded what we have seen in most Ph.D. students or even more advanced trainees.

It would have been difficult to predict the magnitude of impact on the development of professional skills the dual mentorship between university and NIH scientists can have. Students are asked to negotiate across institutions, mentors, cultures, and continents. However, given the right support and structure getting started, and faculty and administrative leadership at both institutions, they acquire skills for negotiation, sustaining autonomy, and control of their work, negotiating complex authorship issues, and many more. These skills do not usually emerge until much later in the development of scientists, often not until well into first professional positions. The ability and rates of development strongly suggest that some students are ready for a more aggressive developmental opportunity than they are provided in most traditional Ph.D. designs. A number of students likened their experience to that of doing postdoctoral research from the start or combining the Ph.D. and postdoctoral experience.

A few potential concerns with dual-mentored Ph.Ds cannot yet be ruled out. Whether students will be less "expert" in each domain of their research due to the demands for breadth cannot be determined at this time. However, their success in passing candidacy exams would indicate they are not lacking by conventional criteria at that point of their training. Another fear that might be raised would be that the complexity of their programs could lead to lower rates or quality of publications; but, again, there is no indication this is true so far.

Not all Ph.D. students will want or be ready to master the extra complexities of dual-mentored dissertations. If the mentorships are established right from the start, as with the NIH–OX/CAM and NIH–KI partnerships, students must have relatively advanced scientific knowledge and interests, because they must propose and start their dissertation research at the start of their first year. This approach is best suited to students ready to accelerate toward independence and advanced research skills that traditional single-mentored approaches may not promote. However, 20 of the students doing collaborative dissertations were not from these programs, establishing those collaborations at various stages of their dissertation research. Thus, the issue of dual-mentored dissertations is completely separable from the unique aspects of the NIH–OX/CAM and NIH–KI partnerships.

Many of the students in this study are engaged in co-mentored collaborations between the NIH and a university lab in another country. Thus, their experiences reflect the collective influences of mentors, institutions, and these countries. Collaborating between institutions in two different countries probably provides a greater potential for growth and challenges, although the study was not designed to quantitatively determine whether this was true. The other complicating factor is that the students attracted to and admitted into the NIH–OX/CAM and NIH–KI partnerships are a very talented and adventuresome group based on their applications and admissions interviews. Thus, they are self-selecting, and being selected, for a specific set of traits that could make them especially receptive to the experience.

There is no reason to expect that the establishment of dual-mentored dissertations would not be just as feasible in typical U.S. Ph.D. programs as the NIH–university partnerships. Students could still establish dual mentorships following the normal time frame and structures of typical U.S.

Ph.D. programs. Collaborative dissertations could be between mentors in a single department or program or could span departments and programs as is encouraged by the IGERT and other new Ph.D. programs focused on interdisciplinary training. It does, however, require faculty and programs to be flexible and interested in their potential value to students and mentors. As noted in the *Introduction*, a number of Ph.D. programs around the United States are exploring this option, and it will be important to determine the impact of these issues on their graduates.

In the early years of the partnerships requiring co-mentoring, the types of problems students encountered were carefully watched and adjustments were made in the program design. Based on these problems and their subsequent correction, some core principles for success were identified:

1. A written research proposal with research questions, specific aims, and experimental design, and a proposed timeline must be established and agreed to by student and mentors at the beginning of the work. This ensures the expectations and needs of everyone involved in the collaboration are clearly defined rather than being left unspoken or ambiguous.

2. Changes in research direction that invariably occur must be clearly acknowledged and agreed to by everyone involved.

3. Frequent and clear communication among all involved is required in collaborative dissertations, including three-way conversations among mentors and students. The student should not always be the message carrier between the two mentors. This is especially critical when mentors are separated by distance.

4. Care must be taken by mentors and program leaders to ensure that the student has the opportunity to create, design, and “own” his or her dissertation research in the face of two accomplished scientists with their natural interests in the research.

5. When possible, the research should represent an integrated study of a single question, bringing together complementary but distinct approaches and expertise. The blending need not be seamless; it may represent two distinct “chapters” related to a broader research question. Universities must be prepared to recognize that the dissertation may seem somewhat different from what is traditionally seen but can still meet the expectations of a scholarly contribution to the field.

6. As in all research collaborations, attention must be given early to explicit discussions of intellectual property and authorship of likely publications.

Not all mentors are equally prepared to be good dual mentors. To be effective, they must be willing to participate in the collaboration, share decision making on guiding the student with another accomplished scientist, engage in the extra communication required, and give the student greater independence than they might normally give. In other words, they must be able to think outside the traditional graduate training “box.” From our experiences, it is much better to select mentors who are willing to grasp this model than to try to convince reluctant mentors.

The results provided here demonstrate that early mentoring by two or more scientists with complementary but distinct interests and approaches to research is not only feasible but also may be advantageous in some ways. Students in this study see nothing unusual about what they are doing; collaboration across scientific approaches has become second nature to them. Because only the first students in the partnerships that require collaborations are beginning to graduate, it is too early to comment on the ultimate impacts on their career choices and trajectories. It is not unrealistic to hypothesize, however, that their high level of independence and ability to establish productive research collaborations could allow them to move more quickly and effectively through postdoctoral training into an independent scientist role. With the well-recognized advancing age at which young scientists are able to establish their independence, often measured by the age at which they achieve their first NIH RO1 grant, anything that could speed this process would be a significant step forward.

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