Abt Associates Inc.

Contractor Annual Report and Summary of the Cross-Site Monitoring of the NSF Intergrative Graduate Education and Research Traineeship (IGERT) Program

Final Report

February 2006

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This monitoring report on the National Science Foundation's Integrative Graduate Education and Research Traineeship Program was prepared under contract numbered REC-99-12174 that gave the National Science Foundation (NSF) the right to place the material into the public domain. This research was conducted in accordance with OMB 3145-0812. Any opinions, conclusions, or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the United States Government.

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We thank the 112 content specialists who visited projects with us and who provided the subject area perspectives and academic assessments so vital to our understanding of the projects. Our special thanks are extended to the 33 content specialists who were able to attend one of our annual June Analytic Meetings and contribute to our synthesis of data across the sites we visited in that year.

IGERT Annual Report

Executive Summary

Introduction

In 1998 the National Science Foundation launched the Integrative Graduate Education and Research Traineeship (IGERT) program, a major initiative aimed at Science, Technology, Engineering, and Mathematics (STEM) graduate education. IGERT was developed to meet the challenges of educating U.S. Ph.D. scientists, engineers, and educators with interdisciplinary capabilities, deep knowledge in chosen disciplines, and technical, professional, and personal skills to become leaders and creative agents for change in their own careers. The program is intended to catalyze a cultural change in graduate education, for students, faculty, and institutions, by establishing innovative new models for graduate education and training that transcend traditional disciplinary boundaries. It is also intended to facilitate greater diversity in student participation and preparation, and to contribute to the development of a diverse, globally engaged science and engineering workforce.

The IGERT Program builds on current research on STEM graduate education, which calls for graduate programs to increase the versatility (and therefore the career options) of doctoral students, stresses the importance of interdisciplinary work, and suggests programmatic improvements (such as exposing students to a broad base of state-of-the-art research tools and methodologies, providing instruction in ethics, and fostering an international perspective). Institutions awarded an IGERT grant currently receive up to $640,000 per year,[1] the bulk of which is distributed as traineeships to approximately 15 students each year who take part in a new interdisciplinary or multidisciplinary STEM graduate education program.

This report is the third in a series of annual IGERT reports from the contracted evaluation of IGERT (OMB 3145-0812), and differs from earlier reports in that it combines our findings from site visits to the first three cohorts of IGERT projects (1998, 1999, and 2000) with broader summary survey data collected from *all* IGERT project PIs and students (1998-2003 cohorts) through annual web-based surveys beginning in the spring of 2000 (OMB 3145-0136). The report describes the perceived impact of IGERT participation on students, faculty, and institutions, as reported through web survey responses of PIs and trainees, and through site visit interviews with students and faculty taking part in the project and with associated department chairs and university administrators. We are limited in our discussion to the reported experiences of our respondents within their IGERT projects. Although we have no measure of how different their experience might have been absent IGERT support, our observations nonetheless provide an in-depth view of these projects and their impacts as perceived by their participants.

Project Characteristics, Leadership, and Management

NSF program guidelines for IGERT intentionally allow considerable flexibility to design projects that build on disciplinary strengths, promote research at disciplinary boundaries, use innovative learning

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[1] Based on the 2003 increase in student stipend from $21,500 to $27,500. The 2004 Announcement (NSF 04-550) expects 38 awardees, each of whom may receive up to $3.0 million plus additional funds for one-time research support and for international travel.

strategies, and adapt to institutional settings. The 100 IGERT projects funded through 2002 span 38 states and sixty-six universities, including twenty-three universities that house multiple IGERT projects. Most projects are discipline-plus models that supplement departmental or interdisciplinary degrees with IGERT requirements, but a handful have developed new interdisciplinary degrees. About a quarter of the projects involve consortial arrangements with industry or other partners that contribute facilities and resources. Slightly less than half of the projects have additional funding sources outside the IGERT grant.

IGERT projects average 15 trainees per project, with fewer trainees in newer projects and a greater number in more mature projects. Although they all have similar training goals for their students, projects vary widely in design and scope. The number of departments and research units involved ranges from one to more than ten, resulting in leadership challenges and management tasks that are many and demanding. Even research universities with traditions of strong support for interdisciplinary research may have institutional structures and policies that pose significant barriers to changing graduate education. Taking on these challenges requires effective and creative leadership—to design an intellectually compelling project, to secure necessary resources and institutional support, and to move from idea to reality by attracting others to the enterprise. PIs have different strengths and styles that influence project implementation, ranging from the PI exercising sole leadership with practically no faculty involvement, to a formal management team with the PI serving as an equal member. Most projects receive support from non-faculty administrative staff, and PIs draw on a variety of other resources to manage projects: co-PIs, other affiliated faculty, technical staff, internal evaluators, post-doctoral fellows, and graduate students. Faculty commitment to IGERT projects varies; a few projects have struggled to find ways to sustain faculty involvement, but most benefit from faculty excitement and commitment to IGERT activities, even at the expense of adding to their existing loads (for example, by teaching IGERT courses as overloads).

Recruitment and Retention of Students and Faculty

Almost all projects use faculty contacts, non-electronic media, competitive stipends, and visits to campus as tools in recruiting students. The most successful recruitment of students to IGERT projects comes through personal connections faculty or other students have with prospective applicants. Overall, projects appear to attract high quality students, with faculty and administrators at several institutions praising IGERT trainees as the most talented, highly qualified students in their programs. Attempts to diversify IGERT student bodies along gender and ethnic lines have met with mixed results. Students from minority groups underrepresented in STEM fields (African American, Native American, and Hispanic) constitute 9 percent of trainees, and women constitute 35 percent of trainees. Projects have begun efforts to move beyond directly recruiting students from these underrepresented groups towards expanding the pool of prospective applicants by enlarging pipelines (e.g., summer research programs for undergraduates, long-term collaborations with minority-serving institutions).

Retaining original faculty and attracting new faculty to IGERT is essential to the health and growth of these projects. The key to sustaining faculty involvement is intellectual engagement; faculty frequently are drawn initially to these projects through their students, and stay because of the excitement of work on problems accessible only through interdisciplinary research collaborations.

Assessment and Evaluation

IGERT projects use a range of approaches to project assessment and evaluation (internal and external, formal and informal), with findings from these evaluations leading to important changes for many projects. Project development and use of evaluation plans has increased over time; many projects did not initially plan for project-level evaluation but began such efforts in the wake of NSF's increasing emphasis on evaluation. One-third of projects employ an evaluator who is external to the university, and one-quarter of projects employ an evaluator from within the university, but external to the IGERT project. The key to successful program modification is a project management that is flexible and open to change, and those projects utilize feedback, either formal or informal, to modify and improve their graduate programs.

Impact on Students

The IGERT program encourages the development of a range of student skills, including research, teamwork, and communication across disciplinary, sectoral, and national boundaries. The common goal of training students as inter/multidisciplinary researchers binds the IGERT projects together, despite considerable differences in project disciplines, research areas, intensity of requirements, scope of involved departments, and mix of educational components. Although projects differ in the ways they attempt to introduce students to multiple disciplines and in their expectations for the degree of student mastery of multiple disciplines, IGERT trainees are virtually unanimous in reporting that their IGERT projects provide them with a much broader, more interdisciplinary education than they would have received in a traditional program. Students may earn interdisciplinary doctorates through new or preexisting programs in 16 percent of visited projects and an IGERT-related certificate or minor in 20 percent.

IGERT projects have combined course work, laboratory, and research experiences to create an integrated doctoral experience for their students, melding multidisciplinary themes into each educational experience. Interdisciplinary understanding is gained through IGERT seminars and sets of core courses, often team taught, that weave the disciplines together to form the multidisciplinary theme. Students' research experiences can include rotations through laboratories of various faculty as well as group multidisciplinary research projects. About two-thirds of the IGERT projects either require internships or offer them as an optional component.

IGERT projects have made progress towards program objectives. Topping the list of activities PIs believe to be most effective were those that bring students from different disciplines together: multidisciplinary trainee activities, from courses, seminars, or brown bags with individuals in other fields to participation in multidisciplinary research endeavors. Also highly rated are activities aimed at preparing students for careers outside of the academic world.

Site visitors found some IGERT projects more successful than others in providing rich, multi-disciplinary programs for their students. The more successful projects often require trainees and faculty to work together across disciplines, rather than simply rotating students through one faculty laboratory after another. They are more likely to directly address any shortcomings students may have in their cross-discipline academic preparation through "bridge" coursework. Such projects are self-reflective as well, seeking feedback and modifying their program to fit student needs. They also make good use of IGERT's funding flexibility, giving students freedom to explore research topics in ways not possible in the traditional apprenticeship model. Students report valuing the "real world" problems being addressed in some IGERTs, and almost uniformly report feeling well positioned to enter the job market—whether in academia or in other venues. Conversely, students in the IGERT projects that are struggling report less attention to these issues, less faculty buy-in, less research across disciplinary lines, and overall, a less cohesive multidisciplinary experience.

Impact on Faculty

The impact of IGERT projects on participating faculty reflects the goals of the program as a whole. PIs report that faculty are sharing mentoring responsibilities across disciplines, teaching new courses that cross traditional disciplinary boundaries, and participating on multidisciplinary dissertation committees. We see signs that IGERT is fostering among faculty a more collaborative culture in which new research problems are identified and fields are advanced. Although some barriers remain, IGERT faculty are generally invigorated, both personally and intellectually, by their projects.

At most IGERT projects, faculty report an increase in their contact with faculty from other disciplines, and several individuals at various sites reported that their own research was directly affected: it changed direction, they gained a student with new ideas, or they began working with another faculty member. Several faculty mentioned collaborating on grant proposals they would not have pursued (or been aware of) without IGERT's influence. At many IGERT institutions, students are the conduit for faculty interactions; thus co-advising or lab rotation arrangements for trainees represent mechanisms for bringing faculty together. Faculty report excitement at being able to work with the talented, energetic students who are the IGERT trainees. IGERT funding has the added benefit of making it possible for students (and associated faculty) to pursue research that does not clearly fit into a single department or is too exploratory yet to be a good candidate for research grant funding.

IGERT projects have been credited with attracting new faculty hires, individuals interested in the inter/multidisciplinary collaboration taking place in and around IGERT projects. Several institutions even dedicated faculty lines to new interdisciplinary hires.

In addition to generating new interdisciplinary research among faculty, the IGERT program has also changed faculty practice in training graduate students, and in some instances, their conception of graduate education altogether. Faculty interact with each other while team-teaching new IGERT course offerings or jointly mentoring doctoral students across disciplines. IGERT courses often contain students from a variety of disciplines, and the presence of "non-expert" students in their courses has affected faculty teaching methods because these students ask questions of a different nature. Faculty also report benefiting from sitting in on each other's courses and interacting within the context of seminar series offered for students. These venues provide fertile ground for faculty to exchange ideas with their peers in other disciplines.

In examining factors that support faculty engagement in these projects and those that raise barriers to success, we noted that strong institutional support seems to go hand in hand with greater faculty participation in the IGERT project. Some institutions view IGERT as a new model for graduate education, something that enhances the university's reputation in general, and/or something to emulate in other areas of the institution. Departmentally-oriented institutional policies, on the other hand, can limit faculty participation. Difficulties assigning course credit can inhibit team teaching or prevent otherwise interested faculty from taking on an IGERT-related course. In spite of these difficulties, committed faculty sometimes take on the course(s) as an overload anyway. We also noted that history makes a difference. In instances where collaborative efforts had already begun to take root before the PI(s) applied for the IGERT grant, faculty engagement is more reliable, and projects seem to mature more quickly then those where epistemological differences between the disciplines have not yet been adequately tackled.

Impact on Institutions

In their first years of operation, these IGERT projects have had an impact on their home institutions in two ways: by soliciting increasing levels of support from their institutions, and by altering mechanisms for graduate education. Institutional support for IGERT projects comes in the form of increased resource allocation, and in the form of modifications to institutional policies to better accommodate inter/multidisciplinary education. IGERT institutions have provided a variety of resources for project activities, including financial resources, staff assistance, and the dedication of space to IGERT project activities. They also have begun changing institutional policies that govern course credit, team-teaching, faculty hiring, promotion, and tenure.

In response to increasing university support for inter/multidisciplinary education, IGERT projects have sparked innovation in graduate education, including new courses, modified degree requirements, and in a few cases, entirely new interdisciplinary doctoral degree programs. Support for inter/multidisciplinary research and education may be catalyzed by the arrival of IGERT projects or be part of an ongoing institutional initiative. IGERT projects at universities with a history of inter/multidisciplinary endeavors benefit from a groundwork of supportive institutional policies and from faculty readiness to collaborate across disciplines. Other universities are using IGERT projects as springboards to develop cross-disciplinary endeavors. It is encouraging to note that projects have begun altering their institutional landscapes, for it is in changing institutional values that IGERT projects have perhaps the best chance of initiating permanent change in graduate education.

Project Development and Growth

Mirroring the dynamic nature of the IGERT program, projects themselves evolve as they implement their plans and respond to changing circumstances and demands. There was evidence that projects transform in response to trainees' needs and feedback. Although most activities are implemented as planned from the outset, projects do expand the activities they offer after the first year. Overwhelmingly, any change occurs between the first and second years of implementation, with most projects offering features addressing specific trainee goals by their second year of activity. There is little change in project offerings from years 2 through 4, partly due to the large proportion of projects whose PIs report addressing a given goal or activity by their second year.

Institutionalization and Future Impact

Institutionalization of IGERT projects occurs along two fronts: making permanent innovative forms of graduate education developed by IGERT projects, and spreading IGERT-influenced ideas about collaboration across disciplines in research and teaching. Successful institutionalization in one area is not dependent on success in the other, though both may certainly occur. The steps taken toward institutionalization vary across projects. Sixty-nine percent of PIs across all cohorts reported having planned for the continuation of IGERT initiatives, concepts, or collaborations, with PIs of more mature projects more likely to report such plans.

Of the 57 projects visited, 15 projects appear likely to institutionalize their entire IGERT educational programs, either as free-standing programs or as part of a larger center or institute. In the majority of the remaining cases, participants are confident that at least some elements of IGERT training will remain: new courses, for example, or departmental requirements (like lab rotations). Unrestricted funding, a cornerstone of the traineeship program that allows students more freedom in exploring research opportunities, will be harder to sustain. A few projects have begun the search for other sources of funding to continue student funding once NSF funding ends. Many projects are looking outside their home institutions, because they fear internal funding will not be available.

Much less tangible than weaving new courses into institutional programs or offering funding for students is the impact participation in IGERT has had on the way faculty and students think about graduate education and cross-disciplinary experiences. Many faculty emphasize IGERT's influence on how they think about teaching and research, and anticipate continuing to work with colleagues outside of their own discipline after IGERT ends. We also observed evidence that IGERT values, ideas, and behaviors have begun to spread to other members of these university communities. Non-IGERT programs at several universities have adopted IGERT-inspired components (e.g., common core classes, ethics courses, internships). New interdisciplinary institutional centers or institutes are also spreading, in part because of IGERT.

A project's ability to institutionalize itself appears to rest on four factors: institutional commitment (financial as well as ideological), adequate resources, faculty interest and leadership, and a compelling conceptual and intellectual base. Institutional commitment is key; to survive long-term, any novel educational program must find a way to fit within its supporting university's goals and missions. University administrators at more than half of these IGERT projects told us that IGERT fits well into their institutional plans to create more inter/multidisciplinary forms of graduate education. Projects also need adequate resources to maintain activities, and finding sufficient funding to continue after NSF funding ends was cited as the most pressing barrier to institutionalization across the board. Many projects have begun the process of seeking alternate resources necessary to sustain project activity. The third necessary condition for survival is sustained faculty interest and involvement. Difficulties assigning course credit can inhibit team teaching or prevent otherwise interested faculty from taking on an IGERT-related course, especially in the long term. Projects that successfully navigate institutional barriers to faculty involvement stand a better chance of surviving long-term. Finally, there are issues related to the project's research/education focus. No project will continue unless there is real interest on the part of faculty and students in its conceptual and intellectual base. This may be the most important factor for success—without interested students and faculty, there is no program. It is also true that a project's success in eliciting funding support is dependent to a large degree on the match of its research theme with the academic priorities of its home institution, internally, and on the "hotness" of the topic, externally.

Conclusion

Many IGERT participants believe that five years is perhaps too short a time in which to change the delivery and culture of graduate education. Still, IGERT projects have already had numerous impacts on students, faculty, and their home institutions. There are good prospects for some form of continuation of many of the IGERT projects, and little doubt that each of these projects, in some way, has had a positive impact on those involved.

Chapter 1. IGERT and the Graduate Education Context

Introduction

The National Science Foundation's Integrative Graduate Education and Research Traineeship (IGERT) program made its initial awards in 1998. Since that time, the program has funded approximately 20 projects a year and, in the fall of 2004, was accepting proposals for its seventh annual competition.[2] IGERT monies are directed to university Ph.D.-granting entities, and are intended primarily for the support of graduate students. Both stipends and cost of education allowances are provided for students, and some additional funds for international travel and for special equipment or materials associated with the project may also be provided. Institutions currently may receive up to $640,000 per year, allowing for the support of approximately 15 graduate students each year.[3] This program is intended to have a substantial impact on graduate education in selected institutions.

Abt Associates Inc. began work with NSF to design an evaluation for the IGERT program in 1999, within a year of the initial program awards. Two sets of monitoring activities were designed, based on a jointly developed conceptual model of the program that specifies program inputs, implementation, outputs, and outcomes—distance monitoring and on-site monitoring. This report addresses findings from these monitoring activities. Distance monitoring is accomplished through an annual web-based survey of all IGERT PIs and trainees (with an optional survey available for project associates), while on-site monitoring takes place via individual site visits to each IGERT project in its third year with trainees. These monitoring activities serve to address the question "Is the IGERT program doing what NSF had in mind?" Specific areas included in the monitoring process, with report chapters in which these issues are addressed, are listed below.

- project leadership, characteristics, and management, including consortial partnerships and their contributions to the projects; strategies for ongoing assessment; additional funding sources leveraged; strategies for recruitment, retention, and mentoring of students, including those from groups underrepresented in science and engineering; and participation of talented and diverse faculty and students (Chapter 2);
- educational experiences and outcomes for trainees and faculty, including evidence of integrative, research-based, graduate education and training activities that are organized around an inter/multidisciplinary theme and are relevant to both academic and nonacademic careers; training in personal and professional skills, including teamwork, communication within and across disciplines and sectors, and international perspective; strength of community culture and presence of collaborative research and education efforts among departments and institutions; evidence of student academic achievement and growth in skills (e.g., academic achievements, publications, self-reported experiences, post-graduation

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[2] This competition, unlike those in past years, proposes to award up to 38 new and renewal awards.

[3] Based on the 2003 increase in student stipend from $21,500 to $27,500. The 2004 Announcement (NSF 04-550) expects 38 awardees, each of whom may receive up to $3.0 million plus additional funds for one-time research support and for international travel.

outcomes); and evidence of faculty growth (e.g., development of connections beyond disciplinary boundaries in teaching and research) (Chapters 3 and 4);

- evidence of institutional change (e.g., expansion of IGERT innovations to other departments or programs; changes in university policies affecting multidisciplinary education) (Chapter 5);
- growth and development of projects over time (Chapter 6); and
- evidence that the IGERT project may be sustained, in whole or in part, after the five-year funded period (Chapter 7).

The annual web-based surveys take the place of NSF-mandated annual reports from the IGERT projects. They provide longitudinal, factual information from each project's PI and trainees, on project structures, participants, and activities. The one-time, on-site monitoring is intended to serve several purposes: to verify and validate web-survey data, and thus encourage accurate annual reporting; to address questions not addressed by the web surveys (e.g., to understand *why* a particular decision was made, to uncover unexpected areas of concern or unexpected ideas for solving common problems); to assess affective responses to project elements (e.g., enthusiasm, intellectual excitement, collegiality); and to permit peer scientist assessment of faculty, trainees, and facilities.

This report is the third in a series of annual IGERT reports from the contracted evaluation of IGERT directed to several audiences: the IGERT Program Office/DGE and the IGERT coordinating committee, for oversight of specific projects, and of the program in general; NSF, to inform decisions about the worth of the IGERT program as a part of its graduate education portfolio; and Congress, as a part of NSF's program evaluation report. It differs from our earlier two reports in that it combines our findings from site visits to the first three cohorts of IGERT projects (1998, 1999, and 2000) with broader summary survey data collected from *all* IGERT project PIs and students (1998-2003 cohorts) through annual web-based surveys.

Site Visits

Visits to all three cohorts of projects were made in their third year of implementation.[4] Two program specialists from either Abt Associates Inc. or our subcontractor, WestEd, spent two days at each project, interviewing all project trainees, the principal investigator (PI), co-PIs, faculty active in the project, chairs of associated departments, and relevant school and university administrators. Two or three content specialists, peer scientists in the research areas included in the project's multidisciplinary theme, accompanied the contractors for one day; they focused their attention on the academic quality of the project and its participants and on the effect of the IGERT project on the development and growth of the multidisciplinary research area. Following each visit, we prepared an individual site report that included verbatim reports from the content specialists. Yearly, after site visits to each cohort were completed, the contractors and selected content specialists convened an Analytic Meeting at the National Science Foundation, where NSF staff and site visitors participated in a discussion about the projects and their cumulative progress toward IGERT's program-wide goals for graduate education reform.

[4] We visited projects in their fourth year of funding; because most projects did not fund trainees in their first year, this is considered their third year of implementation.

Site visit information is based on the 16 1998 IGERT projects we visited during 2001-2002, the one 1998 project and 21 1999 projects we visited during 2002-03, and the 19 2000 projects we visited in 2003-04, focusing largely on the self-reported impact of IGERT participation on students, faculty, and hosting institutions. Our report is based on interviews of participating students and faculty as well as relevant department, school, and university administrators. We want to note that our discussion is limited to the reported experiences of our IGERT respondents, and we cannot measure or report how different their experiences might have been absent IGERT support.

Annual Web-Based Surveys

Information on the current year of operation was collected by ORC Macro each spring through a web-based Data Reporting System from project PIs, funded graduate student trainees, and non-funded associates (graduate students participating in the IGERT doctoral program but not receiving IGERT funds) under OMB 3145-0136 EHR Generic Clearance. Respondents from all 100 projects in the first five cohorts completed the surveys in the spring of 2003. The surveys cover a number of topics, such as multidisciplinary experiences, research, communication skills, internships, and international exposure. Respondents answer a series of closed-ended questions in each section of the survey and then elaborate on, explain, or provide examples for their responses in an open-ended textbox. Each year the web survey collects data on a year-long reporting period beginning September 1 and ending August 31.

For the most part, our discussion of the web survey results revolves around the current reporting period (September 1, 2002 to August 31, 2003), with results from the previous reporting periods, as well as differences between project cohorts (defined by each project's first year of funding), being included when relevant. Data describing project activities come from the PI survey and data describing trainee experiences come from the trainee survey. In many cases, responses are presented only for the 86 projects identified as "active."[5]

There are a few general observations about the trainee survey data that readers should keep in mind when reading this report. First, unless otherwise indicated, trainees' survey responses have been combined from multiple years to reflect their experiences over the course of their graduate program, not just in the current reporting year.[6] Second, it is likely that trainees, when answering questions, report on their whole experience as a graduate student at their university and not just on experiences directly tied to the IGERT project. This is demonstrated when trainee responses are examined at projects whose PIs report not utilizing a particular activity or method. At such projects inevitably some trainees still report having experienced the activity, sometimes in equal proportions as those trainees at projects with the activity. Another common observation is that percentage of trainees reporting a given activity is often low, although the PI reports that the activity in question has been implemented by his/her project. This may be due to multiple factors, including PIs' tendency to report all activities both required and *available*, while trainees only report activities actually experienced. Also, many trainees are in their first years of graduate study and are primarily engaged

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5 An active project has at least two trainees, at least one of whom was funded within his/her first three years of doctoral study. Two additional projects reported at least one trainee, but did not meet the criteria for an "active" project.

6 The yearly surveys ask trainees to report only on their experiences for the current reporting period, so the activities reported in a single year's survey are an incomplete measure of trainees' total experience in the IGERT project.

in taking courses; they have not yet taken part in other project activities. For these reasons, the comparison of trainee survey results with PI results should be viewed with caution.

Because IGERT is not simply a funding stream for student support, but a program that (a) has a strong agenda for the reform of graduate education and (b) makes specific demands of institutions accepting IGERT funds, it is important to situate the IGERT program within the broader context of graduate education reform.

IGERT and the Graduate Education Context

Since the 1980s, institutions that conduct research in concert with graduate education have been buffeted by political, social, and economic changes. The end of the Cold War led to major cuts in defense spending, and resulted in research funding that grew less rapidly than inflation for the first time since the end of World War II. Changes were forced not only by fiscal restraints, but also by a shift of emphasis from a more open-ended support of "basic" research to the support of "strategic" research oriented toward specific national economic, educational, environmental, and other societal needs. Legislators and society at large began to expect scientists and engineers to contribute to new debates on public policy, help improve our competitive position in global markets, create high-value jobs, and improve the education of citizens at many levels.[7]

Such changes in funding and perspective were accompanied by a more insistent concern and immediate stress on the system: namely, the failure of a substantial proportion of Ph.D. graduates in many fields to find employment in the basic research positions for which they had been trained. While the demand by non-traditional employers grew fast enough to absorb most graduates, many employers noted that Ph.D. graduates' training was so specialized that they were neither suitably prepared for entry jobs nor able to readily adapt to non-academic settings.

The cumulative effect of labor market shifts and the concomitant ascendancy of applied research highlighted the graduate education system's inattention to meeting the full range of societal needs for advanced talent in science and engineering. While the U.S. has no federal human resources policy for advanced scientists and engineers, it has become increasingly important to recognize the potential contribution of graduate education to a wide array of national needs through career preparation for professional service, applied research and development, and consulting. In order to address this national problem, the National Academy of Sciences COSEPUP Report of 1995 recommended that graduate education:

- shift graduate student support to education/training grants to bring about institutional change;
- make science and engineering programs more flexible and provide more options for students, so they acquire a broader skill range, and become more versatile;
- control time to degree;
- provide better and more timely career information and guidance while maintaining diversity and excellence in research;

[7] National Research Council, *Federal Support of Basic Research in Institutions of Higher Learning.* Washington, DC, National Academy of Sciences, 1994.

- attract more women and minorities; and
- bring major participants together to discuss these issues.[8]

The COSEPUP authors believed that these changes could be made without disrupting the traditional commitment to basic research, and turned to universities (with the assistance of national and state governments, industry, business, and others) to remold graduate education to address current national needs and realities.

The current discussion about doctoral education has been framed by subsequent research on graduate education, including four studies in particular: Maresi Nerad and Joseph Cerny's *PhDs: 10 Years Later Study* (1999),[9] Jody Nyquist's *Re-Envisioning the Ph.D. to Meet the Needs of the 21st Century* (2000),[10] Chris Golde and Timothy Dore's *At Cross Purposes* (2001),[11] and the Woodrow Wilson National Fellowship Foundation-supported *Responsive Ph.D.* program.[12] Each examined graduate education from a different perspective: Nerad from that of Ph.D. recipients ten years after graduation, Nyquist from that of nine different stakeholder groups,[13] and Golde and Dore from that of students in their third year of graduate study. The fourth endeavor, the Woodrow Wilson National Fellowship Foundation-supported *Responsive Ph.D.* program, had the goal of "sharpen[ing] into major recommendations for change the findings of several recent studies and projects on doctoral education." They focused on what they call the three "P's": paradigms, practices, and people.

Despite their diverse perspectives, findings and recommendations across these studies were remarkably similar to each other, and to those of the COSEPUP report. All of these authors emphasize the importance of:

- **Increasing the versatility, and therefore the career options, of Ph.D. candidates** (1) through training in skills commonly required in business, industry, and the private sector, including teamwork and managerial skills, (2) through participation in internships, and (3) through the provision of more career assistance and job placement; and

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8 Committee on Science and Public Policy (COSEPUP), *Reshaping the Graduate Education of Scientists and Engineers*. Washington, DC, National Academy Press, 1995.

9 Nerad and Cerny's study surveyed nearly 6,000 PhDs who completed their graduate education in six disciplines between 1983 and 1985 (www.educ.washington.edu/COEWebSite/Cirge/HTML/research_projects.html).

10 Nyquist's study includes a compendium of more than 300 "best practices" at participating institutions; this highlights the movement toward innovative strategies and actions for change within the academy (http://www.grad.washington.edu/envision/practices/index.html).

11 Golde, C.M. and Dore, T.M. "At Cross Purposes: What the Experiences of Doctoral Students Reveal about Doctoral Education" (www.phd-survey.org). Philadelphia, PA: A report prepared for The Pew Charitable Trusts, 2001.

12 According to their website (www.woodrow.org/responsivephd), the Woodrow Wilson National Fellowship Foundation received a beginning grant from The Pew Charitable Trusts. They are working with 14 Ph.D.-grant universities to test and develop a model for innovation and change.

13 Nyquist's stakeholder groups are research universities, teaching universities, K-12 education, government funding and hiring agencies, business and industry, foundations, professional societies, educational organizations, and graduate students.

- **Encouraging interdisciplinary work**, not solely in support of wider career options but also, as noted in the *Responsive Ph.D.*, for the encouragement of "adventuresome research."

These two thrusts are instrumental to the notion put forth both by Nyquist and the *Responsive Ph.D.* of **doctoral graduates as citizen scholars** who use their scholarship and creativity to address the needs of society.

Other suggested **programmatic improvements** included:

- inculcating values and ethics,
- increasing exposure to technology, and
- incorporating understanding of the global economy and environment.

Better preparation for a variety of professorial roles was addressed through recommendations to involve students in departmental and university governance and to provide broad pedagogical training.

Some authors also addressed the **structure of doctoral programs**, suggesting that programs:

- review Ph.D. program requirements and courses to ensure that they contribute to the programs' educational goals and to ensure the shortest possible time to degree;
- clarify the doctoral programs' expectations for graduate students;
- provide (adequate/good/multiple) mentoring for students, reward faculty for such mentoring, and conduct annual reviews of student progress; and
- improve program assessment by students and communicate with students about their experiences.

Some of the reports also emphasized the need for more racial/ethnic diversity among Ph.D. recipients. The *Responsive Ph.D.* pointed out that, while retention earlier in the educational pipeline is a crucial part of the solution to this problem, doctoral programs must do their part in improving recruitment and retention strategies. Finally, several reports stressed the importance of creating partnerships with all groups involved in graduate education, either as producers or utilizers, to bring about the changes recommended.

As of 2001, then, notions of needed graduate education reform were very much in discussion, moreover, there was some consensus in the literature. This consensus may well have reflected the pressures on graduate education—from those who hire Ph.D. recipients, from the increasingly interdisciplinary direction of research itself, from graduate students as the consumers of graduate education, and from the needs and demands of the larger society. However, regardless of scholars' consensus on next steps, most doctoral programs remained within the traditional paradigm: students worked within a single department, apprenticed to a single professor, and engaged in narrowly focused coursework and research. Their expected career goal was to remain in the academy as professors. Breaking this mold would require will, time, effort, and resources.

NSF has played a significant role in stimulating and supporting changes of the sort recommended in the reports cited above through its use of graduate traineeship awards. Because these student support grants are given to institutions rather than to individual students, NSF has an opportunity to mold the graduate education agenda on an institutional level. If university entities have the will and a plan for change, NSF can provide resources to support their effort.

NSF's GRT program, the precursor to the IGERT program currently under review, funded 157 projects from 1992 through 1995. The program sought to stimulate the development of graduate training environments that promote and sustain broader participation in areas of national science and technology priority. GRT projects extended the traditional concept of graduate science, technology, engineering, and mathematics (STEM) education to broaden the STEM human resources base, as well as to include educational interactions, mentoring, and professional development opportunities above and beyond focused research with one major professor. IGERT, in keeping with its later origin, is not only more forceful in terms of potential impact through greater funding, but also more explicit in its encouragement of changes in graduate education.

The IGERT program has been developed to meet the challenges of educating U.S. Ph.D. scientists, engineers, and educators with interdisciplinary capabilities, deep knowledge in chosen disciplines, and the requisite technical, professional, and personal skills to become leaders and creative agents for change in their own careers. On a broader level, the program is intended to catalyze a cultural change in graduate education for students, faculty, and institutions by establishing innovative new models for graduate education and training in a fertile environment for collaborative research that transcends traditional disciplinary boundaries. It also is intended to facilitate greater diversity in student participation and preparation, and to contribute to the development of a diverse, globally engaged science and engineering workforce.[14]

The IGERT Program Solicitation lists the features NSF expects funded projects to incorporate. The expected features parallel very closely those put forward in the current reform literature discussed above. Grouped under the major points cited earlier, IGERT's programmatic expectations include:

Increasing the versatility, and therefore the career options, of Ph.D. candidates:

- provisions for the development of personal and professional skills (e.g., communication, teamwork, teaching, mentoring, leadership); and
- opportunities for career development, such as internships and mentoring in various settings (e.g., industry, national labs, academic institutions, non-U.S. institutions).

Encouraging interdisciplinary work:

- a comprehensive inter/multidisciplinary theme that serves as a foundation for traineeship activities; and

[14] Integrative Graduate Education and Research Traineeship (IGERT) Program, Program Solicitation, NSF 02-145 (http://www.nsf.gov/pubs/2002/nsf02145/nsf02145.htm).

- integration of inter/multidisciplinary research with innovative graduate education and training mechanisms, and other educational features that foster strong interactions among participating students and faculty within and across disciplines.

Programmatic improvements:

- exposure to a broad base of state-of-the-art research and educational tools and methodologies;
- instruction in ethics and responsible conduct of research; and
- fostering of an international perspective.

Structure of doctoral programs:

- a strategy for recruiting, mentoring, and retaining U.S. graduate students, including members of groups underrepresented in STEM fields;
- a strategy for formative and summative assessments of project performance;
- an effective administrative and organization management plan; and
- institutional commitment to a supportive environment for integrative research and education.

Thus, the IGERT program is located within the main thrust of current graduate education reform. By supporting interdisciplinary graduate education projects, NSF is seeking to stimulate and support innovative change in graduate STEM education. Because the overall IGERT program is flexible, allowing each individual grantee considerable latitude to operationalize its own IGERT project, NSF is encouraging the development of new ideas that allow for accommodation to specific institutional contexts. There is much to be learned from this series of experiments in innovative graduate education.

Recent Changes in the Literature of Reform

Have the reforms discussed above had a noticeable effect? It appears that they have, at least within some graduate schools. In 2004, Catherine Stimpson, Dean of the Graduate School of Arts and Sciences at New York University, wrote a review for the *Chronicle of Higher Education*[15] stating that today's graduate students are more likely to "find diversity among the people in your seminars, to be taught how to teach, to learn how to enter 'the profession' and also how to use a degree outside the academy, to hear your graduate school worry how long it will take you to get your degree, and to enter programs that weave disciplines together." All of these are goals that the reforms discussed above sought, and would applaud.

Even as these reforms within graduate education have been accepted generally and at least partially implemented, however, other concerns have surfaced. In the same review, Dr. Stimpson expressed

[15] "Reclaiming the Mission of Graduate Education" (http://chronicle.com/weekly/v50/i41/41b00601.htm), June 18, 2004.

“deep anxieties” about graduate education and the American research university in 2004. Her major concerns are three-fold:

- American graduate education is dependent on international students (83 percent of humanities doctorates are awarded to U.S. citizens, but just 60 percent of science and 43 percent of engineering doctorates). She cautions that this influx of international students is not reliable, both because of the growing competition from graduate education in the students’ homelands or from Canadian, European, and Australian universities, and because post 9/11/01 American visa policies are deterring foreign students from seeking to enter the U.S.
- American students will not be available to fill this potential void, because of American attitudes towards science education and science. Pathways to the sciences, beginning in middle school, are inadequate for leading American boys and girls of all races and ethnicities into science as a profession. As Stimpson writes, “we have opted for importing human capital instead of richly blending local and international intelligences.”
- All universities, except the very richest, are being ground down by financial difficulties—governments are asking more of public institutions and giving them less with which to do it. Public funds cover a smaller proportion of public university’s costs, despite overwhelming evidence that research and education are fundamental to the growth and well-being of modern society.

These concerns were foreshadowed by, among others, the National Science Board in their *Companion to Science and Engineering Indicators 2004, An Emerging and Critical Problem of the Science and Engineering Labor Force*.[16] They highlight the lack of growth in the number of U.S. citizens who are training to become scientists and engineers and the decline in availability of people from other countries, while the number of jobs requiring scientific training continues to grow. They also point to the need for a sustained, long-term commitment to address this problem, given the length of the educational pipeline to the workforce. Their recommendations emphasize education: “The Federal Government has primary responsibility for supporting higher education in science and technology at levels that allow the study of science or engineering and future careers in those fields to be competitively attractive with other fields.” The NSF’s substantial investment in the IGERT program and the decision to increase the annual IGERT trainee stipend to $27,500 in 2003, and to $30,000 for awards based on the 2004 Program Solicitation (NSF 04-550), reflects this effort to make graduate study in the sciences and engineering more competitive with other career options open to the brightest American students.

There are two main dissenting voices from this analysis of scientific workforce challenges. One questions the accuracy of the pipeline and workforce assessments cited above; the other suggests that, viewing education as the supply side of the equation and workplace conditions as the demand side, the more effective solutions focus on the workplace, or demand side, of the equation.

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16 National Science Board, *Companion to Science and Engineering Indicators 2004, An Emerging and Critical problem of the Science and Engineering Labor Force.* Arlington, VA: National Science Foundation, (NSB-04-07), 2004.

Those who question pipeline statistics[17] point, as a possible parallel, to the mid-1980s NSF warning that the nation would soon lack enough scientists to maintain the professoriate, "a forecast that turned out to be wildly inaccurate." They point out that, while the *Science Indicators 2004* does show fewer earned doctorates and fewer visas issued to foreign students, NSF and American Chemical Society statistics also show more Americans earning bachelor's degrees in science and engineering, increased graduate enrollment as of 2002,[18] and increased unemployment, at least among chemists, in 2002 and 2003. NSF also reports that 76 percent of international students getting Ph.D.s in the U.S. intend to stay within the country, up from 63 percent a decade ago.

The demand-side argument is described by Zumeta and Raveling,[19] who list three disincentives for students choosing advanced science education: (1) training and apprenticeship times are very long, ten years or more; (2) compensation for graduate and postdoctoral appointees, often in their mid-thirties, are very modest for professionals of that age; and (3) graduates' prospects for an autonomous research position in academe or elsewhere are "uncertain and increasingly slim." These authors, taking a policy perspective, see it as "critical to recognize that the research and teaching most scientists do has an important public good element, meaning that society as a whole benefits in ways not fully valued in market signals such as compensation levels." They point out that policies have traditionally focused on the supply side of the equation—an effort that, even were it to succeed, would lead to "the unappealing postdoctoral logjam pattern that is now common in the life sciences." Instead, the authors suggest federal support for a modest number of selective research assistant professorships at universities as a demand-side effort to improve the situation.

Richard Freeman, a professor of economics at Harvard University, points out that students and postdoctoral associates, especially from foreign countries, make up the academic science engine's corps of "cheap labor." "It runs the system, and it runs it very efficiently, in terms of the taxpayer."[20] The vested interest of academe in keeping the numbers of graduates students and postdoctoral associates high, regardless of career options for graduates, leads some to be skeptical of forecasts of undersupply.

Warren Washington, Chairman of the National Science Board, says professors in departments have the responsibility to ask themselves, "Are they generating too many students? Or are they generating students who haven't got the skills to apply for the jobs out there?"[21] This returns us full circle to questioning how universities are training graduate students, and what skills they gain to apply to jobs outside of academe—an issue at the core of IGERT's program goals.

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17 Monastersky, R. "Is there a Science Crisis? Maybe Not." *The Chronicle of Higher Education* (http://chronicle/weekly/v50/i44/44a01001.htm), July 9, 2004.

18 Monastersky quotes NSF as follows: "Overall, the declines in total graduate S&E enrollment from 1994 through 1998 have reversed with gains in enrollment every year since 1999."

19 Zumeta, W. and Raveling, J. S. "Attracting the Best and the Brightest." *Issues in Science & Technology*, January 10, 2003.

20 Monastersky, R. "Is there a Science Crisis? Maybe Not." *The Chronicle of Higher Education* (http://chronicle/weekly/v50/i44/44a01001.htm), July 9, 2004, p. 7.

21 Monastersky, R. "Is there a Science Crisis? Maybe Not." *The Chronicle of Higher Education* (http://chronicle/weekly/v50/i44/44a01001.htm), July 9, 2004, p. 8.

The remainder of this report describes findings from site visits to the first three IGERT cohorts, couched within the broader context of all IGERT projects as described by data from the annual web-based surveys. In the next chapter, we focus on projects' general characteristics and their leadership and management. Chapters 3, 4, and 5 focus on what the project-specific implementation of these programmatic features has meant to key groups within the graduate education enterprise—the students, the faculty, and the graduate education institutions. Chapter 6 explores these features from the perspective of the longitudinal record of the annual web surveys, and Chapter 7 concludes with a discussion of steps taken by projects towards institutionalization.

Chapter 2. Project Characteristics, Leadership, and Management

Introduction

The NSF IGERT program has an explicit goal of promoting change in graduate education, yet it allows projects considerable latitude in designing graduate education models that build on disciplinary strengths, promote research at the boundaries, use innovative learning strategies, and adapt to institutional settings. This flexibility is evident in the considerable variation we found in project design across projects.

- While most projects employed a discipline-plus model in which IGERT requirements are fulfilled in addition to departmental requirements, a handful had created new interdisciplinary degree programs.
- Over one-fourth of projects reported at least one consortial arrangement with industry or other partners.
- Under one-half of projects had additional funding sources for their projects outside IGERT.
- Three-quarters of projects visited had a non-faculty administrator. Leadership styles ranged from PI management with minimal faculty input to management structures that involved faculty teams in shared decision-making.

There was additional variation in the practices and strategies employed across projects. For example, projects employed a variety of strategies to recruit top graduate students. They met with varying degrees of success, especially in recruiting individuals from groups underrepresented in the science and engineering workforce. In efforts to involve faculty with the appropriate expertise and interest, projects recruited from participating departments and sometimes by influencing new faculty hires. Also, projects differed in their approaches to and use of student assessment and project evaluation—tools that help projects measure their progress toward their educational goals, integrate the various program components, and adjust in response to changing needs. Some projects relied on informal student feedback, while others employed an external evaluator.

IGERT projects bring together investigators from one or more departments within a single institution, or from more than one institution, in a spirit of collaboration. The emphasis of the IGERT program is on the education of graduate students, but the program also supports efforts that include undergraduate and/or postdoctoral students if such participation strengthens the proposed graduate education program.

This chapter begins with an overview of the IGERT projects, the participants in the 1998 through 2002 cohorts, and variation in project design among projects. It then moves on to describe program details that emerged during site visits to the first three cohorts and to consider the basic elements on which IGERT projects depend:

- project leadership, including leadership styles of principal investigators and the nuts and bolts of project management;
- recruitment into the project of both trainees and faculty; and
- project use of assessment and evaluation.

Project Characteristics

Through 2002, NSF funded 100 IGERT projects: 17 in 1998, 21 in 1999, 19 in 2000, 22 in 2001, and 21 in 2002. The 100 IGERT projects funded through 2002 span 38 states, and sixty-six universities serve as home institutions, including twenty-three universities that house multiple IGERT projects.[22]

Project Participants

The IGERT projects have involved a sizable number of participants. Exhibit 2.1 presents numbers of projects, faculty, trainees, and associates by cohort. Overall, 88 sites had trainees through the 2002-2003 academic year, and 57 sites included associates. Across all cohorts, projects average 15 trainees per site. As might be expected, more mature projects have more trainees: 1998 and 1999 projects average 19 trainees, while 2000 and 2001 projects average 15 and 12 trainees, respectively. The 9 2002 projects that worked with trainees in the 2002-2003 academic year averaged fewer than 5 trainees. All cohorts show growth in the number of participants from year to year. For example, collectively the 1998 projects had 273 trainees last year and 320 this year. Together IGERT projects funded 1,294 trainees in the 2003 reporting year, up from 932 in the previous year.

In addition to the 1,294 trainees who were active and included in the 2003 web survey, many projects also involve students in IGERT activities who are not trainees. Not all projects choose to report these associates in the web survey (it is optional), so the total of 452 associates reported in 2002-2003 may underrepresent the total number of other students actively participating in IGERT projects.

A goal of the IGERT program is to increase the number of individuals from underrepresented groups in science and engineering programs. Of the active trainees, 35 percent are women and 9 percent come from minority groups underrepresented in STEM disciplines: Black, Native American, or Hispanic. Two percent of the trainees report having a disability (mobility, visual, hearing, or other). Data collected from the annual survey indicate that diversity is even more limited among IGERT PIs. Twenty of the PIs (20 percent) are female (one PI did not report gender) and 3 percent are from underrepresented minority groups.[23] None of the PIs reports having a disability.[24]

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[22] Two institutions house four IGERT projects each; 5 institutions have three IGERT projects each; and 18 others have two IGERT projects each.

[23] An additional 3 percent did not report their ethnicity.

[24] Disability status options include: hearing, visual, mobility/orthopedic impairments, and self-defined “other.”

Exhibit 2.1

Projects, and Active Faculty, Trainees, and Associates, by Cohort by Year

	All	1998	1999	2000	2001	2002
Number of Projects	100	17	21	19	22	21
Number of Faculty						
• 2000 reporting year	465	222	243	0	0	0
• 2001 reporting year	694	256	302	136	0	0
• 2002 reporting year	1,111	267	399	211	234	0
• 2003 reporting year	1,412	267	449	246	329	121
Number of Projects With Trainees in 2003	88	17	21	19	22	9
Number of Projects With Associates in 2003	57	13	17	11	13	3
Number of Trainees						
• 2000 reporting year	307	185	122	0	0	0
• 2001 reporting year	597	245	230	122	0	0
• 2002 reporting year	932	273	323	231	105	0
• 2003 reporting year	1,294	320	401	279	254	40
Number of Associates*						
• 2000 reporting year	128	55	73	0	0	0
• 2001 reporting year	249	58	128	63	0	0
• 2002 reporting year	384	85	188	80	31	0
• 2003 reporting year	452	100	205	76	54	17
Average Number of Trainees per Project (2003)	15	19	19	15	12	4
Average Number of Associates* per Project (2003)	8	8	12	7	4	6

Source: OMB 3145-0136 EHR Generic Clearance: Survey of Principal Investigators, Survey Years 2000, 2001, 2002, and 2003.

Abt Table Production Date: February 2004 for IGERT 2004 Cross-Site Monitoring Annual Report

* The number of associates reported in the web survey is not a complete indication of the number of students who, while not funded through NSF, choose to participate in IGERT projects in some fashion. Projects are not required to have associates complete the web survey, and only some choose to do so.

The 2003 survey provides information on 1,412 co-principal investigators (co-PIs) and/or Faculty Advisors to students who were involved in IGERT projects during the 2002-2003 academic year; 73 percent were reported to be Faculty Advisors, 13 percent co-PIs, and 14 percent both co-PIs and Faculty Advisors. Eighty-two percent of these individuals are United States citizens. These faculty members are similar in gender and race/ethnicity to the PIs: 18 percent are women,[25] and 4 percent

[25] Fifty-one co-PIs did not report their gender.

are from underrepresented racial/ethnic groups.[26] These proportions are fairly consistent across cohorts and similar to those for faculty who were active in previous years. Seventeen of these individuals (just over 1 percent) report having a hearing, mobility, or other handicap.

Overall, 62 percent of projects report undergraduate and/or postdoctoral student participation in their projects in 2003. Table A.1 in Appendix A shows the distribution of postdoctoral and/or undergraduate student participation across cohorts. Thirty-two percent involve only undergraduate participants, 15 percent involve only postdoctoral participants, and 15 percent support both undergraduate *and* postdoctoral participants. In all but the 2000 cohort, projects are more likely to involve undergraduates than postdoctoral fellows. Earlier cohorts (1998, 1999, and 2000) are more likely to involve undergraduates and postdoctoral students than the later cohorts.

Project Design

Establishing a successful IGERT project and building a strong interdisciplinary research agenda require a sound project design, but the design varies considerably across projects. Reflecting the IGERT program's emphasis on multidisciplinarity, the 1998-2000 projects include a wide range of multidisciplinary themes, and are led by PIs from a variety of disciplines. Table A.2 in Appendix A lists characteristics for the 57 IGERT projects visited, including departments/schools involved, program history, and multidisciplinary focus area. An overview of findings included in that table are provided here.

- Although most of the projects built on existing collaborations, 17 (30 percent) represent new programmatic efforts. Five projects in the 1998 cohort (29 percent), three in the 1999 cohort (14 percent), and nine (47 percent) of the 2000 cohort projects reported being new or emerging programs in which IGERT funds played a critical role in jump-starting their efforts.
- Projects involve differing numbers of departments, ranging from one or three at the low end, to 10 or more different departments and research units. One project is an outlier, with 24 participating departments.
- Some projects span disparate fields, including bridging the social science-natural science divide, while others are grounded in emerging fields of study.

Variation in Design

Sometimes IGERT proposals result from a grassroots faculty effort; others are the product of collaborations led by PIs with strong visions. Regardless of their origins, most IGERT PIs and their colleagues have designed projects that have made discernable changes in graduate education and show signs of influencing departmental and institutional cultures. A few have struggled with this task. An IGERT project that both supports institutional goals and motivates faculty participation is most likely to succeed. However, as one co-PI observed: "It is easier to get faculty to put together a proposal than it is to get them involved in the program."

To have an impact on the culture of graduate education, projects must effectively articulate the value of IGERT participation for students and faculty in the relevant disciplines. The Ph.D. is a research

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[26] These included individuals who reported their race or ethnicity as American Indian or Alaska Native, Black or African American, or Hispanic or Latino. An additional 8 percent reported neither their race nor their ethnicity.

degree, and traditional doctoral programs have a research apprenticeship model in which doctoral candidates learn primarily through the conduct of research with one faculty mentor. In contrast, IGERT emphasizes the integration of graduate education and interdisciplinary research, so that how faculty decide to organize student learning is a significant design element. While many IGERT projects focus primarily on research, others have developed innovative courses and other learning opportunities as central elements of their projects.

NSF program guidelines for IGERT intentionally allow considerable flexibility to design projects that build on disciplinary strengths, promote research at the boundaries, use innovative learning strategies, and adapt to institutional settings. Therefore, variation in project design is not surprising. Although most IGERT projects are discipline-plus models that supplement departmental or interdisciplinary degrees with IGERT requirements, five projects developed new interdisciplinary degrees. In addition, one project offers trainees the opportunity to seek a dual Ph.D.

Project designs have also included inter-institutional partnerships. Unlike the initial IGERT cohort (1998), which proposed no such partnerships, the second IGERT cohort (1999) included six grants to multiple institution/campus partnerships. In addition, two different projects later split to include a second institutional partner. In the 2000 cohort, three multiple campus IGERT projects were funded. In addition, the one state university IGERT includes a second university campus, and another state university IGERT includes faculty from a second campus.

For faculty and students in multiple institution/campus projects, bridging campus and institutional boundaries as well as disciplinary differences poses additional logistical and communication challenges, and, although the opportunities for collaboration offer potential synergies, project management also requires a greater degree of coordination. Therefore, when IGERT proposals include multiple institutions/campuses, specific mechanisms are established for decision-making and formulas are agreed upon for distributing IGERT funding. For example, one dual-institution project established a 2:1 ratio for distribution of financial resources that reflected a similar ratio of faculty involved, and co-PIs at each institution share leadership. However, not all IGERT partnerships function as planned in proposals. For example, in one project a partnership between one university and another university's business school did not initially develop the close collaboration envisioned in the proposal. Due in part to lack of clarity in project administration, the proposed business school rotations have not materialized. At another project that involves three institutions, project administration has been a major challenge for the PIs. According to their external evaluation team, the greatest difficulties involve coordinating work and dispensing funds, including how to handle excess funds generated by the lack of trainees from two of the partner institutions.

In the case of the most extreme example of multiple campuses, all project activities take place in the summer at the home university's field biological station. Because of this, the distribution of funds to partner institutions is limited to student stipends, cost-of-education allowances, and travel to and from the station. Management of these multiple transactions, in addition to the usual project management challenges, requires the attention of a full-time project manager.

In addition to partnerships with other universities, IGERT projects also frequently involve consortial arrangements with industry or other partners that contribute facilities and resources that benefit IGERT trainees. For example, IGERT projects may have arrangements with National Laboratories and with research institutes in the United States and in other countries. IGERT projects are encouraged to establish consortial arrangements with other entities to strengthen or enrich the graduate education provided to students.

Across all projects funded through 2002, 28 percent of IGERT projects have at least one such arrangement. The most common partners in these arrangements are other institutions (68 percent of projects with consortial arrangements); federal laboratories (25 percent); and corporations (18 percent). A few projects also have partnerships with state or local governments, federal agencies, and foreign governments. See Tables A.3, A.4, and A.5 in Appendix A for specific information on consortial arrangements in IGERT projects.

Other Funding

Since NSF IGERT funding has a limited duration, PIs and their colleagues recognize that external funding for research is critical to sustaining innovation in interdisciplinary graduate education. External support for research and graduate education in an emerging field signals to faculty as well as university administrators the value of the enterprise. Many IGERT projects have been very successful in attracting additional external funding.

Across all projects funded through 2002, 44 percent have additional funding sources for their projects outside the IGERT grant. The most common donors to IGERT projects are institutions (50 percent of projects with additional funding receive funds from this source), corporations (27 percent), federal agencies (20 percent), and state or local governments (20 percent). Tables A.6, A.7, and A.8 in Appendix A provide an overview of the distribution of additional funding received by IGERT projects from a range of donors, including corporations, National laboratories, NSF, and other governmental and non-governmental sources.

In addition, 23 percent of projects with additional funding receive NSF funding beyond the IGERT grant. The average amount of direct donations varies by donor type, ranging from $18,000 from corporations, to $99,994 from the National Science Foundation. Donation amounts to projects summed across all sources vary widely, ranging from as little as $300 to as much as $2.6 million. The percent of projects with additional funding sources is greater in older cohorts, suggesting that projects may add funding sources after their initial start-up period.

IGERTs also succeed in procuring additional university resources, which in turn strengthens the project and increases the likelihood of sustainability and of further leveraging of external funds. University support comes in many forms, including funding staff positions, creating new administrative units, and providing additional student support (frequently to support international students). Chapter 5, Impact on Institutions, describes university resources in detail.

Leadership

The IGERT goal of changing graduate education challenges the long established research university institutional culture where faculty work on individual research agendas embedded in disciplinary units. Even research universities with traditions of strong support for interdisciplinary research may have institutional structures and policies that pose significant barriers to changing graduate education. Taking on these challenges requires effective and creative leadership to design an intellectually compelling project, secure necessary resources and institutional support, and move from idea to reality by attracting others to the enterprise. The IGERT project leadership takes on these challenges when NSF funds a project. In this section, we explore two elements of project leadership, PI leadership style and project management, that are critical to successful IGERT projects.

PI Leadership

Within university contexts and disciplinary cultures, PIs play key roles in developing the intellectual scope, research priorities, pedagogical approaches, and decision-making processes of an IGERT project. PIs articulate the value of IGERT to university administrators and faculty colleagues in various fields, take the lead in developing consortial relationships and securing external funding for research, and work with the NSF IGERT Program Office to inform decisions about the program's future direction. While the IGERT application process requires identification of a single PI, one or more co-principal investigators (co-PIs) are usually identified, and many IGERT projects effectively have multiple PIs, which makes sense, especially when projects bridge disparate disciplines or break new ground.

Faculty, administrators, staff, and trainees interviewed during site visits generally have very high praise for their IGERT PIs. There is clearly no one best way to run an IGERT project, and different leadership styles can be equally effective. In fact, what works very well for one PI might be counterproductive for another. In addition to the personal strengths and characteristics of a PI, a university's institutional culture may demand or reinforce faculty collaboration, or it may promote a more entrepreneurial leadership style.

We observed considerable variation in leadership styles among the IGERT PIs, specifically in the nature of faculty involvement in decision-making. At one end of this continuum are PIs who make IGERT management decisions with minimal faculty input and, at the other end, are PIs who manage by leading a team with multiple structured roles for project faculty in shared decision-making. Examples, from IGERT projects in the first three cohorts, of the range in leadership styles are provided below.

- At one end of the continuum is the PI who is closely identified with the IGERT project and makes decisions with minimal faculty involvement. At one project, for example, IGERT has benefited from the strong and persuasive leadership of the PI. Faculty comment on her ability to bring together faculty from a variety of fields and forge a common vision. IGERT faculty meet twice a year, and other communication and decisions are handled via email. Few PIs employ this more solitary leadership style, and none from the 2000 cohort.
- Other projects are headed by a PI who is the recognized leader of the IGERT project, but who also makes most project decisions with informal involvement of co-PIs or other IGERT faculty. This is one of the most common leadership styles, and we saw examples in each cohort we visited. At one project, for example, a top university administrator calls the IGERT PI "the perfect PI with universal respect." Faculty and trainees agree, with one trainee pointing out that she "runs a pretty tight ship," and faculty applauding her for convening "limited, productive meetings." The PI credits being "very well-organized" for her success. Her hands-on approach includes meeting individually with each trainee every year to review progress.
- In other projects, the PI serves as the head of a project that includes regular, formal faculty involvement, often in the form of committees. These projects typically include an

executive or steering committee and decisions are generally made by consensus. For example, at one project the PI is an experienced, seasoned project manager described by colleagues as a manager, visionary, and mentor/advisor. A co-PI describes him as a "good director, totally open and non-dictatorial." He makes effective use of the Steering Committee, whose members report that demands on their time are not insignificant, but also are not a drain.

- Finally, there are projects in which leadership and decision-making are shared responsibilities. These projects include structured participation by co-PIs, and other IGERT faculty, who make project decisions as members of a formal management team. At one project, IGERT has an effective organizational structure that involves faculty members at selected points and relies on a strong administrative staff to manage daily operations. An administrator described the PI as a visionary who is able to put her own ego aside to bring others along and encourage collaboration. She and three co-PIs provide project leadership, and faculty committees oversee activities and make IGERT decisions. This is the second most common leadership style found among projects in the first three cohorts, and the most common style among the 1999 cohort projects.

Whatever the PI leadership style, IGERT success requires strong and energetic leadership to implement and sustain these complex, multidisciplinary projects. Whether individual or collective, dedicated and effective PI leadership of IGERT projects is critical.

Project Management

The site visits revealed that management tasks of an IGERT project are many and demanding, and PIs have different strengths that influence project implementation. Although some PIs have extensive management experience, others have limited experience managing complex projects. Some PIs delegate management tasks to administrative support staff or faculty committees, and others are very hands-on managers. Institutional resources and support needed for effective project management (e.g., fiscal reporting, recruitment, logistics, scheduling) are more likely to be available in IGERT projects housed within larger administrative structures. Such existing structures take different forms, including interdisciplinary degree-granting programs, centers, or institutes. For example, one project is situated in an interdisciplinary degree-granting program with established administrative rules and structures that support interdisciplinary study. This preexisting structure has made it easier to allocate faculty work, identify courses, and assign teaching credit.

Most PIs rely on many individuals to manage IGERT projects: co-PIs, other affiliated faculty, administrative support staff, technical staff, internal evaluators, post-doctorates, and/or trainees themselves. Representation on IGERT committees and roles of these committees vary, and committees may meet only once or twice a year, or much more frequently. Generally, the most important decisions involve admitting students, allocating traineeship funds, establishing requirements and, as the project proceeds, redesigning interdisciplinary courses and other educational experiences. Structures include IGERT committees (steering, executive, admissions, curriculum) and external advisory committees. Some IGERT projects include trainee representation in decision-making. One project has a formal Student Leadership Committee.

Resources for Project Management

In spite of formal organizational structures for faculty involvement envisioned in the proposals, site visits revealed that most IGERT projects are managed by PIs with support from non-faculty administrators. The explanation frequently given for this change is that committee structures proved too demanding of faculty time.

As an administrator at one university observed, “Effective administration and coordination is crucial for training grants.” In the first IGERT cohort, many proposals did not include grant support for administrative staff. Although some administrative support was frequently part of the university’s contribution to IGERT, the complexity of project management has proved to be substantial for PIs, faculty, and existing staff assigned to IGERT tasks. Early on, many of the 1998 IGERT PIs sought and received permission from the NSF IGERT Program Office to use grant funds to support a project administrator. In the second and third cohorts, more substantial administrative support was built into IGERT proposals.

Among the 57 projects visited from the first three IGERT cohorts, 75 percent have non-faculty administrators: 28 (49 percent) are part-time, non-faculty administrators, and 15 (26 percent) are full-time, non-faculty administrators. For example:

- One project’s support staff includes a part-time administrative associate, a technical assistant for the User Facility, and an internal evaluator.
- Another IGERT has a full-time assistant director who was hired with grant and institutional funds. The PI and faculty agree that expanding this position from a part-time coordinator has been very helpful, with the PI stating she wished they had had a full-time administrator from the beginning.
- A third project has a full-time project manager, a half-time secretary, and an evaluator, all partially supported by IGERT funds. The project manager has been essential to the management of this multi-university project and is considered an integral part of the project’s active Steering Committee.
- A 1999 project has a full-time administrative assistant, funded in part by the university, who is described as instrumental in running the program. When she left the position for a better paying job within the university, the PI found the money to increase her salary and hire her back.
- A 2000 project has a full-time academic coordinator located in the chemistry department who tracks trainee progress, administers the grant, completes university paperwork, and assists the IGERT leadership team.
- Another 2000 project has a program director who is responsible for day-to-day administration of the program and who maintains close relationships with trainees. He is the resource person for students and faculty, and he organizes the orientation, sets up student teams, and serves as a mentor to those teams.

IGERT projects that are part of new or existing centers or institutes benefit from having an administrative home that facilitates project management and resource development.

- At one project, IGERT is within a National Center established through an earlier grant, and the IGERT PI also serves as center director. This IGERT is thus able to draw on a competent and supportive staff in the Center, as well as the management experience of a skilled PI.
- Another IGERT exists within a university Institute, which has facilitated the development of a degree-granting program. The PI works closely with the dynamic Institute director, who played a major role in IGERT development and provides access to the Institute's external clients for internships and long-term financial support.
- A 1999 IGERT is housed in a university Center devoted to its research area that has substantial institutional and external support.
- Another project's IGERT funding coincided with the establishment of an interdepartmental program that incorporated IGERT requirements. Subsequently, a Center was created to provide the organizational framework for bioinformatics research.

In the 2000 cohort, almost half (47 percent) of IGERT projects are located in a center, institute or graduate program that provides an administrative base.

Faculty Involvement in Management

There are challenges to involving large numbers of faculty in project management, given the range of responsibilities faculty may hold related to IGERT, including: teaching new or redesigned courses related to the project; taking trainees into their labs; overseeing interdisciplinary research projects; advising trainees and serving on dissertation committees; and giving guest lectures or participating in workshops, retreats, and social activities.

However, beyond these responsibilities, some IGERT faculty participate actively in the management of the project. In most IGERT projects, the PI and co-PIs form a management nucleus, make routine decisions, and troubleshoot problems that arise. Co-PIs and other faculty may serve on IGERT committees with various charges, including setting requirements, developing/revising curriculum, and overseeing research activities, admissions, allocation of traineeship funds, and scheduling activities.

Faculty commitment to project management varies. One frequently identified problem is that faculty are not compensated for their time on IGERT. Although faculty governance is important in academia, most PIs find it difficult to add more committee work to advising trainees and teaching IGERT courses (often done as overload). However, where the intellectual content is compelling and quality of trainees is high, faculty may value greater participation and become more engaged in the process.

- At a 1998 project establishing a new field of study, faculty enthusiasm is palpable and has translated into active participation in project development and management. A senior faculty member and co-PI says: "[This project] has forced faculty to get rid of nonessentials and requires courage in the face of nay-sayers in departments. It has changed how we spend our time."
- At another project, a department chair observes: "The default setting is to play well together, with team spirit. The walls here are very low and full of holes. Faculty come together, and administration stays out of the way." However, as the PI observes: "Bridging the gap takes more time than peeking over the fence."

- At a 1999 project, an untenured co-PI assumed major leadership, teaching, and advising responsibilities. He considers it “risky work but an investment in the future.”
- At another 1999 project, a five-member faculty executive board meets every six weeks to make major decisions regarding project operation and requirements.
- At a 2000 project, an untenured co-PI is described by a university administrator as “the driving force championing Bioinformatics with energy, vision and leadership beyond the norm for an assistant professor.”
- At another 2000 project, five co-PIs have assumed individual responsibility for aspects of IGERT project management.

Equitable Distribution of Resources

Equitable allocation of IGERT resources, as well as related university resources, is an important management task for IGERT PIs, involving key decisions concerning recruitment, admission, and funding of trainees and matching trainees with participating faculty. Generally, faculty trust PIs to be fair, and frequently decisions are made by consensus or through informal consultation. However, at one project, the limited number of graduate students has created tensions, with faculty expressing frustration that the PI has most of the students. As one faculty member commented, “The PI is eating all the carrots.” This has been a rare problem for IGERT projects.

Although PIs often play a lead role in allocating resources, designated committees make many of these decisions in IGERT projects. Perhaps because these committees also include the most active IGERT faculty, the allocation of resources is generally viewed as equitable.

Multiple IGERTs on Campus

With approximately 20 IGERT projects funded a year since 1998, each year we have visited more campuses with multiple IGERT grants. Of the 57 grants in the first three cohorts, 33 (58 percent) are on campuses with at least one other IGERT project as of the 2003-2004 academic year. Four universities have four IGERT grants each; 13 universities have three IGERT grants each.

On only one campus did the project we visited report significant interaction among multiple IGERT projects. Across these IGERTs, project staff communicate about issues related to grant administration, and PIs of the later projects reported learning from their colleagues’ earlier successes. Recently, the four IGERTs were able to get a dedicated IGERT seminar room on campus, which they share. The 2000 IGERT experimented with a special case-based ethics seminar, and the other IGERT projects are interested in using this course for their trainees.

In a few cases, campuses are beginning to think strategically across multiple IGERT projects. One university has called on the experience of current PIs to conduct an internal review of potential proposals for new IGERT projects in order to decide which to submit for funding and to work on proposal development. In addition, three universities with multiple IGERT projects have involved the same local evaluator; these evaluations are discussed later in this chapter. There is a growing potential for synergy and developing community across IGERT projects on many campuses, but most IGERT PIs have not taken advantage of the opportunities to interact.

Recruitment

Once funded by NSF, PIs are immediately faced with two critical tasks: recruiting top graduate students as trainees and attracting faculty with appropriate expertise. This section examines the ways in which IGERT projects recruit students and faculty, the outcomes of these efforts, and the challenges they have encountered.

Trainee Recruitment

IGERT PIs responding to the 2003 web survey of principal investigators identified multiple techniques used to recruit graduate students. Across all cohorts through 2002, 99 percent of projects used personal contacts with faculty to identify and attract trainees to the IGERTs. The frequency of this approach may be related to the tendency of projects to recruit students directly into departments, rather than into the IGERT project itself. Within the first three IGERT cohorts, 36 of the 57 projects (63 percent) recruit students into departments, while 7 (12 percent) recruit students solely into the IGERT project and 14 (25 percent) use a mixed approach, recruiting students into either an academic department or the IGERT project. Table A.9 in Appendix A summarizes the recruitment strategies employed.

PIs also identified other common approaches to student recruitment. Across all cohorts, 96 percent offer competitive stipends and other support to prospective trainees. One project distributes a set number of awards for participating departments to use in attracting top students. These awards provide one-quarter of funding for a student in his or her first year. While there is no obligation that students participate in the IGERT, the awards help departments compete for top students, and the PI expects that some of these students will join the project.

Across all cohorts, 94 percent of IGERT projects use non-electronic media (e.g., posters, brochures, letters) describing IGERT and its funding for prospective trainees. In addition, 91 percent invite potential students to campus for visits. Use of other strategies was more variable. While fewer than half (49 percent) of IGERT PIs overall reported making informational visits to undergraduate institutions, 76 percent of projects in the 1999 cohort reported doing so. More detailed information from the 2003 web survey of PIs on the recruiting strategies used by IGERT projects is available in Table A.9 in Appendix A.

Students interviewed during the site visits described learning about IGERT in a variety of ways. Thus far, personal contact and word of mouth have been the most successful approaches to recruiting. Students frequently learn about IGERT from faculty advisors or other personal contacts:

- Several trainees decided to attend one university and participate in its IGERT project based on the recommendations of undergraduate faculty mentors who knew and/or worked with IGERT professors.
- The PI at another university's project described their Research Experience for Undergraduate (REU) as "a prime recruiting tool." Five of seven 2001 REU students applied and were admitted to that university (not necessarily to IGERT), and the other two have expressed interest, but have not yet graduated.
- A 2000 IGERT contacts students applying for admission to participating departments to inform them of the project, and the PI follows up with telephone calls about the program.

This IGERT also operates an REU on campus where students get hands-on experience in the IGERT lab, and the PI actively recruits these students.

In addition, word of mouth among students plays an important role in shaping perceptions of the quality of different IGERT projects. One IGERT trainee said that during the graduate school selection process, he routinely met the same group of prospective students while visiting other graduate programs. According to this trainee, they agreed that one IGERT had the strongest and broadest community for the study of computational neuroscience.

Geography also plays a role in recruiting for some projects, and may be particularly important for those IGERT projects that are more isolated or have less institutional prestige than their competitors.

- Seven of 12 trainees at one project received earlier degrees from the university, and many of them learned about IGERT from other students. Nine of 21 trainees at another project hold a previous degree from the university.
- The vast majority (90 percent) of trainees in a project at a state university have some ties to that state.
- The IGERT in a smaller, primarily engineering university tried recruiting nationally, but had little success, perhaps because its engineering school is not ranked as highly as that of its partner institution. This university has since focused on recruiting highly qualified undergraduates from its own campus through fliers and undergraduate research experiences.

In some cases, reliance on students from within the region may be, at least in part, a function of limited recruitment efforts by the project. One project draws heavily from other institutions in its geographic region for its trainees. One trainee offered a possible explanation: “The internals are good, the organization is decent, but the marketing sucks.”

In contrast, many trainees in another IGERT first learned about the project through its Web site because the project was one of the few programs that came up when students searched *Google* for that research area.

Recruiting Underrepresented Groups

Contributing to a diverse science and engineering workforce is a primary goal of the IGERT program. Thus, in addition to seeking highly qualified applicants from the fields making up their inter/multidisciplinary research areas, NSF encourages IGERT institutions to recruit students from populations traditionally underrepresented in science and engineering (women, specified racial/ethnic minorities, and persons with disabilities). Recruitment of these groups (women and underrepresented minorities) has been a challenge for IGERT projects, and they have experimented with a variety of strategies with mixed results.

PIs responding to the 2003 web survey identified multiple approaches to recruiting students from underrepresented groups. Across the five cohorts funded through 2002, 80 percent of the PIs reported ensuring that entry requirements do not unnecessarily exclude prospective students as one strategy for recruitment. Other strategies include recruiting through minority science organizations (73 percent), offering research experiences for undergraduates (68 percent), and making informational visits to minority-serving colleges (47 percent). More detailed information on the recruiting strategies for underrepresented students used by IGERT projects from the 2003 Web Survey of PIs is available in Table A.9 in the Appendix.

Our site visits provided examples of these activities. Some IGERT projects have sought to cast a relatively broad net by attending conferences and working with minority-serving organizations. Some projects send students and faculty to meetings for groups such as the Society of Black Chemical Engineers and the National Society of Black Engineering. One of the urban projects, which has had substantial success recruiting minority students, created links to related recruitment efforts such as the Alliance for Minority Participation, its university's Pipeline program, and the National Institutes of Health–Minority Access to Research Careers program.

Other projects use targeted mailings to reach out to women and minority students. One IGERT uses information from the CASPAR database (based on IPEDS data) to send materials to related departments at minority-serving institutions.

Some IGERT PIs have also sought to build relationships through formal partnerships or less formal visits to campuses with high concentrations of students from underrepresented groups.

- One project has partnerships with Spelman College, Inter-American University, Howard University, Puerto Rico-Piedras University, and Xavier University.
- Another project has a specific articulation agreement with a nearby historically black university that allows students who earn a master's degree from that university to move seamlessly into the Ph.D. program at the IGERT institution. Two students have taken advantage of this agreement so far, and one came to the IGERT directly from undergraduate study at the feeder university.
- Three projects send faculty and/or staff to make presentations to students and faculty at other campuses, including community colleges, other campuses in their state university system, and institutions such as Morehouse College, the University of Maryland-Baltimore County, and Texas-Pan America University. Another project sends faculty and current IGERT students from underrepresented groups to their home undergraduate campuses for recruitment.
- One of the southern IGERTS works with historically black colleges and universities in the state to develop confidence that the IGERT project will provide a caring, supportive community for their students.

Two projects from the 1999 cohort make special efforts to reach out to Native Americans. However, PIs report multiple challenges, including the hesitancy of Native American students to be apart from their community for extended periods of time, and a sense within these communities that higher education is unfamiliar and unattainable. At one of these projects, a Native American woman has been actively engaged in recruitment for over ten years, beginning at the undergraduate level, and has recruited many Native American families to campus. It remains true, however, that many of the Native American students who are ready to consider graduate education choose professional degrees, such as medicine, over research degrees.

IGERT projects also host events or tap into existing events as a way to recruit women and minority students. One IGERT hosts a "Science is Fun" day for students and faculty from area community colleges. Another invites all potential students to attend a recruitment weekend, and the enrollment results have been particularly positive for minority students.

Many PIs spoke of the need to develop a long-term approach that involves building institutional pipelines for potential graduate students from underrepresented groups and reducing direct competition among research universities for these students. Some have begun to focus on expanding the pipeline, believing that this strategy will show results.

- One project created its National Fellows program and a Scholars Program (which brings 10-14 undergraduate students to the university each summer to engage in a weeklong seminar) to help with minority recruitment.
- At another project, a co-PI uses connections with former Ph.D. students who now teach at historically black colleges and universities to help build a pipeline for underrepresented students.
- A third project has an undergraduate summer program that has a diverse applicant pool and is coordinated with another recruitment effort for high-achieving minority students.
- Several projects are reaching out at the K-12 level to generate interest and enthusiasm for study in their fields.
- At one 1999 project, the PI takes "administrative license" by singling out minority applicants for special review and consideration. IGERT allows minority students to begin by pursuing an M.S. degree, and provides extra academic support to help the students see that a Ph.D. is attainable.
- A 2000 IGERT taps into the efforts of a staff member who has worked in the Chemistry department for a decade to strengthen the pipeline for minority students in the sciences. Efforts include an Upward Bound program, participation in the American Chemical Society Project SEED program, and a program that connects undergraduate with middle and high school students.

Although some PIs reported contact with the IGERT National Recruitment Program supported by NSF, none to date has reported recruiting any students using this newly created approach to recruit underrepresented groups.

Role models are important factors in recruiting traditionally underrepresented students and facilitating their success. One partner in a multi-institution IGERT is actively recruiting minorities for faculty positions. In the interim, it recruits minority faculty from *other* universities to conduct research at the institution over the summer and on sabbaticals, and tries to find researchers from underrepresented groups to present at the project's seminar series.

Across projects funded through 2002, success in recruiting students from underrepresented groups is mixed. IGERT projects report more success attracting women than minority students. Across the 88 IGERT projects with trainees in 2003, 4 projects have no female students. Women make up less than half of the student body at 75 percent of projects, and over 50 percent of the students in just 25 percent of these projects.

Participation of underrepresented minorities varies considerably when examined across projects. Thirty-two percent of projects with trainees report having *no* students from underrepresented minority groups, 39 percent report between 1 and 13 percent,[27] and 30 percent report greater than 13 percent underrepresented minorities.[28] If the projects with no minority students are removed from the analysis, 14 percent of students, on average, come from underrepresented minority groups.

While IGERT projects generally have had limited success recruiting minority students, some projects have recruited a large proportion of minorities. At one project, where both the IGERT PI and program administrator are from minority groups, 16 of 21 trainees are from underrepresented groups. Another project recruited three minority students who had participated in the university's Research Experiences for Undergraduates program. At an IGERT at a southern university, more than 40 percent of trainees are women and 6 of 19 trainees are African American.

The challenges for successful recruitment of minorities may be contextual in many cases. For example, one project's co-PIs explained one reason the project has had difficulty recruiting minority students is that the state has just one predominantly minority institution, and this institution does not have an engineering program. As a result, the project has recently expanded its efforts beyond the state. Another IGERT's faculty believe national perceptions of its state as conservative hamper minority recruitment efforts.

On the other hand, some faculty members cite competition among institutions for a limited pool of well-qualified minority students or other factors beyond their control. One faculty member observed: "Black scientists are few and far between, and the good ones go to MIT or Harvard." Another PI explained, "at the level at which [our project] operates, students who are qualified to be here already know about the program, and there is not much more that can be done to lure them into the program."

Trainee Selection

In the 2003 web survey, PIs were asked to rate the importance of various factors in their IGERT project's admissions process. The top factors, rated as "most important," were recommendations (72 percent), undergraduate GPA (50 percent), students' written goal statements (44 percent), and student background and experience (40 percent). Full details are displayed in Table A.10 in Appendix A.

A central question both for individual IGERT projects and the IGERT program as a whole is whether IGERT trainees represent the best students committed to interdisciplinary work, or whether IGERT is primarily a funding stream for faculty to support graduate students regardless of their interests. Trainees at several IGERT projects were cited specifically as being students of the highest quality.

- At one project, a department chair characterized IGERT as "one of the most attractive options that attracts the very best students." The vice-provost for research, speaking of the university's multiple IGERT projects, called IGERT an "incredible recruitment tool to get the best students."

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27 According to *Science and Engineering Indicators 2002*, Volume 2, NSB-02-10, underrepresented minorities account for 13 percent of graduate enrollment of U.S. citizens in science and engineering across the nation.

28 Percents do not equal 100 due to rounding.

- At another university, where the IGERT money has helped recruit domestic students, one professor noted: “Our pool of domestic students is the envy of other departments on campus.”
- A faculty member from another project said: “Every year, students are turning down [offers from] the top three departments, MIT, Yale, to come here. These students would not be here without the cross-disciplinary connections we have. These students are several standard deviations above the mean.”
- A 2000 IGERT has competed with great success for top students. The PI reported that 75 percent of students admitted to the program in 2002 and 2003 enrolled, and 87 percent are expected to enroll in 2004. One professor commented, “They were people who had the ability to do well in anything.”

Trainee quality and commitment to interdisciplinary work reflect a project’s selection process. Some IGERT projects focus on ensuring a “good fit” between student skills and interests and project goals. Project efforts to achieve a good match between student interests and IGERT varied. On the plus side:

- At one project, each potential trainee has an in-depth interview with the PIs to ensure that there is a good fit between the student’s goals and interests and IGERT. Both new and returning graduate students must submit applications annually to ensure that trainees are a good fit.
- Faculty at another project call prospective students who make contact (web, phone, email) with the IGERT. Some faculty have called as many as 50 students, and students not already at the university are flown in for visits. Faculty have found that many students who visit are impressed by the project and elect to enroll there.
- A 2000 project learned, based on the experience of its first cohort of students, that a sense of team membership is important in their project. As a result, they modified their admission process, and selection for the second cohort of trainees was influenced by what each student would contribute to the cohort as whole.

On the other hand, there were cases where IGERT was used as a funding stream.

- One trainee observed (in reference to his IGERT identity): “When your advisor suggests you do something, you do it, no questions asked.”
- Two trainees in another project arrived at the university to find IGERT was simply part of their funding packages. This IGERT had neither a clear application process nor an interdisciplinary ethos to guide selection.

Faculty Recruitment

IGERT projects must attract both current and potential faculty to the enterprise to ensure a robust program. PIs recruit faculty from participating departments throughout the life of the project, and IGERT influences new faculty hires. Without continuing recruitment, we saw declining faculty involvement over time.

Faculty Involvement

The key to sustaining faculty involvement in IGERT projects is intellectual engagement. For instance, a professor at one project described the IGERT as “the most intellectually stimulating environment I have on campus.” Many projects pointed to joint research grant proposals as evidence of intellectual excitement among faculty. Some faculty become interested after they see the value of IGERT to their own research or for graduate students.

- One project uses traineeship awards to leverage faculty participation in two ways. Faculty advisors say they are becoming more interdisciplinary themselves as they work with trainees. The PI used the promise of a traineeship for the economics department to induce one professor to teach a core IGERT course. This faculty member is now engaged in both the IGERT project and in other interdisciplinary work he otherwise would not have undertaken.
- The number of IGERT-affiliated faculty at another university increased from 14 to 22. One professor noted that IGERT is a “pull for faculty. I go to more IGERT seminars than disciplinary seminars. People are broader-based, less provincial.”
- A third university saw faculty involvement climb from 25 original participants to 67 faculty, representing 14 departments and four colleges. The PI explained that faculty join because they see the value of IGERT and because their work is increasingly interdisciplinary.
- A professor at another project described his growing interest in the IGERT: “For me, personally, the program started as a means of funding graduate students. I have become increasingly involved as an associate director, mentor of undergraduate students, and co-PI on other proposals that have grown out of IGERT. It has certainly increased the extent that I interact with colleagues outside my discipline and this is something I regard as important to current research in the environmental field. I don’t think we are going to be successful solving complex problems without these interdisciplinary interactions.”
- A professor in another project said he was a pure physicist but had always been interested in biophysics. After he built a relationship with an IGERT trainee, the two leveraged seed funds from a university grant and are now pursuing national funding.
- A department chair at a 2000 project said IGERT is “changing the mindset of faculty members who come to the realization that they benefit from team-based research.”

Graduate students often play a central role in energizing faculty by helping professors see the value of IGERT to their own research. Many faculty across the first three cohorts described students as the bridge between professors and labs, bringing them together with colleagues to explore common interests. Interviewees also described the role students played in sparking faculty changes in their own research. For example, one IGERT professor described one of his students as “right in the thick of it—going to all the meetings, bringing back new ideas.” The faculty member and the student have frequent discussions and are writing a grant together. The professor said, “It’s been a tremendous collaboration.” The impact of trainees serving as a bridge to faculty is described in greater detail in Chapter 4.

Although projects are eager to expand faculty involvement in IGERT, IGERT PIs are wary of colleagues who view IGERT as a funding stream for students. One PI noted that some faculty advisors did not fulfill their commitment to fund trainees once IGERT funding ended, and faculty at another IGERT felt that some colleagues will not remain active when IGERT support ends. In response to this concern, several IGERTs have started efforts to screen faculty. For example:

- One project requires interested faculty to submit applications. While no application has been turned down, that possibility exists should the PI perceive that a faculty member is using the traineeship only to fund students.
- At another IGERT, anyone interested in becoming a project faculty member is first designated an “Affiliate” and must demonstrate commitment to the project—by coming to events, helping to recruit students, etc.—before the executive committee votes to bring them in as a full IGERT faculty member.

IGERT projects may also help retain faculty. One professor who is very active in an IGERT elected to stay at that institution despite having a job offer from a university across the country where most of her family lives. She made this choice due to the IGERT and the relationships she had built with colleagues as a result of the project. At another project, IGERT was cited as a factor in one faculty member’s decision to stay at the university when her husband moved out of state to pursue new employment.

Although faculty involvement has been increasing overall, we observed two notable examples of declining faculty participation. The PI at one project noted that while there were 17 or 18 faculty in the proposal, 5 stopped participating early on, and 4 more left the university. The provost attributed some of these difficulties to confusion around the project’s proposed use of multiple mentors for students. The PI, on the other hand, suggested that the problem stemmed from a slow start as well as the university’s reluctance to support IGERT-related hiring. At another project, IGERT experienced a steady decline in faculty participation and enthusiasm as a result of multiple PI turnovers. These examples highlight the importance and complexity of generating sustained interest and support among both faculty and administrators.

New Faculty Hires

IGERT funding can play an important role in new faculty hires. IGERT influences hiring decisions both by creating a demand for faculty expertise, and by attracting faculty interested in interdisciplinary teaching and research to a community of like-minded colleagues and talented graduate students.

In some cases, the IGERT has contributed directly to the availability of new faculty lines, or to searches for candidates with particular backgrounds.

- At one project, the strong relationship between psychology and the life sciences in IGERT made it possible to hire a new faculty member in psychology.
- At another project, two of three faculty hired in the nanotechnology sub-discipline (a direct outgrowth of IGERT) in 2002-2003 are participating in the IGERT project.
- One IGERT professor said of a new hire: “We had other hard core computer science candidates, but…[the new faculty member] is an ideal IGERT member.”

- At another project, the university committed five new half-time faculty lines as part of its support for the IGERT. At the same university, a department chair said he believes the dean approved his department's request to hire two faculty due to the value of another IGERT.

In addition, IGERT projects on some campuses reflect an expanding commitment to a particular field of study that leads to faculty hires. One IGERT was funded at approximately the same time that the state legislature added $200,000 to the university budget to fund three faculty lines in its research area. Similarly, another IGERT is part of a larger institutional commitment to nanotechnology that will result in 12 faculty hires over eight years. At a third institution, the IGERT project's home department was in a growth mode, hiring five new faculty members in 2002-03, with two more planned for 2003-04. Almost all of them are directly or indirectly related to the IGERT focus research area. At a fourth institution, the physics department is hiring 4.5 faculty positions, and recently shifted its focus to biophysics, reflecting the impact of IGERT.

IGERT projects influence recruitment of new faculty by creating a sense of energy, momentum, and quality. New faculty at three different projects reported that the presence of the IGERT project influenced decisions to accept positions. At several other projects, faculty noted that the recruitment of top graduate students made possible by IGERT creates a more vibrant environment that in turn attracts top faculty.

For junior faculty in particular, IGERT funding for graduate students may be an important factor in the decision to accept a faculty position. A new professor at one project explained that, thanks in large part to IGERT support for trainees, she was able to produce 16 publications and 15 conference presentations in 2.5 years. The chair of chemistry at another university said IGERT "was an essential component" of the department's ability to hire three new professors in two years because of the funding it made available for graduate student support and research equipment. The co-PIs at that IGERT added that IGERT support helps new faculty "get results sooner and thus have higher chances for the critical first renewal of an external grant."

Assessment and Evaluation

Student assessment and project evaluation are valuable tools for helping project management integrate courses and research to create more effective interdisciplinary learning environments. Assessment documents student learning and progress toward meeting educational goals, while project evaluation indicates how the IGERT project is functioning, how it is perceived by stakeholders and participants, and what changes would make it more effective.

In the 1998-1999 IGERT Program Solicitation, NSF asked applicants to develop a performance evaluation plan to measure progress toward stated goals and provide examples of indicators. At an IGERT Evaluators Meeting held in April 2000, the NSF IGERT Program Office clarified expectations for project evaluation. Several PIs in the first cohort were surprised by this emphasis on evaluation. One PI said he saw it as a departure from what was in the original program announcement, which most interpreted as student performance assessment rather than project evaluation. The presence of evaluation plans has increased over time. In the site visits to the first cohort, seven projects (41 percent) had established project evaluation mechanisms; seven projects did not; and three had plans under development. In the second cohort site visits, there were 13 projects

(62 percent) with established evaluation plans; 4 without; and 4 with plans under development. In the third cohort, 14 projects (74 percent) had evaluation plans, 4 did not, and 1 had a plan under development. To emphasize the importance of assessment, the 2000-2001 IGERT Program Solicitation explicitly stated that performance assessment should include an evaluator who is external to the project.

Some project-level IGERT evaluation efforts focus on student-level data, often reflecting the sample indicators provided by NSF in the original program solicitation. For example, one 1998 project identified 19 performance measures, such as numbers of participants, gender and ethnicity counts, and publication activity, and project administrators also make some effort to gather qualitative input from students on their experiences and perspectives each year. A 1999 project also collects information on trainee performance on qualifying examinations, trainee grades, publications, and presentations.

Another 1999 project originally pursued this sort of "accounting" strategy, but recognized that such data served a limited role, and has since started to solicit qualitative feedback as well. In response to the NSF call for evaluation, other IGERT projects are also employing both internal and external mechanisms to gain project-level feedback on the quality of the student learning experience. Internal approaches include self-evaluation through a variety of means, and external approaches include hiring an external evaluator, convening an advisory board, and seeking feedback from distinguished visitors.

Many IGERT PIs and faculty assume part or all of the responsibility to gather feedback about the project in ways that vary from informal to highly structured. Results from the 2003 web survey of PIs show that in cohorts through 2002, the PI was involved in project assessment in 60 percent of the projects, and other IGERT-associated individuals were involved in assessment in 51 percent of the projects. Projects most frequently use informal feedback to the PI or faculty (87 percent), surveys of trainees (73 percent), meetings of project participants (59 percent), and faculty assessment committees (55 percent) as mechanisms for assessing the IGERT. For more information on assessment and evaluation, see Table A.11, and on specific assessment methods, see Table A.12, both in Appendix A.

The methods employed to gather feedback about projects varied from highly structured to informal.

- A number of IGERT projects look to students or student boards to provide input. At one project, students meet annually and report to the visiting External Advisory Committee. At another, the student advisory board meets with the PIs every other month to raise and resolve concerns. At a third, students meet once a year, providing faculty with written feedback on the project. PIs then reply in writing, disseminating the entire document to all students. A fourth project has students meet with its external advisory board annually, independent of faculty.
- Some projects have periodic, large-group events. One project, among other approaches, has what are jokingly called "whine and cheese" events at the end of research rotations for students to raise concerns. Another has an annual retreat, with hired facilitators, to discuss project goals and student progress.
- Some projects reach out to graduate students more individually, whereas others include faculty advisors in discussions. At one project, the PI regularly solicits student feedback on their experiences in the project, and at another project, the PI and program assistant

meet with each trainee and associate annually to discuss their academic progress and seek student feedback on the project. At two other projects, PIs have annual meetings to monitor student progress individually with each student *and* his or her faculty advisor.

Some IGERT projects also use external mechanisms to receive feedback. The 2003 web survey of PIs indicated 35 percent of IGERT projects funded through 2002 use an external individual or group to assess the project. Some projects employ external advisory boards for input and evaluation that meet once a year to provide feedback to PIs. One IGERT has its external visitors come once or twice a year, and has acted on several of their recommendations. Recommendations of another IGERT's external board after a 1999 visit led the project to hire two tenured faculty members to strengthen curricular elements, and take steps to build a stronger student community.

Other IGERT projects seek the input and insight of visitors. For example, one project asks for written feedback from visiting faculty and faculty who attend IGERT-related workshops. Another has its keynote speaker provide feedback to the project each year. However, in some instances, visits by advisory boards and guests are relatively infrequent, and do not provide systematic project-level data collection.

Some IGERT projects use internal or external evaluators as a management tool to provide ongoing project-level feedback and inform decision-making. The 2003 PI survey indicated that 21 percent of IGERT projects funded through 2002 use individuals or groups from within the university, but not associated with the IGERT, to perform assessment. In addition, although more than a quarter of the 1999, 2000, and 2002 cohort PIs said they used this approach to assessment, no project from the 1998 cohort reported doing so.

One IGERT project was the first to implement a comprehensive evaluation process directed at project management. The PI hired a faculty member from the university's School of Education to design and implement a formative project evaluation that included trainee self-evaluations, surveys following activities, focus groups, and observations. This evaluation process raised many issues, including how the core seminar was taught and by whom, the nature of student projects, and the products expected from research.

Other projects have engaged various outsiders to assist in project evaluation. One project hired an evaluator who gathered data through surveys, interviews, and focus groups. Another has a rich and varied evaluation process that involves education and sociology faculty members tracking student creativity, social intelligence, and learning. A third funded a doctoral student in education to conduct annual interviews with students and faculty, and is working with a faculty member in education who studies interdisciplinary collaboration and outcomes. A fourth hired an outside evaluator who interviews students and faculty each year. The evaluator explores student attitudes toward research, the value of the experience for students, and how faculty rate their advisees relative to non-IGERT students. A fifth project had a staff member from the university's Institute for Assessment and Evaluation lead a regular project assessment that included an analysis of student writing samples and an evaluation of the extent to which the skills and experiences of IGERT trainees are different from those of non-IGERT students.

Several universities with multiple IGERT projects have also taken steps to draw on the expertise and knowledge they hope comes from the presence of multiple IGERTs. At one institution, the graduate dean brokered a relationship between the IGERTs and faculty and graduate students in the School of

Education to carry out project evaluations. Both IGERT projects at another university worked with the same evaluator from that university, and at a third university, the graduate student evaluator from the project funded in 1999 is mentoring the graduate student evaluating the IGERT funded in 2000.

The key to successful program modification is project management that is flexible and open to change, and even IGERT projects without formal, ongoing assessment efforts have made important substantive changes based on informal feedback. One project, for example, made major changes to its curriculum when students submitted a letter outlining their frustrations and proposing solutions. In contrast, the fact that another project does not have a formal assessment mechanism has contributed to communication problems within the project and a perception among some trainees that faculty are not responsive and students lack a voice in decisions.

One PI speculated that having a formal evaluator might be more important for projects new to interdisciplinary education and research than for those more grounded in interdisciplinary experience. Similarly, one content specialist noted that projects new to interdisciplinary work might need extensive formal feedback, while more established projects may be able to rely on less formal feedback from students and faculty.

Regardless of how IGERT projects have received feedback, PIs generally have been responsive to input from students, faculty, and advisory boards. Projects have made a variety of curricular and structural changes based on what they learned from stakeholders.

- One project implemented more flexible lab rotations, an orientation for trainees, and more social gatherings.
- Three other projects altered the structure, format, and expectations of lab rotations.
- Two projects adjusted curricular expectations and requirements when it became clear that students were having difficulty meeting original expectations.
- Three projects changed recruiting efforts with more face-to-face recruiting, greater outreach to historically black colleges and universities, and a tribal outreach effort.
- Three other projects implemented efforts to clarify program requirements by using the Internet, publishing newsletters, sending emails, and meeting with students individually.
- Two projects were spurred by feedback to improve facilities for students and purchase new computer equipment.
- Four projects implemented more social activities to build a stronger student community.
- One project implemented a new orientation program for IGERT students and created a mentoring program for senior trainees to mentor junior trainees.
- Another project altered the seminar structure, changed its trainee selection process, and created a mechanism for assessing student learning in the context of group work based on what it learned from its evaluation.

Still, the experiences of IGERT projects suggest that using formative evaluation as a management tool is not always easy. One PI believed his budget could not support an internal evaluator, and another project was unable to find a graduate student able to carry out the task. While faculty at a 2000 project are very interested in determining the “valued-added” of the IGERT experience for graduate students, they have had a difficult time establishing meaningful metrics. Another PI from the 2000 cohort said that while he learned from a presentation on adaptive management at the 2000 Evaluators Meeting, PIs would have benefited from more direction and involvement by the NSF IGERT Program Office as follow-up.

Responding to evaluation findings can be a challenge for project management. One project's trainees, for instance, were appreciative that their concerns were addressed, but they were also tired of being surveyed as part of the evaluation. Moreover, PIs must use the information they gain judiciously, walking a fine line between appearing to ignore comments and making too frequent or drastic changes to the project. As an evaluator from another project cautioned: "Making too few changes looks unresponsive but too many makes a program unstable."

Summary

Although IGERT projects vary considerably in terms of leadership, design, and management, strong project leadership, planning, and administrative support are critical elements of success. These elements influence the culture and context within which faculty and students learn and conduct research. As such, they are instrumental in framing the project impacts reported by students, faculty, and institutional administrators. Although most IGERT projects are discipline-plus models that supplement departmental degrees or existing interdisciplinary degrees with IGERT requirements, a few projects developed new interdisciplinary degrees. PI leadership patterns reflect different decision-making styles, ranging from leaders who make most decisions themselves to those who create a management team. Faculty involvement in project leadership and management varies, and increasingly IGERT projects rely on non-faculty administrative staff support. IGERT projects that include multiple campuses or institutions face additional management challenges. Few campuses with multiple IGERT projects have taken advantage of potential for synergy and collaboration.

Recruitment of high-quality trainees and faculty is critical to IGERT success. Personal contact with faculty and students is the most common approach to recruiting trainees. IGERT projects employ a variety of strategies to recruit women and minority students, although only a few projects have had success in attracting trainees from minority groups. Many IGERT projects recognize the importance of role models, extra support, and expanding the pipeline to recruit and retain more students from underrepresented groups. IGERT projects have attracted many current faculty as well as influenced new faculty hires.

Finally, IGERT projects use a range of approaches to project assessment and evaluation (internal and external, formal and informal), with findings from these evaluations leading to important changes for many projects.

The next three chapters describe the IGERT impact on students, faculty, and institutions. We begin with graduate students, the immediate benefactors of IGERT traineeship funds.

Chapter 3. Impact on Students

Introduction

Providing educational experiences that reach beyond single traditional disciplines is the core of the IGERT program, and the heart and soul of the program is the inter/multidisciplinary educational experience received by the funded trainees. IGERT funding frees students from the traditional single-advisor graduate experience and enables them to explore courses, research and knowledge in other disciplines. Faculty members hope that IGERT projects produce students who are skilled researchers, able to work across disciplines, and prepared for a wide range of careers. The goal of training students as inter/multidisciplinary researchers is the common thread that binds these projects together, despite considerable differences in:

- project discipline (e.g., chemistry, biology, engineering, economics, public policy, ecology);
- specific research area (e.g., bioinformatics, sensors, sustainable cities, computational neuroscience, freshwater studies, microelectronics-photonics, evolutionary biology);
- intensity (e.g., number of requirements, number of years of trainee funding);
- scope (e.g., number of participating departments/schools/institutions); and
- the mix of educational components (e.g., courses, seminars, lab rotations, internships).

All IGERT projects have developed an inter/multidisciplinary educational program for their trainees, consisting of some combination of seminars, courses, laboratory research experiences, internships, and/or travel, which may or may not be acknowledged by a unique degree or certificate. Project offerings depend not only on faculty members' goals for their trainees, but also on such factors as:

- the level of cross-disciplinary interaction among the disciplines included in their project;
- the history of collaboration among project faculty members from different departments within the project; and
- the facilitating or inhibiting effects of university and departmental policies on cross-departmental collaboration in research and on educational collaborations such as team teaching multidisciplinary courses.

The impact of IGERT on students is mediated by the inter/multidisciplinary educational experiences and research training they receive. While each IGERT project is unique, in this chapter we discuss the most common educational and research experiences provided for trainees,[29] explore how projects have effectively implemented these new models of education, and summarize what we know so far about the impact of these experiences on students. We begin by describing students' educational experiences: types of degree programs, seminars and courses, professional development in

[29] Unless otherwise stated, project data from the 2003 web survey are presented for the 86 projects that were deemed active in the 2002-2003 academic year. Active projects were those with at least two trainees, at least one of whom was funded within his/her first three years of doctoral study.

communication and teamwork, on-campus research experiences, and off-campus “real world” experiences. We then explore successful implementation strategies, and ways that projects “make it work.” This chapter concludes with a discussion of early indicators of success for students.

The IGERT Experience

Degree Programs

All of the IGERT projects are multidisciplinary, in keeping with the goals of the IGERT program. Table B.2 in Appendix B illustrates common manifestations of the interdisciplinary nature of the projects. All projects fund trainees from a variety of disciplines.[30] In addition, in almost all projects, instruction is provided by faculty from multiple disciplines, students participate in research with faculty from multiple disciplines, and required courses draw on multiple disciplinary fields.

In most cases, students receive their doctoral degrees from their traditional home departments, either alone (64 percent) or with the addition of an IGERT-related certificate or minor (20 percent). Six percent of the projects have developed new interdisciplinary Ph.D. degrees and in 10 percent of the projects students can receive degrees through pre-existing interdisciplinary Ph.D. programs.

Only six of the IGERT projects we visited admit students into a separate IGERT multidisciplinary degree program. The rest (89 percent) of these projects are structured so that students are admitted to a single department and receive their degree from that home department. The inter/multidisciplinary IGERT experience of most students thus consists of additional courses, research opportunities, workshops, and other activities designed to broaden students’ perspectives, knowledge, and professional development. We call this model “discipline-plus.”

Project PIs emphasize that even students earning traditional departmental degrees are still receiving an inter/multidisciplinary educational experience. One PI believes his IGERT project has had such an impact on departmental graduate programs that they are no longer “single discipline” departments, commenting:

> Almost all of these programs are interdisciplinary to some extent. Five of the six programs have faculty members from multiple departments. The IGERT program has fostered much of this interdisciplinary activity. For instance, as a result of the IGERT program, we have added Computer Science faculty, Geology faculty, and Molecular Biology faculty to the Ecology, Evolution, and Behavior graduate program. Similar additions have been made to several of the other graduate programs. Thus, these programs no longer represent “single-discipline departments.” Effectively, we have transformed some of the traditional graduate programs.

The degree to which “discipline-plus” IGERT projects expect students to obtain a firm grasp of another field varies. Twelve of the 57 projects we visited offer trainees the chance to earn a certificate or minor in the multidisciplinary focus area in addition to the home department degree. Most other projects do not emphasize mastery of other fields to the same degree. For example, the PI of one project said in their overview materials: “It has never been our goal to create jacks-of-all-trades between engineering and biology. The problems of the future will certainly require well-

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[30] Through the 2002-2003 academic year, projects have supported 1,685 trainees. Web survey results reported in this chapter include all trainee responses from the 2000, 2001, 2002, and 2003 web surveys.

trained specialists in both of these areas. Rather, it is our goal to train students that can work efficiently in multidisciplinary teams." Similarly, an IGERT faculty member at another university said that he saw the IGERT goal as "producing scholars of first rank" who can produce cutting-edge interdisciplinary work. Such scholars, he said, must have a disciplinary background to make interdisciplinary contributions.

Projects strive towards and achieve these goals through a variety of activities planned for trainees—seminars and courses, professional development in communication and teamwork, on-campus research experiences, and off-campus "real world" experiences.

Seminars and Courses

Most projects initiate a broad inter/multidisciplinary education for students through two principal requirements: 1) an IGERT seminar, and 2) a core set of courses.

Four-fifths of the projects we visited (45 of 57) require trainees to participate in an IGERT seminar designed to expose students to research and content outside of their home disciplines. The remaining 12 generally have colloquia, journal clubs, or other means of sharing across disciplines. As part of one successful seminar, trainees in their fifth semester participate in a Capstone Seminar series to help stimulate interdisciplinary conversation among faculty and students. Students take turns presenting research from their own field of expertise, followed by a round-table discussion. This seminar format serves the dual purposes of providing trainees with experience in presenting research findings and expanding the content knowledge of other participants, some of whom are in a different field than the presenter.

Most of the projects we visited (49 of 57) also require students to take one or more core courses whose goal is to weave together the disciplines that form the project's multidisciplinary theme. These experiences are designed to engage trainees, at some level, with the perspectives, language, and methods of both their own and other disciplines. Projects often also require students to take courses in departments outside their home discipline. The number of required courses is typically three to five; sometimes they all are set for trainees, and sometimes they may be chosen from a menu with specified distribution requirements.

In general, students respond favorably both to the IGERT seminar and to core courses. Trainees from many IGERT projects specifically cite taking courses in other departments as critical to applying an interdisciplinary perspective to their own work. For example, a trainee in one reported,

> Having had the opportunity to take courses in [other departments] in addition to [my department] has been critical in the development of my thesis. The flexibility of the IGERT program has allowed me to explore areas that are not traditionally considered in [my home department].

Content specialists generally commented favorably on the curriculum, although they often had suggestions for small modifications to strengthen the curriculum further.

A substantial number of projects have tried more than one format for the IGERT seminar, often in response to student feedback. Generally students find the core course requirements reasonable, even though these requirements often add to their required coursework overall. For students in "discipline-plus" programs, it is helpful when the IGERT project manages to get core courses cross-listed in participating departments or at least to get their courses allowed as electives in students' own programs.

Professional Development

IGERT projects are structured to prepare trainees for a wide range of career choices, including positions in industry, government, or the public sector as described in Table B.3 in Appendix B. They prepare trainees by developing their skills in communication, teamwork, and teaching and mentoring as described below.

Communication Skills

Broadening students' professional skills in communication and teamwork is a stated goal of the IGERT program, and projects have devised multiple strategies for providing this training: courses, workshops, seminars, internships, research groups, and more. In the 2003 web survey, 92 percent of PIs from the first five cohorts of projects reported that trainees receive regular feedback on their professional speaking/presentation skills, and 69 percent said trainees receive regular feedback on their writing. Projects encourage students to attend conferences and make presentations. Sixty-five percent of all trainees have already attended professional conferences; of these, 80 percent report making a presentation (oral or poster) outside their home institution. Table B.4 in Appendix B illustrates the communication experiences trainees have reported in the web survey. Note that, as is to be expected, trainees in older cohorts (a large portion of whom have been in graduate school longer) report more of these activities.

At one project, the focus is on demonstrating an understanding of different methodologies. Students must complete two publication-ready papers prior to their dissertation work, one involving a formal (computational) methods approach, and the other empirically based. Ideally, the faculty would like the student to address the same research question from these two different perspectives. Students also have advisors representing each of these two approaches.

Especially important are IGERT attempts to develop trainees' abilities to communicate with individuals outside their home discipline, and with non-scientists. Fifty-three percent of all trainees report receiving training in communicating across disciplines and to different audiences. An interesting example of helping students reach broader audiences is found at one IGERT, where students are required to conduct an internship with an organization that presents science to the public such as the National Geographic Society or National Public Radio. The purpose is for students to gain experience enhancing public understanding of science, a longstanding NSF objective. The flexibility of the requirement—work with any institution that presents science to the public, with no strict guidelines as to what students should actually do during the period—has posed an administrative challenge (both for students and for the PI), but the content specialist who reviewed the project commented:

> I like the idea of the public dissemination of scientific information and consider such skills imperative to all of science but particularly [the focus of this IGERT project], which has a tenuous relationship with public opinion. I think this is a really neat idea, and an important one. Experience with how to educate everyone about the knowledge and importance of knowledge, about human evolution, is invaluable but often not taught. As in so many other areas, this program fills the gap.

Teamwork Skills

Many projects have built in requirements for trainees to work together across disciplines, in courses or in the lab. These inter/multidisciplinary teams appear to be most successful when students who work together are interdependent. Table B.5 in Appendix B details trainees' experiences with activities that develop their professional skills. Seventy-four percent of all trainees have participated in team research efforts. The following example illustrates one successful approach.

One of the most carefully designed laboratory experiences is at a project whose lab has four workstations, each with a different experiment, and students work in interdisciplinary teams with one faculty member on a single experiment for an entire semester. Each lab station has a video camera linked to a central television so that particularly interesting activities can be broadcast to the entire class and give all students some exposure to all of the experiments. A content specialist noted, "They are taught that interdisciplinary research requires each participant to learn the language and culture of another area of research, and that they must be able to explain their models and experiments to non-experts. Mathematical scientists learn the experimental method first-hand by doing experiments; experimental scientists learn how to build mathematical models to organize and explain their experimental results." Faculty have become engaged, according to one, because "the work is close to research you are already doing; it attracts good students; and it is fun to do."

It is common for students to work in the laboratories in inter/multidisciplinary teams. For example, students at one project work alongside faculty members in teams consisting of at least two faculty members, two students, and an off-campus team member. Table B.6 in Appendix B presents details on activities that build skills in communication and teamwork, including experience communicating across disciplinary boundaries, presentations at professional conferences, participation in educational and research teams, and training in speaking and presentation skills, which each are found in over 90 percent of active projects.

Finally, an important part of professional development and preparing trainees to become researchers is instruction in ethics. Eighty-three percent of projects (all cohorts) report providing some instruction on research ethics (Table B.7 in Appendix B) specifically, and half of trainees report in the web survey they have received such training already (Table B.8 in Appendix B). During our site visits, we found that while some students had expected to "hate it," most students commented favorably on ethics training once they had been through it. Many projects require or encourage attendance at seminar series, journal clubs, or other supplementary educational experiences focused on ethics.

Teaching and Mentoring Experiences

Some IGERT projects have also developed systematic components aimed at preparing trainees to teach. As shown in Table B.9 in Appendix B, in nearly three-quarters of the projects, trainees have opportunities to serve as teaching assistants, but only about half of the projects provide systematic instruction in effective teaching practices. The proportion of trainees who report involvement with these activities is reported in Table B.10 in Appendix B.

One project expects its graduates to go into teaching and provides them with mentoring in instructional practices. All trainees and associates are expected to learn to teach through an actively mentored teaching experience. Each student observes his/her faculty mentor teaching. Subsequently, the student does all the activities associated with teaching: designing and giving lectures, creating and grading assignments and exams, and dealing with course administration. The mentor provides support, feedback and advice throughout. Other approaches that prepare students for university faculty careers include having students run the second year Proseminar and sponsoring an open grant competition.

Two projects stand out in their efforts to prepare trainees for teaching. The first requires students to have at least one teaching experience and one mentoring experience. For the teaching requirement, trainees can serve as teaching assistants in their home departments. For the mentoring requirement, the project offers a seminar to train and support trainees who subsequently participate in outreach efforts, such as mentoring interns in the Research Interns in Science and Engineering (RISE) program or the campus Research Experiences for Undergraduates program, or high school student researchers participating in the Apprentice Researchers program. This has been very well received by the trainees although they did discover that it demanded more time than they had expected.

At the second project, trainees may apply to participate in a yearlong fellowship, which entails mentorship from a university faculty member and a series of seminars on teaching. Only a few trainees, however, have taken advantage of this opportunity to date.

Student Research Experiences

Developing skilled researchers is a central goal of IGERT projects. Formal training in research methods is provided in most projects (88 percent), and many projects offer training in state-of-the-art instrumentation (79 percent) and statistics (64 percent). Table B.7 in Appendix B describes project elements that advance trainees' research abilities. Preparation for professional roles includes varied research activities, as seen in Table B.5 in Appendix B. Nearly three-quarters of trainees reported participating in research projects involving multiple discipline efforts, and an equal number reported experience in team research efforts as part of their professional training. Trainees' experiences with other activities directed at improving their research skills are presented in Table B.8 in Appendix B.

Inter/multidisciplinary research is of course central to any IGERT project. Students report that it is in doing the research that they really learn what their field is about. As one trainee reported, "The courses introduce us to the methods, but we don't really learn it until we either study papers in the seminar course, or do [the method] in an experimental lab." A trainee at another project explained, "Through my research project I learned new things in an experimental way, not through textbooks. . . By doing simulations myself . . . I can really understand."

Students participate in research in a variety of formats, including laboratory rotations, tutorials and workshops, and multidisciplinary research projects. Laboratory rotations are often where the real inter/multidisciplinary training begins. In many projects, trainees are required to complete at least one lab rotation outside their home department. The great majority of students with whom we spoke found these experiences highly valuable. For example, several different trainees at one project said the following about their lab rotations: "I learn the skills each field requires." "[I've learned] diversified techniques and I use them all in my research." "[Rotations are the] most amazing thing. If you're focused, it's really great. I'm really focused. Elsewhere I never could have done a rotation in electrical engineering."

Lab Rotations

Lab rotations or similar experiences are required in 54 percent of the projects we visited. A typical IGERT lab rotation requires three lab rotations during the first year, one of which must be outside of the home department. Students carry out a short-term research project and subsequently present it at a project brown bag lunch. Several trainees reported experiences that led variously to publication, ongoing collaboration, and a chance to study a problem of interest from several different angles. According to one faculty member, the rotations "allow students to bring new ideas into the projects and carry their ideas from one project to another." In addition, students have the opportunity to train and supervise the work of others.

At one project, students are expected to complete two rotations, with one ideally outside their field. There is considerable flexibility about the timing, format, and location of the rotations. This degree of individualization seems to have helped students both gain true interdisciplinary experience and integrate what they learned into their ongoing research.

In contrast, another project had proposed "reverse rotations"—in which trainees spend at least six months of their third year in the laboratory of their dissertation co-chair (outside their home department)—but have not had success in enforcing it. One reason for the lack of success is that the IGERT funding does not cover the "reverse rotation" period; another reason is that it would occur just at the point where the student would begin to make a substantial contribution in the advisor's lab, so there is less encouragement on that front than there might have been had the rotation taken place during the student's first year in the program. One content specialist noted that this type of rotation would benefit students "who have developed projects that rely extensively on techniques from an alternative discipline . . . [and] will happen naturally in cases where the joint advisors are truly joint but [the reverse rotations] do not benefit the student whose primary focus is [just] one of the participating areas."

Several projects have modified their rotation requirements along the way. For example, at one project, which had planned to require a specified set of lab rotation experiences, the PI concluded that students did not need an extensive lab rotation experience because they were coming in with already well-defined research interests. Now students spend time principally in their own lab, but they can work in other labs as needed to accomplish their research goals.

Another project also modified its plan. Originally students spent several weeks in each lab during their first and second years. They reported this approach to be "a waste of time," and "just show-and-tell." The project now has students from different disciplines working together in teams in the summer after their first year. They must identify a project that will require them to work in multiple laboratories and then spend two to three months working on the project. They present their results to students and faculty in the fall. Similarly, at another IGERT, project participants opted for interdisciplinary depth of understanding over breadth of exposure by reducing the number of rotations to one and requiring this single rotation to be outside the trainee's major field. They decided that students and faculty both would benefit if students had the time to prepare to work in the lab by becoming more familiar with the field before beginning lab work.

At one 1998 project, the initial plan had students spending a few weeks on each of the lab's experimental rigs, rotating from one station to another. Experience showed, however, that the sophistication of each rig and the mathematical models used to explain the observations took most students a semester to master. Student feedback led the faculty to decide that full mastery of one system was better than superficial exposure to many.

Tutorials and Workshops

Another way of bringing trainees up to speed on state-of-the-art tools and techniques (so that they are able to do inter/multidisciplinary research) is to provide tutorials or workshops—highly focused, intensive sessions tailored to the specific need of the project's inter/multidisciplinary research. For example, at one IGERT, one of the courses runs a parallel series of tutorials on tools for optimization and simulation for students who may not be completely familiar with the tools of the subfield. Another IGERT includes a technology transfer process workshop series, which prepares students in the processes that comprise the central focus of its research area. A third project, in addition to two lab rotations, also offers short courses and other training sessions (often non-credit), that can be used by students to expand their knowledge of research methods.

At one IGERT, an important resource for trainees is the IGERT computer cluster. One co-PI referred to the cluster as "do-it-yourself supercomputing" because the lab is designed, built, and administered by trainees. The idea began when faculty asked for input from students on how to use the IGERT funds for research equipment. One trainee said students worried that purchasing individual computers for students would become a problem as students graduated. Instead, trainees worked with faculty to refine the idea of an IGERT computer cluster, and subsequently built a cluster of 126 computers for trainee use in conducting research.

Research Groups and Teams

Three-quarters of trainees across all cohorts report participating in team research. Some IGERT projects created defined inter/multidisciplinary research experiences, enlisting faculty from multiple disciplines and specifying overarching research questions that each group is to address. Two projects identified these experiences in their original IGERT proposals, and although they found that research projects and associated faculty have evolved over time, they continue to find the groups useful for structuring their programs. Students can affiliate with a group and experience multidisciplinary research in action.

In some projects, the lab experience is the focal point of cross-disciplinary learning. At one project, for instance, trainees work in small groups, using state-of-the-art research tools and methodologies, and focus on solving problems in multiple disciplines that require nonlinear systems applications. These small group projects resemble government labs and industry settings where group work is often the model for addressing problems.

Multidisciplinary team research work is regarded as the primary teaching vehicle at another project, where trainees participate in industry-related research projects set in university multidisciplinary labs. Site visitors report that this approach is typical for this institution, in which *all* students, even freshmen, work on interdisciplinary group projects.

At one project where inter/multidisciplinary research is required, trainees must take eight units of directed research. The first two components (2 units each) are devoted to individual research related to their theses, and the third is a semester-long (4 units) collaborative project involving professors and students from at least three disciplines. Participants describe this as the centerpiece of the IGERT project. Students tackle real problems and get training in effective teamwork and communication. Similarly, at another project an intensive year-long research experience outside of the students' home disciplines, but tailored to their interests, is the core element of the IGERT project. Students receive extensive and in-depth training in the methods of the second discipline and are, of course, funded for the full year of research. As one student commented on this experience:

> It is very unorthodox for a computer science major to be doing electrophysiological recordings of rats. The program is allowing me to develop theories and test them, particularly through access to a joint lab. From a research perspective, it is unfeasible to be just relying on someone else's data. I feel that this [working in a cross-disciplinary lab] is a much stronger way to do science and has helped me to develop the vocabulary necessary for the ongoing dissertation now.

Other IGERTs employ a collaborative research model to encourage interdisciplinary research. One project requires students to participate in two collaborative research workshops and to work as a team member to produce a product of some kind at the end of the experience. This component involves students in the whole range of research-related activities, from proposal writing to data analysis to manuscript submission, and students reported that these collaborative projects were their favorite part of the program. Another project has an even more practical version of this: its trainees participate in a second-year practicum, in which they work in teams with an industrial partner/client on a real-world technology commercialization project. This real-world experience helps solidify the content taught in coursework and extends the other skills that the IGERT project aims to teach, such as communication, teamwork, and cross-cultural communication skills. Both of these program components are successful in involving students in collaborative, real-world applied research.

Gaining Experience in "Real-World" Settings

Connecting students with "real-world" applications and settings can take numerous forms, such as the workshops, collaborative projects, and practicum described above. Many IGERT projects also provide internships and other opportunities for students to get off campus and bridge the gap between the graduate study environment and the world of work that awaits students post-dissertation.

In a few projects, a connection to real-world industry is at the center of students' education. For example, the entire educational/research structure of one IGERT project closely resembles the work environment of a national or industrial research and development laboratory. Teams made up of faculty from various departments, trainees, other graduate students, undergraduate students, and senior researchers/engineers from industry conduct research. The site visitors reported that individuals genuinely collaborate because projects require expertise from multiple disciplines. A researcher from an external industry firm that has a consortial relationship with the host university commented, "This is learning by doing in a team environment that is cross-disciplinary. The work could not have come out of one discipline only." Trainees and faculty are enthusiastic about their research because the devices at the center of the various projects have the potential to solve important problems in society. The culture of this program affirms that any challenging problem can be attacked by assembling a team of researchers from multiple disciplines, each of whom is willing to work at and just beyond his/her disciplinary boundaries.

One project provides opportunities for internships but does not require them. Instead, it holds a monthly Student-Industry seminar at which invited industry guests speak with students interested in careers in nanotechnology (the focus of that IGERT). The university also has a system for arranging informational interviews for students. This is the least prescriptive approach to connecting students to industry. Below we examine more direct connections made through internships and exposure to international science.

Internships

Nearly two-thirds (62 percent) of the 86 active IGERT projects offer internships either as a required or optional IGERT activity (Table B.3 in Appendix B). Among our site visit sample of 57 projects, 17 (30 percent) required students to participate in internships, and 27 projects (47 percent) provided optional internship opportunities.

Trainees in one project pursue internships in diverse settings, including research labs in other university departments, at other academic institutions, and at businesses such as IBM. Another project also requires internships at a private company or a public agency. In addition, because that project has a number of consortial relationships, students can participate in collaborative research across institutions and gain access to real-world data that are useful in testing their simulations. They can also participate in projects of urgent current interest such as biosurveillance and national security issues.

A 2000 project requires that each student spend one academic quarter as an intern in either an industrial research laboratory, a government laboratory, or a foreign academic laboratory. They do this some time after the first year of IGERT funding. This flexibility accommodates the diversity of trainees' prior experiences and goals.

A 1999 project requires all students to complete an international internship before they start work on their dissertation proposals. Ideally, students integrate their international experiences into their dissertations. Students were enthusiastic about this internship requirement; however, one content specialist was concerned that it could be difficult to coordinate projects with both the international collaborators and the student's dissertation advisor.

Across all cohorts, close to one-fifth of trainees report having taken internships. Those students who have taken advantage of internship opportunities report numerous benefits, as detailed in Table B.11 in Appendix B. Most notably, trainees report that their internships provided them with experience communicating with individuals from diverse disciplinary and professional backgrounds (86 percent). Other common benefits reported were applied research experience (79 percent), experience with team problem-solving (72 percent), and increased awareness of non-academic job opportunities (71 percent).

Where internships are optional, they are appreciated even if infrequently used. At one project, students work in labs at local institutions, and faculty members' many ties with local industry facilitate connections for their students. Even so, industrial internships have not played a major role for students, despite the expectation that most will begin their careers in genomics firms. One faculty member explained that many advisors prefer that their students not take internships. They do not believe the advantages outweigh the lab time lost. In addition to this faculty reluctance to release students, other barriers to implementing internships cited by various projects include the short duration of some internships relative to industry needs, possible disruption of family life if the internship is distant from the home institution, and intellectual property concerns.

One project integrates industry into graduate education by using trainees' internships in the summer after their first year as the focal point of their future work. Each year, all of the three or four trainees in the entering cohort go to the same industry for their internship. From this experience, the trainees develop plans for their thesis research, focused on an industrial/environmental problem, and then enlist university faculty to serve as their advisors. A trainee explained that the differences between this and a conventional program are the emphases on sustainability and life cycle assessment: "That's all new stuff that other students don't know about. In this program there's a sense of being on a building edge."

Several universities proposed requiring internships but have either eliminated the requirement or are considering doing so. For example, one project made an internship optional because trainees already receive experience working with industry through their on-campus research teams. Another project specified a required externship but is introducing increased flexibility for students because so many students enter with substantial work experience already. At a third project, students are encouraged to do internships, but there is little high-tech work near the university and the economic downturn has made connections even more difficult. Site visitors reported that few students had done internships; they are more concerned with finishing degrees in a timely fashion.

International Experiences

International opportunities in IGERT projects include attending international meetings and conferences, working with foreign scientists and engineers, and working with private companies abroad. The most common international activity available to trainees (available in 76 percent of projects) is the opportunity to attend international meetings or conferences. While 85 percent of trainees report working with people of different cultures or backgrounds, only 13 percent of trainees report working with scientists, of other nationalities, in their own countries. Table B.12 in Appendix B presents details of the international opportunities available in the IGERT projects, and Table B.13 in Appendix B documents trainees' experiences with activities that broaden their international perspective.

Most IGERT projects would like their trainees to be able to take advantage of the NSF supplemental funding available for international experiences, but for most trainees, the timing is not right: many are not at an appropriate stage of their training for the kind of opportunities that will add significantly to their experience. However, a few projects do have appropriate opportunities—either research partners whose labs are located in international settings, or research areas whose sites are typically international.

At one project, trainees are encouraged to explore opportunities both at home and abroad. Five trainees had traveled abroad, including to Japan and Brazil, to learn alongside experts in their field. Individual professors at other institutions have research relationships with overseas colleagues and have sent students to internships in their labs. For example, one student spent three summer weeks at his advisor's lab in Japan and planned to return the following summer. One project has established a formal collaborative relationship with the National Institute of Physiological Science of Japan, and is developing two other international collaborative relationships. No students had yet taken advantage of the opportunities at the time of our visit.

In addition to internships abroad, trainees at several universities pursue research with an international dimension because of the international nature of their project's field. For example, at one project most trainees in human evolutionary biology conduct their research abroad because most of the currently recognized archaeological and anthropological sites are in Africa, Asia, and western Europe. The PI noted that even though enhancing students' understanding of international issues is not a goal for this IGERT, because paleoanthropological research depends upon the good graces of the international community, students inevitably learn about the diplomacy of science in order to succeed. Similarly, the topic of another IGERT—global climate change—is inherently international, so its trainees must grapple with a global perspective and consider international viewpoints whether or not they actually leave the campus.

How Projects Make It Work

The flexibility of IGERT funding is one key ingredient to making IGERT inter/multidisciplinary graduate education work. Through IGERT funding, students are no longer tied to a single professor's lab, but have independence to explore and engage in multiple research experiences.

In addition to this financial support, IGERT projects use multiple strategies to make inter/multidisciplinary graduate education work in a traditional university environment. Key among these strategies are assigning students dual advisors from different departments, addressing trainees' variations in background preparation and knowledge with courses or seminars, and fostering the development of an inter/multidisciplinary learning community.

IGERT Funds Optimize Flexibility

By virtue of its funding structure, all IGERT projects give students more freedom and flexibility than is typical in graduate education. According to one trainee:

> The financial support allowed me the opportunity to engage in more in-depth and novel research approaches with collaborators/mentors from other disciplines providing unique insights to the scientific questions at hand.

With IGERT funding, trainees do not have to rely exclusively on one faculty member or lab for their funding. Students appreciate not having to constrain their thesis work to the work of their advisor and his/her lab. Examples from three students illustrate:

> . . . the freedom afforded [IGERT] students in pursuing our own research ideas, then bringing them to faculty for collaboration has been challenging, but absolutely necessary to my satisfaction as a student.

> The highlight of being an IGERT trainee is the ability to not be tied down to the particular research project that provides my funding . . . and [to] choose higher-level research that I find interesting, not research which is thrust upon me by the needs of my advisor.

> [An] aspect of the IGERT program that has been beneficial to my development [is] . . . the flexibility of having a [traineeship] allows me to pursue my own research and professional interests without the need of financial support from a professor's specific project.

For students who plan to work in industry, IGERT funding allows them to forgo supporting themselves through a teaching assistantship (TA). While a TA may be a valuable job-training experience for those going into academic careers, it is irrelevant to industry-bound students. With IGERT funding, they can concentrate more on research, as reported by several students:

> [B]eing able to devote the time to figuring out what I wanted to study and begin my research rather than being forced to teach my first year were all IGERT highlights for me.
>
> The stipend IGERT provides definitely gives trainees important freedom. We do not have pressure to affiliate with a lab (and thesis project) prematurely, and of course, have more time for research and study in the absence of TAing responsibilities.
>
> [This] flexibility allowed me to work in other labs to get exposure to a wide range of computational and theoretical approaches. These opportunities would not have been possible without the support of IGERT.

One project has developed a somewhat novel approach to using IGERT funds to facilitate students' research and faculty access. During their first year, students develop proposals for research projects and teaching modules. IGERT faculty work with them to craft the proposals. When the proposals are accepted, students receive a "credit card" backed with funds that they can use to access facilities or pay for expenses incurred in starting their research or in developing a teaching module. Not only do students begin learning how to write proposals early in their careers, but also, since they come with their own money, they may more easily access the resources of other faculty members' labs, both on and off campus.

The money also provides IGERT trainees with time for professional activities. One student notes, "The financial support of the program has been extraordinary. Receiving a stipend for my fourth year of study enabled me to focus on writing conference papers and developing connections with nationwide faculty working on similar subjects."

Inter/Multidisciplinary Advising and Faculty Interaction

About half of the projects we visited require students to have advisors from more than one department. In the majority of cases, this arrangement seems to work well, and students rarely report feeling pulled between competing advisors. Programs and individual students vary in the perception of time spent with each advisor. In some cases, the time split between advisors is closer to 90-10 than 50-50. At one project, for example, trainees are required to have co-advisors from at least two disciplines and have at least two IGERT faculty on their dissertation teams. This has led to many shared activities, with trainees from one discipline working on problems in another discipline or, at the very least, using the methodologies from the other discipline in their own work. In only one instance did we hear of faculty discouraging trainees from having advisors outside their own discipline. There students reported that faculty feared outside advisors would have unreasonable expectations about the number of courses students should take outside their home department.

Students also commonly mentioned the importance of having access to faculty in other departments in lab and course work as well as in choosing and implementing an inter/multidisciplinary research topic. One student comment, "IGERT faculty [are] more approachable than non-IGERT faculty," is typical of many students' opinions. Through working in multiple laboratories, students interact with faculty members outside their home discipline. It is not surprising, then, that students were frustrated when faculty from multiple disciplines were not involved.

At one project, trainees describe working on research projects in isolation from faculty, unless they seek them out. Even though small interdisciplinary teams of students identify an interdisciplinary research question and carry out investigations, the absence of faculty involvement and support leaves trainees frustrated. One student said that faculty felt that students were not meeting expectations, but the student complained that this occurred because faculty had not provided needed guidance and support. Trainees report that although faculty may be available, they are often not visible. Nonetheless, some trainees found the projects rewarding and stimulating. One trainee reported that, as his group mapped out their question, they realized that they needed each other to find the answers. This dependency meant that that the quality of students' experiences was highly contingent on their own group.

Filling in Gaps in Trainees' Disciplinary Knowledge

To enable students to work productively across disciplines, projects have had to deal with variations in students' level of preparation. This issue becomes more acute as the stretch across fields becomes greater. Project participants referred to the disciplinary gap variously as "soft" versus "hard," "qualitative" versus "quantitative," "field-based" versus "lab-based," or "math" versus "non-math." This could be the gap between computation and wet labs in bioinformatics; between economics and anthropology in social inequality; between applied math and neurology in computational neurobiology; and so on. Several projects offer special courses to bring those without the content background of their fellow trainees up to acceptable speed. For example, one project has a set of mathematics/statistics requirements for entry that visitors felt might deter those with humanities backgrounds. However, the project offers a crash course in engineering for trainees from the social sciences.

One project, as part of its commitment to diversity, has admitted a few students that it expected would require some extra help. To provide the help and avoid stigmatizing those students, they hired a senior-level student to be a tutor for the *entire* incoming class, and discovered that *all* students benefited greatly from the tutoring, not just those who were originally targeted.[31] At another project, the co-PIs work closely with students individually and recommend appropriate courses to strengthen their base of skills and knowledge. At several other programs, the PI or another advisor meets with students and helps them plan a sequence of courses that will address weaknesses in their background. Students report feeling challenged by these "gaps," but seem to be more than willing to work to overcome them to accomplish their goals.

One project, for example, includes a one-credit reading group, coordinated by a faculty member in Ecology, which is offered each fall. The reading group has evolved since it began four years ago. Interviewees explained that faculty ran the course the first year. Before the second year, the senior trainees asked the PIs if the students could take the lead (faculty retain oversight), and the trainees used the reading group as a way to teach each other the basic tenants of their disciplines. Students found this useful, although they noted that there was no unifying theme to the course.

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[31] They have also admitted and funded two minority students at the master's level, in the hope that once these students came to campus and found a supportive community, they would stay for a Ph.D. In one case, at least, this strategy is working. One student has decided to stay on because faculty and fellow students are so supportive, and, the student says, "I can see myself finishing."

Where either bridge courses or other assistance was absent, students said they wanted more opportunities to improve their quantitative skills.

Creating a Learning Community

During site visits, trainees expressed more excitement and described greater research collaboration when there was deep, cross-disciplinary faculty participation in the project—as team teachers across disciplines in core courses and as joint mentors across disciplines in labs addressing multidisciplinary problems. For example, at one project students noted how important it was to have faculty members who were open to learning, as evidenced by their participation in IGERT seminars and informal conversations. A content specialist elaborates:

> The quality of mentorship offered to the students by the faculty is outstanding. Their success lies in a true dedication to training as well as a natural ability to work with one another in such a way that, when a student is integrated into the project, the overall product is of greater strength than the individual players. Students in turn provide a fresh perspective on research projects and the faculty is receptive to new ideas as well as criticism. The result is that the students have an experience that is closer to postdoctoral training. They are given greater responsibility in the research project and thereby reach a greater amount of independence and maturity. In this way the faculty prepares students well for their academic research careers and, rather than viewing teaching as a responsibility, they use it as a way to facilitate innovative research projects. Faculty are tuned into one another's activities, thereby strengthening the basis for communicating with the students. For example, it is not untypical for faculty to attend one another's classes.

The community becomes a *learning community* when faculty members visibly model the type of inter/multidisciplinary dialogue they hope to instill in their students by being active, visible, and accessible. When faculty hang back, or when faculty members from one of the constituent disciplines are under-represented, students are less satisfied. Common elements in projects with a sense of learning community include: a sense of common mission, genuine pleasure in and excitement about the work, and collegial relationships.

Healthy learning communities are strengthened by activities that provide opportunities for cross-disciplinary interaction. One strategy for fostering community is to have students take a foundation course or a set of core courses together. A few projects explicitly use a "cohort" approach to organizing their programs. Shared office or lounge space, regular seminars, brown bags, "pizza lunches," periodic retreats, journal clubs, and symposia also contribute to a sense of community in different projects. Where this feeling of community is absent, students do not see what they are doing as particularly different from their non-IGERT colleagues. In at least one project that was less successful in creating a sense of community, some students were meeting each other for the first time during our site visit. At others, although there was a core group of courses that trainees took together, trainees' experiences were much more determined by their home laboratory. According to one student, "My world is defined by my lab." Students who were not associated with the PI's lab, or who were on other campuses, felt more peripheral and isolated from the rest of the project. At the time of the visit, this issue had not been addressed.

Informally, several projects encourage students to work in study groups to help each other survive some of the really difficult courses. As mentioned earlier, some projects also have interdisciplinary research teams that students join as they identify their own research priorities, while others have structured interdisciplinary teams in which students truly need the input of others in order to be able to do their work. Less successful programs are more likely to have students working in relative isolation.

Some PIs and co-PIs are perceived by trainees as outstanding in their capacity to foster a supportive climate for students. In several projects, the person who (under a variety of titles) assists with running the program is often singled out for praise from students and faculty alike. Not only do these people relieve the PI from administrative burden, but they also provide both formal and informal support for students. In a few cases these people are scientifically trained, which deepens their understanding of students' situations.

Two projects in particular illustrate the development of a learning community. In one case, the program is residential, provides for intensive interaction with faculty, and gives students important professional roles early on. The structure of the first project makes it unique among IGERT projects. Students come to the host university's field biological station from all over the country for two consecutive summers. In their first summer they devote approximately 50 percent of their time to intensive coursework that helps bridge the cross-disciplinary gap. In their second summer, almost all of their time is devoted to research. Regular meetings with an advisory committee and a three-day retreat are additional project elements. Second-year students are required to mentor first-year students, and a student serves alongside faculty on the students' advisory committees. A particularly important program element is that students' on-campus mentors also come to the facility, for about a week. Faculty and students work side-by-side, as well as eating meals together and socializing in this residential setting. Site visitors quoted students as saying that "the most important aspect . . . is being here with a bunch of people. All processing of learning goes on in these groups," and "there's contact in the lab and in living quarters." "The professors are casual and accessible, and the atmosphere models multidisciplinary interaction." Content specialists echoed students' comments. One noted that "the 'total immersion' nature of the experience and the ease of access to faculty and other students remove barriers to the flow of information, build confidence and establish a sense of camaraderie and 'shared experience' that will last long beyond the 2-3 summers on site."

In the second illustration of a program in which the learning community seems particularly evident, both an intelligently planned program and an extraordinarily involved and enthusiastic faculty seem to be what makes the program stand out. This IGERT program has successfully brought together two cultures of researchers: field workers and lab workers. In the core IGERT course, taken by all first-year students, the trainees work in multidisciplinary teams on course-long projects. They teach each other about their own disciplines, meet and learn about the work of the faculty, work with the post-docs who help teach the course, and also meet some of the more advanced IGERT students who come in to speak about their work. At the end of this course, on presenting an acceptable proposal, students receive a "research credit card" that provides research funding for their work. Crucial to the success of the program is an accessible and open faculty who are themselves excited about their work. One trainee was amazed to see the PI actually *in* the lab, contrasting this with the norm in other fields where faculty are much less available. One student joked, "[IGERT] faculty are used to random [IGERT] people approaching them and asking them for help. You just pop in and say, 'Hi, I'm a[n] [IGERT] student!' and they say 'Hi, come on in!'" This atmosphere of collegiality and support is promoted by monthly pizza lunches that are hosted by a different IGERT faculty member's lab.

Several projects organize shorter retreats at the beginning of the academic year as a way of building community while providing opportunities for trainees and faculty to take stock of each other's research and key issues in the field. For example, one project holds a student-organized three-day retreat off site each fall. Students present their research, and there are opportunities for discussion. Another project has a similar retreat that is faculty-organized, and a third has a student-organized symposium.

A 2000 project has a two-week neuroscience “boot camp” (required of all new students) that includes wet-lab experiences for the new computational neuroscience students whose biological backgrounds may be less well-developed than their computational backgrounds. However, those with strong biological backgrounds also participate. The 9 a.m.-to-midnight schedule helps forge social bonds in each new group of trainees.

Some IGERT projects have been less able to establish a fully functioning multidisciplinary program, due primarily to implementation delays, changes in project leadership, or limited institutional commitment and faculty support. One project, for example, sought to create a separate new degree program, but the review process itself and changes in project management delayed the program for two years. The stalled momentum resulted in a lack of interaction among students and faculty. According to the site visitors, the program seems "traditionally academic in nature" and has little of the inter/multidisciplinary teamwork that characterizes other IGERT projects. Sabbaticals for several key leaders delayed the start of another IGERT. Project faculty then concentrated on developing an institutional base for the project (i.e., a new institute for computational analysis) rather than on the programmatic elements for students. On the plus side, the project has solid prospects for institutionalization. On the other hand, only 13 trainees have been enrolled in the first three years of the project.

Distance compounds the difficulties of creating integrated programs. Several projects have had to deal with the challenges of working across scattered sites, either by design or when the original PI left one university for another. In these instances, the IGERT projects have more than twice as many challenges—those within each institution and those created by the cross-institution focus.

Project Success: How Effective Are IGERT Projects?

The students in IGERT projects are young, although some enter IGERT programs with advanced degrees and/or some work experience in hand. Twenty-nine percent of students across all cohorts report some degree beyond their bachelor’s, and a larger proportion (45 percent) report having been employed in the public or private sector for, on average, three years before entering graduate school. The fact that two-thirds of IGERT trainees (73 percent) were enrolled at their institution one year or less before joining their IGERT project indicates that the trainee population tends to be concentrated in the early years of graduate study.

During the program’s first six years, 255 of the 1,685 trainees (15 percent) have stopped pursuing a Ph.D. degree associated with their IGERT project. Thirty percent of these graduated with a master’s degree. The most common reasons for ceasing pursuit of a doctoral degree in an IGERT program were: pursuing other academic interests (33 percent of those who stopped) or beginning employment (23 percent).

To date, 129 IGERT trainees have graduated from IGERT projects with their doctoral degrees. The median time to degree for these doctoral students was 4.6 years. It should be noted that 45 percent of these graduates had a prior graduate degree (such as a master's degree) before earning their doctorate, and graduates with a prior degree obtain their doctorate faster than those without, on average.

Since so few students have graduated from IGERT projects at this point in time, the effects of IGERT on students' career outcomes are yet unknown. Those few students who have graduated spent the first years of their graduate training in traditional programs before the IGERT project began, making them at best only a partial indicator of the outcomes of the IGERT educational process.

Even without waiting for more students to graduate, we found numerous self-report indicators that IGERT projects are effecting change for students. In the annual web survey, PIs detailed their projects' successes at fostering trainee growth; the results are presented in Table B.14 in Appendix B. Close to three-quarters of PIs judge their trainees to be "successful" in interdisciplinary coursework, functioning in an interdisciplinary environment, ability to communicate across disciplines, teamwork skills, and ability to conduct high-quality research.

In the site visits, students have high praise for their IGERT educational experience, and it appears they are receiving an excellent education in inter/multidisciplinary science. In the remainder of this chapter, we discuss early indicators of success for students under four topics: creation of truly inter/multidisciplinary educational programs, quality of student research, value of gaining "real world" experiences, and expanded career options for graduates.

Creating a Truly Inter/Multidisciplinary Program

IGERT trainees almost unanimously report that their project provides them with a much broader, more interdisciplinary education than they would have received in a traditional program. They say they are being exposed to research and scientific literature that otherwise might have been unknown to them. Trainees describe IGERT as expanding the breadth of their graduate educational experiences, and they appreciate the opportunity to connect their own research interests to other current research. IGERT faculty and visiting content specialists generally agree with students' perceptions.

Many students use terms such as "introduced," "exposed," and "learned from" to describe their interactions with material and scholars from other disciplines. One student noted that, "My major excitement from being an IGERT trainee is the opportunity to learn from students and faculty of various different academic backgrounds all with computation as a common interest." Faculty members and students at another IGERT described a lively interdisciplinary culture as a result of the interactions that are taking place. Students characterized faculty and other students as ready and eager to provide advice both formally and informally, and one trainee said IGERT promotes many more interdisciplinary conversations than take place in his department. A professor said that, as a result of the array of interactions, "the cross-fertilization has been incredible." A content specialist visiting a third IGERT reported, "Students . . . are exposed to methodologies beyond their own disciplines. . . . Students seem likely to come out of the program with greater depth and breadth of knowledge . . . than would be the case had they not been in the program." The site visitors noted, ". . . several students whose focus is economics appreciated learning about qualitative fieldwork, typical in the field of sociology, while sociology students stated that they were grateful for the advanced training in quantitative methods they received."

Student excitement about interdisciplinary work is widespread. For example, one said, "These interactions foster new and interesting ideas [and] different views and methods for attacking research problems." A trainee at another IGERT stated that "the walls are very low here," while students in a third project reported that NET offers them more breadth and opportunities to explore "a broader scope of approaches" to problems, and trains students to be able to know and use the language of both neuroscience and engineering. In another example, site visitors to another project reported on a trainee from computer science who is doing a project that also includes electrical engineering:

> He said he likes the mixing of ideas. For Computer Science students, in particular, such collaboration provides real world applications that they usually don't see. He enjoys having two different groups in the same lab overlap, "stealing ideas from each other."

Those projects that put the greatest effort into developing real inter/multidisciplinary experiences for their trainees received the highest marks from students for preparing them to feel equipped to work across disciplines and define and solve complex problems. If a project fails to provide real inter/multidisciplinary experiences, it may be due to a lack of vision, a lack of sufficient effort in project design, an unwillingness to engage in mid-course correction, or university/department policy barriers. Regardless of the reason, if a project simply provides a menu of pre-existing, single-discipline courses for students to choose from, or lab rotations in which students travel alone from department to department, integration across disciplines occurs only to the extent that students make it happen on their own. Some students do well regardless; others recognize that their program is not as interdisciplinary as it might be; and still others have no idea what they are missing.

Among many projects that appear to have successfully integrated an inter/multidisciplinary focus, we chose three to present in more detail. Each, in differing ways, has combined a number of elements in order to achieve their goals.

At a 1998 project, trainees in neuroscience minor in scientific computation, while trainees from the other eight departments in the project minor in neuroscience. Newly eligible students from the physical and computational sciences were found to lack the prerequisites necessary for neuroscience graduate work, so the project developed a bridge course for these students. Trainees participate in a five-week summer retreat at the university field station where they are introduced to the concepts and experimental techniques of neuroscience. They also participate in laboratory rotations during their first year in which they work collaboratively with each other, postdoctoral fellows, and professors. As a result of these and other structures, the trainees report that computational neuroscience is truly an integration of disciplines in which their research questions could not be answered without merging fields of science and broadening perspectives.

The goal of another 1998 project is to create and nurture an environment for a new generation of students who will be able to work across disciplines. Trainees have advisors from multiple departments, take core courses together, and have access to labs in several departments. Students are required to work in teams and collaborate on their design projects, in which they develop and test prototype solutions to real-life problems. The students are also strongly encouraged to present at conferences. One student commented, "IGERT taught me not to be afraid to tackle something outside my area of expertise. I can jump in the middle of anything and make it work."

The theme of a 2000 project is multidisciplinary, in that it involves two interdisciplinary areas. Scientists who work in either of these disciplinary areas work across traditional disciplines, developing deep expertise in both a traditional discipline and an interdisciplinary discipline. Students in both areas of this project's program are, therefore, expected to develop the capacity to work productively with scientists from their complementary area on cross-disciplinary problems. One content specialist felt that the project had been very successful in inculcating the kind of content knowledge that it set out to develop: "Students coming from different backgrounds have in general 'got up to speed' in areas they had not previously been trained in—this appears due in large part to the efforts that faculty have made in giving students extra help in those areas." He also noted that the program had positively affected the faculty: "The cross-disciplinary nature of the program has definitely broadened faculty interactions in research and also in general scientific outlook and culture." In fact, the faculty involved in this project had laid a strong foundation for the endeavor through a long history of collaboration in many areas, from research to dissertation committees to strategic planning.

Quality of IGERT Research

The doctorate is a research degree, and trainees' exposure to and mastery of high quality research is central to their graduate education. IGERT projects are almost universally successful in this realm, although some faculty and administrators, and an occasional student, express concern that inter/multidisciplinarity might lead to, or be perceived as, breadth without depth. Nonetheless, the content specialists typically have high praise for the quality of the science in these projects. In only a handful of instances did they express reservations about whether a particular student's work was of doctoral quality. More typically, they regard students' work as very good and, sometimes, truly outstanding. Faculty and students are equally enthusiastic about the research conducted in the context of IGERT projects. In several IGERT projects, the content specialists characterized the faculty as "world-class." Below, content specialists comment both on the quality of project research and on student mastery.

> The IGERT program has arisen from a very strong base at [this university] . . . a strong foundation in the teaching and research of cell, systems and molecular neuroscience and psychology, as well as an existing nucleus of world-class experimental and computational neuroscientists, physicists and chemists.

> Perhaps the most telling aspect of the success of this program is the quality and cross-disciplinary nature of the IGERT graduate student research presentations. Student projects in this program consistently involved cross-fertilization between approaches to issues, such as combining computational modeling or psychological experiments with investigation of complex linguistic phenomena.

> Perhaps the most impressive aspect of this program is the students. The scientific presentations during the morning session were extremely well done, demonstrating excellent scientific achievement, as well as excellent presentation skills. The students were articulate and well educated.

Value of Applied and "Real-World" Work

When students have the opportunity to work on "real-world" problems, they value them greatly. For example, a female student was working on a sensor that might lead to more effective ways of detecting breast cancer; she was highly committed to her work and expected to continue working in this area after graduation. Recognizing that research problems that emerge from real-world contexts are often interdisciplinary by nature, another student in that program commented, “This interdisciplinary training is good . . . because this mixture is more like what is in the real world applications of the science, rather than the usual separations by disciplines.” At another project, conducting research with direct real-world applications, such as rapidly deployable broadband wireless for emergency and disaster services, has provided some trainees with opportunities for interactions with local, state, and federal officials.

Trainees are generally satisfied that their programs are preparing them to work in the real world, and they value the broad utility of their research. The following quotations exemplify the attitudes of many trainees.

> Almost all real-world solutions to problems involve interdisciplinary action, and the IGERT program has opened my eyes to this truth.
>
> . . . as most real-world problems are multidisciplinary in nature, it is useful to be able to obtain a well-rounded graduate career with multidisciplinary perspectives.

Expanded Career Options for Graduates

Students almost uniformly report feeling well positioned to enter the job market. Trainees’ perceptions of their own readiness to enter the academic or industrial workforce are exemplified by comments like the following:

> I feel that my trainee experience has positioned me well to compete for a variety of post-graduate careers, both academic and non-academic (e.g., more policy, advocacy, program oriented than pure research).
>
> The traineeship has placed me in a position of coordinating various aspects of a project, and has prepared me for a group leadership role in industry or academics.
>
> [IGERT] is beneficial in terms of giving me an idea of what skills and attitudes industrial companies might be looking for me to develop whilst in Graduate School.
>
> [IGERT] has also given me the freedom to explore my research interests more fully and to grow my knowledge base in order to apply it to practical research problems. Because I can focus on applied research, I know I have learned enough statistics, economics, political science, transportation and environmental policy, ecology, and engineering to incorporate aspects of each of these fields into my work. I also know that in doing this I’ve developed a foundation for future collaboration with a diverse group of specialists and professionals. Being an IGERT trainee simply makes me feel more prepared to enter the working world, and to collaborate with those from different professional backgrounds.

Site visitors also reported on trainees’ assessments.

> Trainees state that positions are calling for faculty members with broad, interdisciplinary knowledge. According to one trainee, “They’re waiting for us.”
>
> Trainees report that they have gotten a solid grounding in theoretical and experimental approaches to research in neuroscience, extraordinary experiences in working as a team in an interdisciplinary setting, and multiple opportunities to meet prominent scientists in their field,

> as well as opportunities to develop teaching skills and to present, and in some instances publish their research.
>
> Trainees value being trained to work in teams and taught a large range of technical skills. They mentioned that they felt they would be more marketable to industry because of IGERT. One newly funded student commented that she is looking forward to learning how to talk about her work to those outside her discipline. "You need to know how to talk to a physicist and how to read their work!"

Some projects explicitly emphasize preparation for future employment. At one project, administrators describe their IGERT's mission as "giving students a broad base of knowledge which can be applied in the workforce, and avoiding such specialization that the graduate cannot work in the real world, where science is integrated." All students take summer industrial internships and are assessed by their industrial sponsor on their performance in the "employable quintet" of technical knowledge in depth, problem solving ability in a laboratory setting, flexibility in learning and working, an ability to work in teams, and clarity in oral and written communication. Another project has a similar focus. In addition to encouraging internships, "soft" skills courses that focus on topics such as teamwork, ethics, proposal writing, and management are among their core requirements. Also, trainees are provided with Microsoft Project files with which they are supposed to plan and lay out their graduate careers, an exercise students reported to be difficult and not always helpful. At one 1999 IGERT, an "out of state" experience is *required*, in recognition of the fact that the university is relatively isolated and may not have all the resources that students will need. Students can take short courses, work in other labs, etc. In addition to the learning gained, this experience gives them opportunities for networking and collaboration.

Although most IGERT students have not yet earned their Ph.D., some have, and there are already some employment success stories:

> As the direct result of the training received through the IGERT program, I am happy to say that I will be joining a company upon graduation with which I partook an internship in the previous months.

A number of students have moved from IGERT projects into post-doctoral appointments at universities or national laboratories. One Ph.D. graduate moved directly into a tenure track position at Purdue, and project staff regard this success as a vindication of their interdisciplinary approach.

Occasionally, both faculty and students still express concern about whether job placement into traditional departments will be harder for trainees because of the interdisciplinary training they have received. While the very earliest data suggest that student placement is not a problem (or is at least no bigger a problem than in traditional departments), the next two to three years, as many students complete their programs, will tell.

Summary and Conclusions

IGERT projects have combined course work, laboratory, and research experiences to create an integrated doctoral experience for their students, melding inter/multidisciplinary themes into each educational experience. Most IGERT students are enrolled in "discipline plus" degree programs, where they earn their doctorate in their home department but engage in inter/multidisciplinary education and research through IGERT. Students may earn inter/multidisciplinary doctorates in 12 IGERT projects. Inter/multidisciplinary experiences generally are obtained through an IGERT seminar and a core set of core courses, often team-taught, that weave the disciplines together to form the inter/multidisciplinary theme. Students' research experiences can include rotations through laboratories of various faculty as well as inter/multidisciplinary research project experiences. About two-thirds of the IGERT projects either require internships or offer them as an optional component.

IGERT trainees are virtually unanimous in reporting that their IGERT projects provide them with a much broader, more inter/multidisciplinary education than they would have received in a traditional program. All respondents—students, faculty, content experts—agree that the IGERT research is top-notch as well.

Some IGERT projects have been more successful than others in providing a rich inter/multidisciplinary program for students. These projects often require trainees and faculty to work across disciplines, not simply to rotate students first through one disciplinary experience and then into another. The more successful IGERT projects also directly address any shortcomings students may have in their academic preparation across disciplines, and the projects are self-reflective as well, modifying the program to fit student needs. They use IGERT funding flexibly, giving students more freedom to explore research topics than the traditional model of working with a single professor. Students have valued the real-world problems being addressed in some IGERT projects, and almost uniformly report feeling well positioned to enter the job market—whether in academia or other environments. Conversely, students in the IGERT projects that are struggling report less faculty buy-in, less involvement of faculty whose research crosses disciplinary lines, and overall, a less cohesive inter/multidisciplinary experience.

Chapter 4. Impact on Faculty

Introduction

Although the central focus of IGERT is on changing the graduate student experience in science, technology, engineering, and mathematics (STEM), IGERT can also affect faculty. As of the 2003 web survey administration, 1,606 faculty had been involved in IGERT as co-PIs or advisors. In the 2002-2003 academic year, there were 1,412 active faculty members across all projects. In this chapter, we describe:

- PI perceptions of program impact on faculty;
- faculty reflections on how IGERT projects have affected their thinking and practice with respect to research, pedagogy, and interactions with colleagues; and
- evidence of cultural changes that foster collaborative faculty research across disciplinary boundaries and an integration of research with innovative education.

The impacts of IGERT on faculty are reflected in PIs' responses to the annual web survey, displayed in Table C.1 in Appendix C. Almost all PIs (95 percent) recorded faculty impacts in at least one area as a result of the IGERT program. Seventy-nine percent of PIs report that faculty in their projects are sharing mentoring responsibilities across disciplines. Nearly two-thirds report that their faculty have been teaching new courses that cross traditional disciplinary boundaries, and a similar number report an increase in faculty participation on multidisciplinary dissertation committees. In addition, over one-half of the PIs report increased faculty participation in each of the following four areas: non-home discipline activities (57 percent), membership on multidisciplinary teams that win awards (55 percent), team-teaching across disciplines (55 percent), and jointly authoring papers across disciplines (55 percent). Just over one-quarter of PIs report that their faculty are employing new pedagogical approaches.

Likewise, site visits provided an indication of the ways in which faculty have been affected by IGERT.

- Faculty at IGERT projects report increased interactions with faculty from other disciplines and they report a direct impact on their own research.
- Students serve as conduits for faculty interactions through co-advising or lab rotation arrangements.
- Institutional support of IGERT lends itself to greater faculty participation in IGERT, and difficulties with institutional policies or bureaucracy can inhibit faculty efforts in innovative approaches to teaching.

Our visits suggest that, given adequate institutional support, IGERT projects can significantly influence the research and pedagogy of faculty, and this influence can extend beyond those faculty who are initially involved with the project. Below, we begin by highlighting site visit examples of IGERT influences on faculty involvement in cross-disciplinary research and in new educational training endeavors. We then describe the ways in which IGERT has influenced the academic culture at institutions. IGERT has played a significant role in increasing participating faculty members' interdisciplinary research, and we explore the role that students play as the bridge that unites faculty with the innovations associated with IGERT. We also describe the role IGERT has played in new faculty hires. We then illustrate the ways in which IGERT faculty have changed their practices related to training graduate students including new curricular offerings, the use of shared laboratories, and involvement in extramural activities.

Inter/Multidisciplinary Research

Across the three cohorts visited, there are many examples of IGERT projects stimulating new research collaborations across traditional disciplinary boundaries. These collaborations have led faculty to conduct research in still-emerging fields, to explore development of new, innovative technologies, and to pursue joint publications and grant proposals. For example:

- At one project, faculty from electrical engineering, chemistry, and chemical engineering are engaged in collaborations in new sensor materials, molecular recognition, microfabrication, systems architecture, and interface electronics.
- Computer scientists and applied mathematicians at another project have co-authored publications with linguists; faculty have established joint, cross-disciplinary laboratory meetings; and faculty are coordinating efforts with neuroscience faculty to develop a new Brain Sciences program with its own building.
- Faculty in the Earth and Mineral Sciences and the Microbiology departments at a 1999 project have forged productive research collaborations. A comparison of faculty vitae conducted by the project indicates that IGERT faculty members have more interdisciplinary publications and presentations than the non-IGERT faculty in the four core IGERT departments.
- At another 1999 project, research expenditures among IGERT-affiliated faculty grew from $2.8 million in 1998 to $4.5 million in 2002, and the administrative home of the IGERT has been asked to submit a proposal for a grant from the National Institute of Environmental Health Sciences for as much as $10 million.
- At a 1998 project, a geographer and a philosopher are collaborating in the emerging field of spatial ontology, and social scientists assert that IGERT has validated the pursuit of research in such areas as cross-cultural conceptualizations of space, the legal construction of space and its relation to indigenous populations, and the spatialization of library data.
- At a 2000 project, an economics professor and an ecology professor, along with an IGERT student, are researching urbanization and land use change in a nearby area and have secured funding to pursue related research. Through participation in IGERT activities, this ecology professor has also discovered common interests in the science/policy interface with a political science professor. A biology professor and a journalism professor are in discussions about co-authoring a book dealing with the global nitrogen cycle.
- At another 2000 project, the IGERT project has stimulated collaboration among faculty in different departments including chemical engineering and materials science, chemistry, and computer science. IGERT has contributed to the growing focus on scientific

computing on campus, and has “provided a focal point for this type of work that didn’t exist before,” according to one department chair.

- A third 2000 project has spurred research groups into areas they would not have pursued without IGERT's influence. The investigation entails ventures into biological chemistry outside the traditional analytical scope of the chemistry faculty. IGERT has brought techniques into labs that would not otherwise be there. In addition, researchers in a biophysical lab are starting a new collaboration that will bring a cell biology expert into the group.

Both participating faculty and visiting content specialists credit IGERT with stimulating and supporting these collaborations. One content specialist reported that “not one of the [IGERT] research projects that was described to me would necessarily be in the domain of a single university department as traditionally defined.” One PI noted:

> I have been here for over ten years and I have never in the past seen the interactions that I see now. In my first nine years, I never put in a grant with the Medical School—now, I have two grants with faculty from the Medical School. None of this would be happening if it were not for this program . . . if it were not for NSF. [This university] has a lot of multidisciplinary programs, but nothing like this.

Senior faculty at another university have also been extremely supportive of its IGERT project. They have begun new collaborations, willingly expanding their research interests in order to join the IGERT project, and encouraging junior faculty to participate in interdisciplinary work. One faculty member remarked that participation in IGERT facilitated her promotion to full professor. Faculty gain experience and confidence using equipment and methods borrowed from other departments, and report that the benefits of participating far outweigh the cost of added work. For example, one faculty member said, “Working with people outside your discipline is difficult, but you get opportunities to do something you wouldn’t ordinarily do, and it adds to the motivation.”

At university with a 2000 IGERT project, two junior faculty members who were extremely active in IGERT credit IGERT with helping their tenure cases. At another university, junior faculty members, in particular, found the collaborative atmosphere fostered by the IGERT project very important to their career development. IGERT funds allowed these faculty to encourage more student-led research projects, projects which often led to publications and/or conference presentations as well as serving as a vehicle to leverage further funding. And at a third project, IGERT was described as particularly important for junior faculty, who uniformly felt IGERT allowed them to pursue high-risk, high-return research they would not have pursued with standard university start-up funds.

Changing Cultures

The faculty-to-faculty interactions across departments have begun to change the academic culture at many institutions, encouraging a greater degree of collegiality across disciplinary lines. A content specialist visiting a 2000 project described the impact of this cultural change: “The faculty interact with each other actively, and are very interested and involved with their students. They model interdisciplinary research and teaching, so that the students are ‘growing up’ in this environment and not only do not consider interdisciplinary research unusual, they don’t seem to be able to imagine the world being any other way.”

Citing the warm atmosphere among his IGERT colleagues, one IGERT junior faculty member commented, "I've never seen an institution where the faculty from other departments were so social with one another. They are real colleagues, they greet each other so warmly." At another project, a high level of cooperation across departments active in the IGERT resulted in the biology department granting laboratory space to an incoming psychology professor whose space needs could not be accommodated within the psychology department.

Faculty members at a 1999 project have noticed a marked change in the intellectual culture as a result of IGERT. One professor summarized the effects of IGERT this way:

> Math, computer science, and biology were here before IGERT but they were not linked…. Math, electrical engineering and computer science were off in their own worlds. IGERT has succeeded in making computational analysis a major campus-wide focus. IGERT also got the physical chemists involved. That would not have been done without IGERT.

A visiting content specialist concurred with this faculty member: "In most cases, institutional training programs really help to improve graduate training. At [this university], however, the impact went beyond that and had a qualitative effect on the research life at this institution."

A faculty member in a 1998 project indicated that IGERT reflects a "paradigm shift in science to a multi-investigator approach," and said the project is a "pull for faculty. I go to more IGERT seminars than disciplinary seminars. People [in IGERT] are broader-based, less provincial." At other IGERT sites visited, faculty have begun to attend conferences outside their home disciplines in order to stay current in emerging fields and to enhance their own professional development as they explore interdisciplinary collaborations.

One IGERT faculty member described IGERT's impact this way: "[This program] has forced faculty to get rid of nonessentials and requires courage in the face of naysayers in departments. It has changed how we spend our time." At another project, a faculty member who was relatively new to IGERT remarked, "You can't force people to work together, but a place like this . . . people are so open to new ideas and people, so collegial, and wanting to work together cements and expands on it."

IGERT faculty members credit IGERT with increasing collaborations and expanding their research. One faculty member described the collaborations among IGERT biology and engineering faculty as having "radicalized and changed [the biology department's] research in a very positive way." He added, "faculty now press forward doing more creative interdisciplinary work than they otherwise could do." At another project, faculty commented that while the university encourages collaboration, IGERT has offered new opportunities. For example, one professor works with three different colleagues in three different labs, due in part to IGERT. Two other professors with shared interests said they would not have known each other without the IGERT project and now have plans to collaborate. One department chair observed that even the interdisciplinary search committees that must be formed to hire IGERT faculty bring current professors together. Several faculty members at another project described IGERT participation as changing the way they thought about their work and the kind of work they pursued. Two professors said that by working together on a collaborative workshop they taught each other their fields. As a result, they are now working on a biocomplexity proposal with another colleague. A faculty member of this team stated, "I don't think I'd be thinking these thoughts if I were still in my discipline." The Dean of Biological Sciences at a university hosting an IGERT project stated that IGERT has led to "a sea change in the labs [by introducing] strong computational tools such as modeling, and to new areas of faculty research."

Many IGERT faculty members believe that the IGERT project has given them the opportunity to work with the top students in the country. There is a widespread perception by faculty that IGERT attracts a more talented pool of graduate students than those enrolled in traditional departments. One of the co-PIs at one project views IGERT trainees as "world class" and a valuable resource: "For the first time I have students to whom I can say, here is a research problem, go find out how to do it, and they do." He rates the IGERT trainees much more positively than non-IGERT students. At another project, the perception that IGERT gets the best students led the chemistry department to bar first-year students from the program, for fear of losing them. At a third project, faculty and administrators interviewed were unanimously impressed by the quality of the trainees. One faculty member described the type of student who thrives in IGERT as "someone willing to not follow a traditional path, to push themselves, to be an independent learner, and not to take the path of least resistance." Non-IGERT faculty at another university increasingly seek IGERT bioinformatics students for their own laboratories and are requiring their students to take a bioinformatics course (whether or not the student is enrolled in the IGERT bioinformatics program). At one dual-institution project, faculty said they particularly value IGERT for the quality of the graduate students who are recruited into their programs and the contributions these students can make to their research.

There is some evidence that the cultural changes associated with IGERT may extend beyond project participants. One PI noted that as IGERT faculty serve on university committees, they "promote a culture that supports multidisciplinary education across the entire university. This makes it easier for other interdepartmental or interdisciplinary projects to be accepted at the university." At another project, the original IGERT PI was appointed Vice Provost for Research in large part to implement IGERT principles across the university. Several content specialists suggested that IGERT establishes a good model for the future of graduate education.

Even within departments, IGERT has served to dissolve barriers. At one project, the chemistry chair pointed out that within the chemistry departments there are disciplinary divisions. He credits IGERT with blurring the lines between these intradepartmental divisions, and promoting more collaboration among professors within chemistry who might otherwise not collaborate. An administrator stated that IGERT "has helped to break down walls of the silos." He felt that the influence of IGERT reached beyond the scope of IGERT as the 20 active IGERT faculty collaborated with other faculty. At another project, the interaction among the different departments resulted in new collaborations and exchanges of ideas. A chemistry professor said IGERT is a "major driver" for collaborative research, and is changing the way the department works to a more collaborative approach. A physics professor noted that conversations with faculty from other departments are revealing common interests, and an engineering professor said some faculty are working to redirect their research to nanotechnology because of the energy and enthusiasm around the field.

In addition, the IGERT has reinforced the existing collaborative and/or interdisciplinary climate in some institutions. For example, one IGERT builds on a strong foundation of collaboration and multidisciplinary research and educational practices. This IGERT has allowed the faculty to organize courses in scientific computing and to bring together faculty working on scientific computing. Another IGERT project operates in a highly collaborative culture already well established at its university. Beginning in the 1980s, the university began hiring science and engineering faculty from industry because they were accustomed to collaborating across disciplines and being at the forefront of interdisciplinary research. Joint appointment of faculty to multiple departments also lowers barriers to collaboration, and contributes to the university's strong reputation for cutting-edge research. At another project, four of the participating faculty have had a decade of working together on interdisciplinary graduate training because of a prior Graduate Research Traineeship (GRT) grant. According to the PI, they have "developed a great relationship because their students have been conducting collaborative research and they hold joint lab meetings, and the collaborations are driven by the research problems they are working on."

Students as the "Bridge"

The IGERT program fosters interdisciplinary research among faculty through faculty contact with IGERT students. At one project, graduate students are often the ones initiating ideas and contact with faculty. One faculty member explained that he presented at the nanotechnology seminar, and was subsequently approached by a student who shared his interests; the student is now conducting research in the professor's laboratory. Another professor said his own students regularly send *other* graduate students to him for ideas, conversation, and assistance. At another project, the collaboration between a Chemical Engineering trainee (whose research interests are at the interface of biology and engineering), his primary advisor (a theoretical computational chemical engineer), and his co-advisor (an experimental cell biologist) has resulted in a viable research project.

At a 1999 project, faculty members also cited the importance of trainees in advancing interdisciplinary research. As students rotate among laboratories during their first year of the traineeship, they bring ideas and perspectives that benefit the projects on which they are working. At another project, the faculty members describe the IGERT program as a way to prepare themselves for the interdisciplinary future of anthropological research, through continued learning about and use of new tools and approaches. Students often serve as the bridge in this process, bringing back new knowledge and techniques.

At a 1998 project, IGERT students must have four faculty members on their committee from different disciplines. As a result, students often serve as the "bridge" or catalyst that brings faculty together and helps forge their collaborations. At another project, because IGERT students are required to have co-advisors, faculty members are increasingly engaged in sharing mentorship of students and participating in multidisciplinary dissertation committees. Similar results are reported in other projects that require trainees to have co-advisors or committee members from outside their primary field.

At a 1999 project, the talented young engineers and scientists attracted to the IGERT have stimulated faculty to become more excited about cross-disciplinary collaboration among faculty. As one professor said, "NET students are the links between the professors." At another project, engineering faculty have become increasingly interested in policy issues as their students consider the policy and marketing questions associated with a new technology. One member of this IGERT's external advisory board noted that, "the faculty themselves are not really interdisciplinary, the students are. The students bring the faculty together and IGERT promotes that." This holds true in a number of other settings. One administrator commented on the key role that trainees play in sustaining an interdisciplinary culture: "For faculty it is hard to cross the boundaries. Without students who know how, interdisciplinary research will not work well." Many IGERT faculty talked about this bridging role that students play.

A common refrain is that IGERT allows faculty to pursue research that otherwise would go unfunded. Faculty heartily appreciate the flexibility IGERT gives them to pursue innovative research, primarily through supervising graduate student projects. For instance, one faculty member noted that IGERT trainees are often able to carry out preliminary analyses that can be used to attract additional grant funding, a sentiment echoed by faculty elsewhere. At one university, IGERT is highly valued as a means through which student research can be funded outside of the normal departmental research path.

IGERT involvement has also led some faculty to rethink how they advise and mentor students. One professor related a story about a student who wanted to work with him, despite the faculty member's concerns that he lacked the appropriate expertise. If not for the fact that IGERT provided a broad network of faculty for both the advisor and the student to draw on, the professor said, "I probably wouldn't have taken him as a graduate student." The professor (from plant biology) said he is now involved in a partnership with an archeology professor. Another professor explained the multiple-mentor approach that has evolved with IGERT allows faculty to be an "academic godparent" to a student, providing advice and guidance without the ownership a formal advisor might feel.

Faculty Hiring

IGERT has also played a role in attracting new faculty hires. New faculty credit IGERT in their decision to accept positions at their university. An assistant professor stated, "IGERT was absolutely a part of my accepting the position here because of the ability to do both theory and experiments with collaborative colleagues." Another new professor in biology was attracted by the opportunity to have students early in his career and by the synergy in the area of urban ecology with the presence of IGERT, a center for environmental studies, and an ecological research program. Another professor pursued and accepted his position because of the interdisciplinary opportunities available. For another, the opportunities for interdisciplinary work were an important factor in his decision to accept a tenured position. One faculty member identified the IGERT as "one of the determining factors" in her decision to leave her previous institution, noting that her position would have been less attractive had it been in only one department.

At one project, IGERT played a role in luring two new hires who were looking for a place to pursue their own multidisciplinary work in a supportive and stimulating environment. One faculty member noted that his work on simulation and robotics to test biological ideas previously had made it difficult to find collaborators in engineering. Another professor was drawn to the biology department because she had difficulty finding biologists elsewhere who looked at biological processes from a neuromechanical perspective. Similar reports were heard from faculty at other IGERT sites.

At two other sites visited, IGERT led to the cross-disciplinary recruiting of new faculty, with departments working together to secure candidates who would directly augment their IGERT projects. At the first project, two faculty were hired directly into the university's Bioinformatics program, and other new faculty on campus are officially affiliated with bioinformatics. One faculty member in the second project cited the atmosphere of collegiality, "the fact that people here were very open to collaboration," as "the reason I chose to come here." At another project, one professor commented that the IGERT grant was a significant factor in both why she was interested in the position and why she was hired. She was looking for a place where she could continue her interdisciplinary research, while the Computer Science department was actively seeking faculty whose research spanned multiple disciplines. At a 2000 project, IGERT is an asset in recruiting faculty. In seeking to fill two open positions, a department chair said, "I think [IGERT] is helping us a lot with these two new hires." The department highlights IGERT and its relationship with bioengineering and a university Institute, and they are getting applicants from top schools. The importance of IGERT as a tool for faculty recruiting is perhaps best expressed by a new faculty member in another IGERT:

> The interdisciplinary nature of [this university] attracted me.… I'd seen other institutions [where] people had their little kingdoms, but here, people invited me to be part of IGERT. It's like they said, "Come, share our money." . . . The people at the [IGERT-related] meetings were exactly the people I wanted to talk to.

In short, IGERT clearly plays a significant role in increasing participating faculty members' interdisciplinary research. Such collaborations are often initiated and/or mediated by faculty interaction with IGERT trainees, who are themselves working with faculty across disciplines. As a result, the culture in which graduate education takes place is changing, and these changes are increasingly inviting to potential faculty recruits.

Innovative Education

In addition to generating new interdisciplinary research among faculty, the IGERT program has also changed faculty practice in training graduate students and, in some instances, their conception of graduate education altogether. The pedagogical structures implemented at IGERT sites include new curricular offerings, regular seminar series, co-advising arrangements, laboratory rotations, industry internships, off-campus retreats or workshops, and new certificate or doctoral programs. Below we describe how the implementation of new training components has affected faculty.

Curricular Offerings

The development of new interdisciplinary courses, seminars, or speaker series provides faculty as well as students with invaluable experience interacting with scientists in different disciplines and opportunities to learn the language of other disciplines.

Interdisciplinary training often takes the form of new or revised course offerings that require faculty cooperation. At one project, for example, the first-year course was cooperatively taught by the co-PIs and project faculty. It was designed to cover five key areas of central importance to the project. Classes and labs were held at the University, two federal research institutions, local newspaper editorial meetings, and local television stations. One format for these sessions was a mock senate hearing at which faculty experts were called to "testify" before the student panel on climate change issues. At another project, new interdisciplinary courses have been designed and are taught primarily by faculty serving as advisors to IGERT trainees, and new courses are continually proposed based on input from the students. At a third project, an economics professor and a finance professor teamed to develop and co-teach a new IGERT course that covered the technical and business aspects of the wireless industry and the economic and financial building blocks necessary to create a commercialization plan. Furthermore, this IGERT provided the opportunity for an engineering professor to develop an optimization and simulations course that bridged the deterministic and probabilistic camps within his department.

One IGERT has implemented course requirements for IGERT trainees that have generated improved curricular offerings and have required significant faculty cooperation across departments. Two core courses are team-taught, as is a non-core course. Although there is growing interest in such courses, some trainees, especially chemistry students, needed prerequisite undergraduate courses. Because these prerequisites did not fulfill their chemistry department requirements, faculty agreed to cross-list the courses so as not to prolong students' time to degree. Physics faculty also were willing to change their examination requirements to accommodate IGERT trainees. In all, the team teaching, cross-listing, and other arrangements indicate that faculty recognize the need for common planning and compromise to meet the challenges of interdisciplinary training.

Trainees at a 2000 IGERT are required to take a three-credit multi-disciplinary course covering many-body problems and algorithms for solving them that is team-taught by IGERT faculty. In response to student feedback, the course is being revised to develop the links between the topics covered by this course and the students' research. In addition, several courses on topics such as pair-wise comparisons and power computing have been developed to meet the needs of IGERT students for training in research methodologies.

Many faculty remarked that the presence of non-expert students in their courses has changed how they develop and revise curricular offerings. For example, because students in their IGERT often do not have a sufficient computational background, faculty engaged in an intensely collaborative effort to develop a three-semester course sequence in Formal Methods. Three faculty members piloted the courses, each attending the class sessions of his colleagues' courses to provide feedback. They were initially skeptical that students would respond well to these courses, but the Formal Methods courses are the most highly rated in student evaluations. A faculty member at another project commented, "our students are carving out this new field and demanding of the faculty courses which are not in place yet." At a third project, a new, team-taught Frontiers in Nanotechnology course, cross-listed in bioengineering and chemistry, was designed to help new graduate students from different fields build a common language around nanotechnology. Sometimes, the changes in teaching lead to new scholarship: a new hire at a 1998 IGERT developed a Brain-Computer Interface course, which led him to consider writing a new textbook. Because students in the course have come from a variety of disciplinary backgrounds, he sought, but was unable to find, reading material to bring various constituencies up to speed. This book will be the first such project of its kind.

Faculty ideas about curricular offerings have been significantly affected by student input. One notable example is the revision of the curriculum undertaken by the first cohort of IGERT trainees at a 1998 project. Initially, faculty proposed that students with biology and physical sciences backgrounds would need different introductory courses. But because these trainees already had strong interdisciplinary preparation, they seized control of the curriculum and designed a single course, required of all trainees, that would allow them to learn from each other. The result was a student-taught course with faculty oversight. Although faculty were initially skeptical, the course was well-received. Now taught by faculty, the required course introduces students to the project research area as a discipline. One faculty member remarked, "We are all students in [this new discipline]."

Additionally, IGERT course offerings can benefit the continuing education of faculty members themselves. At one project, faculty members have attended the *Intellectual Issues* course because they liked the discussions and welcomed the chance to debate and learn with the graduate students. One geological sciences professor described an IGERT-sponsored ecological research group as "the most intellectually stimulating environment I have on campus." As a result of his participation in a collaborative workshop, he said, he has learned ecology and is co-authoring a paper with the colleague with whom he co-taught the workshop. At another project, faculty also spoke of sitting in on each other's courses. Seminar series at several sites also provided fertile ground for faculty to exchange ideas and learn to communicate with scientists in other disciplines. According to a content specialist who visited a 1998 IGERT,

> Some participating faculty have found the [Biomathematics] seminar liberating in that it gave them confidence and access to students and other faculty in generating new mathematical and computational approaches to problems of great interest in their own research. This . . . is a hallmark of success for an interdisciplinary seminar.

Faculty experiences in courses also have led them to take their research in new directions. At one site, a physical chemistry professor developed an interest in biological molecules through teaching in IGERT's multidisciplinary course. He noted: "We actually made a discovery in class that was crucial in doing my own research."

Shared Laboratories

Another pedagogical tool that has benefited faculty is effective use of shared lab space for training graduate students and structured lab rotations that benefit both students and faculty laboratories. At one project, several interconnecting laboratories in the Engineering and Physics departments facilitate faculty interactions. Site visitors compared the work environment to that of a team-based national research and development laboratory. For example, one team included three IGERT students, two Electrical and Computer Engineering faculty, two Physics faculty, one Chemical Engineering faculty, and one private industry engineer. Such teamwork has led to publications co-authored by faculty and students from several disciplines, to a cross-fertilization of knowledge, and to a willingness, on the part of all faculty, to learn from each other (e.g., a physics professor teaching a biologist how to apply a technique to a tissue sample). Similarly, in another IGERT, the primary activities of IGERT take place through involvement in multidisciplinary teams that utilize shared state-of-the-art research labs.

One site's Biological Physics laboratory resulted from the cooperation of several academic units and the administration. The Applied Mathematics program provided staff support for the lab, the Physics department donated the space, and the university contributed funding for renovations. During the required laboratory course, several faculty are present at a time, and cameras at each workstation allow for videotaping and immediate broadcast of interesting results to the entire group. The laboratory was praised by a content specialist as "a miracle of university and inter-departmental cooperation" that "separates this IGERT program from others, and is a unique model for success in interdisciplinary training." At another project, two young faculty members have developed so many collaborative research projects that the one from Engineering moved his lab to the College of Veterinary Medicine to share space with his colleague. One remarked, "IGERT has catalyzed a partnership."

A core element of one IGERT is an intensive year-long research experience that provides the opportunity to conduct hands-on research in the areas of computational science, cognitive systems, and cellular/molecular neuroscience. One content specialist described the impact of the IGERT program as follows:

> With an IGERT [traineeship], students . . . recruit another faculty (sometimes from a very different discipline) to take active interest in their PhD thesis. The result is that an IGERT [traineeship] nurtures not just a multi-disciplinary student, but more importantly, draws faculty into multidisciplinary work and thus creates an educational environment that is hospitable to such future students.

Extramural Events

Incorporating intensive annual workshops, retreats, or mini-conferences has also led, perhaps incidentally, to strengthening faculty connections with one another. One IGERT, for example, includes a summer institute, attended by faculty, trainees, and approximately 20 National Fellows, faculty from other universities around the country whose research interests match those of the project. This two- to three-day research symposium gives faculty a unique opportunity to interact not only across disciplines but also across institutions. Moreover, some Fellows return to campus periodically during the year, allowing university faculty the chance to develop ongoing professional relationships with these visiting scholars.

A similar three-day annual workshop at another IGERT facilitates strong faculty interactions. These workshops are organized as hands-on fieldwork opportunities in which faculty, postdocs, and students participate. This component of the training "physically unite[s] the faculty and students, and provide[s] an intellectual forum . . . for hands on exploration and investigation which reveal the different approaches, techniques, and ways of thinking about a particular discipline." One of these workshops was organized as a national conference and led to the first graduate-level textbook in that discipline; this volume, edited by two IGERT faculty, will be published by a university press.

A several-day January term workshop hosted by a 1999 site drew high praise from faculty for the intellectual synergy it generated. According to one participant, "it is one of the few venues I've been a part of in which linguists and experimental psychologists spoke directly to one another and actually communicated." This remark was representative of the kinds of praise offered by other attendees.

At another, an annual conference has grown to 75-100 faculty and student attendees per year. The popularity of this conference has spurred participants to form three international branches of a new professional society, one each in the U.S., Europe, and Japan; each branch will alternate hosting the conference in upcoming years.

In 2000 and again in 2003, an IGERT and a university Institute organized conferences that drew participants from across the country; 140 people attended the 2003 workshop. At another site, both faculty and students consider the annual IGERT "retreat" a highlight of the program. The less formal atmosphere of an off-campus site encourages students and faculty to interact and leads to greater opportunities to discuss research.

Another IGERT is unique in that it is almost completely structured around a series of intensive annual summer research retreats, where faculty and students from multiple universities convene for nine weeks. The total immersion in a biological field station, where participants share living quarters and collaborate on research, fosters unusually strong faculty interconnections among those who attend.

Although the graduate education components inspired by IGERT were intended primarily to benefit students, they have also strengthened faculty connections with one another, energized faculty to expand their own knowledge, and challenged these scientists to create new curricula for educating students from diverse backgrounds. For senior faculty, IGERT can be a reinvigorating influence, while for junior faculty, IGERT provides an opportunity to develop their own burgeoning interdisciplinary interests, free of many of the constraints of traditional departments. In the words of one faculty member:

> Most [IGERT] faculty feel that exposure. . . to [the IGERT project] has stretched their thinking process. It changes how you ask certain questions and gives you the ability to ask questions you wouldn't have asked before. Now they're trying new experiments in this field. It keeps you on the cutting edge.

Supporting Factors and Barriers to Success

The 57 IGERT sites visited utilize a multitude of strategies to implement inter/multidisciplinary research and training. Some strategies are more successful in meeting the IGERT program goals than others; correspondingly, the degree to which faculty attitudes and practices have been affected also varies. The sites we visited are themselves so diverse in organization, content, and magnitude that finding patterns, especially at this early stage, is a challenge. That said, faculty involvement is clearly affected by institutional context and by the intellectual content of the focal areas.

Institutional Support

Few of the successes noted above could have occurred without strong support from the home institution. At several sites, institutional support has promoted faculty collaborations and has reduced or eliminated barriers to innovative training components. On the flip side, some projects have suffered from lack of institutional support and lost momentum in spite of initial faculty dedication to the project. Often, IGERT faculty are so committed to the project that they will teach additional courses as an overload, but such volunteerism can carry a project only so far. At some sites difficulties assigning teaching credit or resources to involved faculty have been a significant institutional barrier. The ways in which institutions have supported IGERT faculty and projects are detailed in Chapter 5.

Nature of the Intellectual Domain

At most sites, we saw evidence that new conceptualizations of problems in a discipline fostered the growth of disciplinary interactions and the professional growth of participating faculty. At one project, for instance, a new faculty position, a collaborative effort between the psychology and neuroscience departments, was added in the psychology department in fall 2002. The IGERT project helped put the groundwork in place that led to the hiring of a professor with interests in the axis between biology and psychology (neural dynamics).

Some sites established interdisciplinary training programs where the potential for cross-fertilization of disciplines was less well-developed. For example, despite a tradition of interdisciplinary research at one university, an IGERT was challenged from the outset by the inherent intellectual distance between its two disciplines. Trainees acknowledged that there were some fundamental epistemological differences about the nature of knowledge between—even within—the two disciplines. A content specialist identified another disparity:

> The scientific problems of matching human behaviors with environmental results—or, for that matter, changes in the environment with human behaviors—are great. How does one find comparable data in the two systems? How does one set up models amenable to further scientific elaboration and validation? How, in general, do complex adaptive systems behave?

Her questions point out that collaborations between these disciplines are not yet sustainable, and may require a longer incubation period than some other IGERT-supported collaborations.

Questions about the integration of disciplines also arose at another IGERT, which included faculty from medicine, political science, geography, civil engineering, chemical engineering, environmental engineering, biology, international relations, and earth sciences. Two external visitors from different disciplines—geography and environmental studies—commented that the participating disciplines were, as yet, too intellectually disparate to generate a compelling direction for integrative research and training.

Challenges for Inter-Institutional Grantees

Some institutional collaborations have fostered an innovative and highly collaborative atmosphere for faculty, yet other grantees, while enjoying some degree of success, have encountered difficulties when trying to bridge physical distances. One project, for example, was intended as a collaboration among five universities, but most of the activities and students are located on one campus. Although another project calls for students at both the home institution and a partnering business school, the project has had no success in recruiting students from the partnering business school. Furthermore, there appears to be more involvement with the home institution's own business school than with the proposed partner.

At another dual-institution IGERT, site visitors observed that facets of the project were better implemented in one site than the other. For example, one content specialist noted that there was only limited research collaboration between the two institutions' faculties, and that the research at the home institution appeared to be more team-oriented than at its partner. Although another dual-institution IGERT has overcome several inter-institutional challenges (e.g., by offering distance-learning courses, facilitating cross-institution advising, and orchestrating annual workshops that require moving significant numbers of people from one setting to another), each site has encountered its own internal problems that have made implementation somewhat uneven. At the home institution, administering interdisciplinary endeavors is complicated by a strong inclination to maintain departmental dominance, including allotting credit for all grants awarded to the PI's department rather than to the centers which house their interdisciplinary work. In contrast, at the partner institution, every faculty member interviewed commented on the strong university and departmental traditions of interdisciplinary research and the added value such collaborations bring to the faculty as a whole. Yet, partner institution faculty participation in the cross-institution fall workshop was not as robust as that of the home institution's faculty, and weekly IGERT seminars at the partner were only sparsely attended by faculty

Summary

In general, the impact of IGERT projects on participating faculty reflects the goals of the program as a whole. We see signs that IGERT is fostering a more collaborative culture among faculty, one in which new research problems are identified and new advances are made. At many projects, these collaborations have progressed beyond multidisciplinarity to truly integrative, interdisciplinary research. Although barriers remain, IGERT faculty are generally invigorated, both personally and intellectually, by their projects. Below we summarize the key observations made in this chapter:

- At most IGERTs, faculty report an increase in their contact with faculty from other disciplines, and individuals at various sites report that their own research was directly affected: it changed direction, or they began working with another faculty member. Several faculty mentioned collaborating on grant proposals they would not have pursued (or been aware of) without IGERT's influence.
- At many IGERT institutions, students are the conduit for faculty interactions: co-advising or lab rotation arrangements represent mechanisms for bringing faculty together. In addition, students sometimes pursue research under IGERT that is risky or does not clearly fit into a single department (and thus would be a poor candidate for other research grant funding) that helps bring in preliminary data useful in future grant applications.
- Strong institutional support seems to go hand in hand with greater faculty participation in IGERT. Some institutions view IGERT as a new model for graduate education, something that enhances the university's reputation in general, and/or something to emulate in other areas of the institution.
- Difficulties assigning course credit can inhibit team teaching or prevent otherwise interested faculty from taking on an IGERT-related course; on the other hand, committed faculty sometimes take on the course(s) as an overload anyway (see Chapter 5).
- Collaborative efforts that had already begun to take root before the PI(s) applied for the IGERT grant seem to mature more quickly then those where epistemological differences between the disciplines have not yet been adequately addressed.

Chapter 5. Impact on Institutions

Introduction

In addition to its impact on students and faculty, the NSF program announcement calls for change at the institutional level to better support inter/multidisciplinary education and research. In this chapter, we describe IGERT projects' impact to date on their home institutions, as manifested through:

- increasing institutional support, both financial and organizational; and
- changing graduate educational policies, offerings, and requirements.

Our site visitors found many signs that IGERT institutions support their IGERT projects and the inter/multidisciplinary graduate education they offer. PI responses to the web survey also indicate that the impact of IGERT extends to the institutional level. In this chapter, we look at evidence of institutional support for IGERT projects, and at the success projects have had in shifting university priorities as evidenced by changes in the allocation of resources, bureaucratic regulations, and institutional policies. We then discuss modifications that have been made to graduate programs involved with IGERT projects.

Institutional Support for IGERT Projects

It is common for universities to allocate resources along departmental lines, hire faculty into specific departments, and set rules governing faculty teaching requirements, promotion, and tenure at the department level. As IGERT projects center graduate education on an inter/multidisciplinary theme and utilize faculty and resources from multiple departments, they begin to push against these independent departmental silos. By providing resources and changing policies to support IGERT project activities, many IGERT institutions have demonstrated that they value the types of cross-disciplinary research and education that IGERT projects are trying to foster.

Allocating Resources

Institutional commitment to IGERT projects is often expressed in terms of supplemental resources allocated for project activities. IGERT projects benefit from financial support, staff support, and physical space and equipment. Thirty-four (60 percent) of the 57 projects in the first three cohorts benefit from assistance with tuition and stipends beyond that provided by NSF traineeship funds. Nineteen (a third) of their home institutions make up the difference in the cost of tuition beyond NSF's cost of education (COE) allowance. Nine other schools provide tuition waivers: they may waive out-of-state tuition, count trainees as "employees" so they can receive half-tuition, waive in-state tuition, or waive all tuition costs, both in-state and out-of-state. In addition to tuition assistance, some universities supplement student stipends, and others provide some additional tuition support for trainees beyond the COE—typically between 50 and 80 percent of tuition.

Thirteen universities also support IGERT projects by providing additional traineeships beyond those supplied by NSF, which both increases the total number of IGERT traineeships available and makes it possible to fund foreign students who are not eligible for NSF funding. Three projects support their projects' associates, who are often foreign students, and additional university fellowships have been allotted to 11 other IGERT projects across ten universities.

Beyond tuition assistance, in 25 (44 percent) of the projects visited, universities provide financial support for other project activities. The most popular form of other support is purchasing new equipment, as evidenced by the thousands of dollars donated to 12 IGERT projects by their home universities. For example, one state university IGERT receives several forms of financial support from the university, including a $1.6 million award from the state for new equipment, technical support, post-doctoral support, and major supplies. The project received a university excellence award that comes with financial support. Internal university funding also supplements student travel costs. The university continued this tradition by providing a subsequent IGERT project with matching grants and additional funds totaling almost $1 million for new equipment, including a new computer cluster. A 1999 IGERT received a total of $2.7 million in matching funds, some of which went to purchase new equipment. And another IGERT received money both for the purchase of new equipment and for hardware and software for trainees.

Other IGERT projects received university support for a range of project activities. One project has received $25,000 in matching funds from each of four other university entities to support the general program administrative and recruiting expenses, summer interns, an Annual Symposium hosted by the project (including travel and honoraria for presenters), and post-doctoral fellows. Another project covers all faculty-associated costs for its IGERT, including $20,000 to support curriculum development and an Advanced Seminar. The university also pays approximately $100,000 to cover expenses related to a Summer Institute. At least eight other projects report similar university support, including such items as maintenance of software licenses, computers for trainees, and IGERT seminars.

Another manifestation of university support for IGERT inter/multidisciplinary education is the provision of university space in the form of new or renovated space dedicated to IGERT use, a form of support 12 IGERT projects enjoy. One project hosts its multi-university IGERT each summer at its field biological station. The Physics Department at another site contributed space for the IGERT project's Biological Physics Training Laboratory, while the university itself paid for necessary renovations. A 1998 IGERT also provided common laboratory space and then leveraged resources from an industrial partner to equip the space. Three interconnected laboratories were allocated to the IGERT project. An Institute is being built at one site to house an IGERT project, and at another university an IGERT project is housed in an Institute that overlaps two participating campuses, helping to unite the project. IGERT students at a 2000 site enjoy a dedicated seminar room and office space for the program director. A half-dozen other projects also reported university support through the provision of laboratory, office, or lounge space for their trainees. These institutional commitments ensure that project collaborations have space to root and grow outside of the traditional departmental structure.

Common space is not always available. For example, at one project, while Engineering and Computer Science students benefit from the dedicated space in the Engineering building, students who work in the Medical Center two miles away do not feel as attached to the program, although a campus bus runs between the two locations every hour. At another project, a small amount of space was made available, but it is not enough to provide all students with office space. A similar problem exists at a third project, where a lack of a central place to locate student offices was mentioned as contributing to a weak project core. The IGERT program at another university has also been unable to locate its trainees together. At a 1999 project, however, project participants are not deterred by their separation across a large campus, and credit monthly lunches with bringing participants together and creating community.

Institutional support for IGERT inter/multidisciplinary education also comes in the form of full or partial salary support for project administrators and technical staff. Twenty-one (37 percent) of the 57 IGERT projects receive some form of personnel salary support. Examples include the following:

- *salary support for laboratory technicians*, such as 25 percent of the salary for the IGERT laboratory technician, or full salary support for the systems analyst ;
- *administrative support* from a larger university entity; and
- *support for part of the PI's salary*.

Bureaucratic Regulations

University bureaucracies have a reputation for not being very flexible. Some bureaucratic barriers are trivial, but all take time to overcome. One sign of IGERT projects' value at their home universities has been their ability to evoke change in institutional bureaucracies. For example, at one project all co-PIs receive credit for the IGERT grant, whereas in the past credit could only be awarded to a single, lead PI. At another project, the university computer system allowed students to enroll in only one college, yet IGERT trainees are enrolled simultaneously in two colleges. This problem was overcome by adding a field to the university computer system. Other barriers still remain, however. At the same school, the PI wanted the credit hours for industrial internships to vary as a function of their length, but the university insists on a two-credit hour minimum. Prior to the IGERT project at a third institution, money was linked to a department's credit hours of student enrollment. This budget structure hindered the development of interdisciplinary courses, and has since been formally changed to make the creation and administration of interdisciplinary courses easier. Another university developed a new policy allowing students to receive research credit in departments other than their primary department and under faculty other than their major advisor.

Changes in Institutional Policy

Along with allocating resources, universities have also altered institutional policies in support of IGERT projects. We observed evidence of these impacts in two key areas: assignment of teaching and enrollment credit, and issues related to faculty promotion and tenure.

As outlined in Chapter 4, IGERT projects have developed numerous new or revised course offerings, many of which are team-taught by faculty from multiple disciplines. Traditional teaching credit policies often fail to accurately count courses taught by teams of faculty or listed in multiple departments. At least three universities have changed the way teaching credit is allocated in order to accommodate IGERT and keep faculty teaching loads from ballooning. UC Berkeley [2000] accomplishes this by splitting teaching credits for team-taught courses. On a related topic, one project is exploring ways to count student FTEs in a way that would provide incentives for departments to let students take courses in other fields, thus promoting multidisciplinary exposure, and another project now allows cross-listing of courses in multiple departments, so that students can meet departmental requirements with IGERT courses.

Universities have also begun supporting joint faculty appointments to attract interdisciplinary faculty and help forge connections between departments. Several IGERT faculty interviewed held such appointments. In 20 (35 percent) of the 57 projects we visited, the presence of IGERT cross-disciplinary collaborations has influenced departmental hiring by attracting like-minded faculty. Most of these new faculty have been hired into a single department, but at two separate projects, one faculty member was hired jointly into two departments. Another university provided temporary adjunct faculty appointments to several external researchers working with the IGERT team to serve as consultants to the project, do research, and teach courses.

Such structural adjustments help faculty realize their vision for IGERT, attract new faculty to the project and maintain the motivation of already participating faculty, and reduce the amount of additional time faculty must "volunteer" to keep the IGERT project going. Dedication of faculty lines to IGERT projects, whether situated within departments or elsewhere, is evidence that institutions value interdisciplinary collaboration and research. At one project, there is universal consensus that the IGERT grant played a large role in the Biology department receiving money for new faculty lines. Similarly, another university has funded five half-time faculty lines for faculty to affiliate with the IGERT project and spend the rest of their time in their home department. A third university created a completely new department in the IGERT focus area, with 10 new faculty lines, and, at the time of the site visit, a fourth university was considering awarding tenure in multiple departments or through multi-disciplinary centers, which would represent a fundamental change and a visible commitment to a stronger institutional interdisciplinary culture.

Conversely, even a strongly dedicated group of faculty will lose momentum if unsupported by their institution. Lack of administrative arrangements for faculty to receive teaching credit for IGERT courses has posed a significant challenge to faculty at several sites. At two projects, only the primary instructor receives teaching credit for team-taught courses; thus team-taught courses are taught as an overload, a practice not easily sustained long-term. Another IGERT chose not to team-teach courses in order to prevent interdepartmental conflicts over teaching credit altogether. However, the lack of team-taught, interdisciplinary courses may have limited cross-disciplinary collaboration, especially progress towards integrating engineering with the other disciplines. A geography professor pointed out that the trainees from the "softer" disciplines rarely enroll in engineering courses, and the only course that brings all IGERT trainees together is a non-engineering core course. Another faculty member suggested that team-taught courses could introduce all trainees to the quantitative aspects of Geographic Information Science.

At other sites, faculty have attempted to work around the issue of teaching credit but have been thwarted by their regular departmental duties: faculty who may have wanted to contribute to the interdisciplinary curriculum have had to take on extra teaching burdens in addition to their IGERT administrative responsibilities. This kind of barrier prevented a professor at one university from revising a course to accommodate IGERT trainees. At several other universities, the lack of credit for team-teaching created much the same tension. Whereas content specialists who visited the one project called for a smaller student-to-faculty ratio in lab courses and the addition of an optics course to the required curriculum, the PI believes the issue of teaching credit must be resolved before any suggested changes can be implemented. Likewise, faculty at another IGERT bemoaned the university's revenue-centered management system as a barrier to team-teaching, and a content specialist noted that "by not collaboratively teaching the courses, the faculty are unable to demonstrate the positive or negative feedbacks between the different perspectives."

To be fair, each of these sites faced other, not insignificant challenges. However, there is a perceptible difference between institutions that enthusiastically supported IGERT projects and those that demonstrate either benign neglect or lack of active advocacy on behalf of participating faculty. Support for interdisciplinary work also flows out of institutional management of research grants. At one project, the institution's policy of giving credit for grants to just one department can be a "minor disincentive" to working together across disciplines. This issue also arose at another site, where the university encourages the formation of interdisciplinary centers but does not give centers credit for bringing in grants (instead, grants are credited to the PI's department).

What motivates the substantial institutional commitments seen at many of these sites? There may well be an institutional predisposition toward interdisciplinarity; in fact, the majority of the sites we visited characterize themselves as institutions that value and support interdisciplinary research and education. Four 1999 projects and one 2000 project are situated at universities that have clearly specified the development of multidisciplinary and interdisciplinary graduate education as part of the institution's strategic plan. This also clearly seems to be the case at two other institutions, which have three and four IGERT grants, respectively. A content specialist for one of these IGERTs praised the institution for its support of that IGERT:

> I must confess my own amazement that the [IGERT] was established within [a university Institute] rather than in an academic unit. To my knowledge this is unprecedented in [this university] system. It was clear that . . . [the IGERT] was the outcome of years of collaboration and building trust. However, even the most committed faculty cannot do what the administration does not want to do. [This university's] administration is to be credited for its insight and willingness to allow innovative interdisciplinary activities such as [the IGERT].

Other projects are newer to the policy and culture changes that cross-disciplinary work engenders but have found their universities open to change. Thus in their first three years of operation, many IGERT projects have strengthened or encouraged inter/multidisciplinary culture at their institutions. Where IGERTs have engaged institutional support, respondents report changes in institutional structures and re-allocation of resources to better accommodate the projects' inter/multidisciplinary graduate education activities. Where this support is neither already present nor stimulated by the IGERT award, projects butt up against institutional inertia and bureaucracy, and face greater difficulty navigating institutional channels.

Impacts on Graduate Education

Changes in institutional resource allocation and academic policies represent increased institutional support for inter/multidisciplinary education, but do not mean much if faculty do not then create cross-disciplinary educational programs that take advantage of this increasing support. As a result of NSF's funding and institutional support and openness to inter/multi-disciplinary education, IGERT projects have catalyzed a number of modifications to their respective graduate programs. These include altered degree requirements, new and modified courses, interdisciplinary seminars and journal clubs, and new degree programs and certificates. These changes represent real impacts on graduate education at IGERT home institutions, and in many cases have spilled beyond IGERT projects to surrounding departments and academic units at large.

The creation of new degree programs ensures not only that various elements of the original IGERT project will continue but also that its general philosophy and mission will be maintained. While new degrees as a result of IGERT are relatively rare in the first three cohorts of IGERT projects, perhaps attesting to the difficulty of installing a completely new degree program at an institution, 6 of the 57 programs do offer new interdisciplinary degrees. One project is evidence that developing a new degree program requires a considerable investment of time. It took two years for the university to obtain approval for a new Ph.D. program in Bioinformatics, but now that it exists as a free-standing degree program, it is effectively institutionalized. It offers a new, innovative model for other interdisciplinary programs to follow, and project staff are hopeful that their model will be emulated elsewhere in the university. At another university, an IGERT led to the creation of the two new joint Ph.D. programs. These new degrees now exist as a direct result of the original IGERT project and incorporate IGERT's main curricular elements. The presence of IGERT at a third university led to the development of a new Ph.D. sub-discipline in Nanotechnology that is housed in the Department of Chemistry. For the first two years of the grant (1999 and 2000), this IGERT was a "discipline plus" project in which students completed the requirements of their home departments as well as an additional set of IGERT requirements. As a consequence of the new Ph.D. program, for trainees beginning their studies in fall 2001 or thereafter, the IGERT project is no longer a discipline plus program. A similar arrangement now exists at a fourth university, also in Nanotechnology, where graduating students will receive a Ph.D. in Nanotechnology and their home department. A fifth university also developed a new interdisciplinary Ph.D. in Microelectronics-Photonics as a part of their IGERT program.

One project originally was perceived as a catalyst for introducing a new Ph.D. program in Photonics that would build upon an existing master's program. However, obtaining the needed approval of a new Ph.D. program from various committees both within the university and within the state's regents system took almost two years. Although the degree has now been approved, students are not required to enroll in the Photonics Ph.D. program in order to be IGERT trainees. Students were concerned about the degree's marketability and were reluctant to forego a Ph.D. from their home departments, and faculty recognized the difficulty of attracting students to a new area. Thus, the project is now a discipline plus program. Students do have the option of obtaining a degree in photonics but they are not required to do so. It is possible that more IGERT graduate projects might ultimately evolve into new degree programs, but they had not yet done so at the time of our visits.

Most of the projects we observed are discipline plus projects where students must meet all Ph.D. requirements in their home department while satisfying IGERT requirements as well.[32] For many students, this seems to be satisfactory. When students come together from disparate fields, however, meeting both departmental and IGERT requirements may prolong their graduate careers. Thus, in at least three instances, departments have adjusted their requirements to fit the IGERT project. One university's engineering departments relaxed their requirement that students have a master's degree before being admitted to a Ph.D. program in order to facilitate recruitment into IGERT. At another university, the departments of Chemistry and Physics both modified their requirements in order to align better with the IGERT project. The Chemistry department allowed optics courses to be cross-listed to fulfill the Chemistry requirements, so that students would not have to take additional courses, and the Physics department changed its exam requirements to accommodate the IGERT project. Finally, at a third university, the chemistry and biology departments relaxed their departmental course requirements so that IGERT students could complete their coursework within two years.

[32] In some cases these may be interdisciplinary home departments.

In addition to establishing new degree programs and influencing departmental requirements, IGERT programs have also had an impact on graduate education through the development of new interdisciplinary courses. Once added to course rosters, these courses are likely to remain a part of departmental course offerings as long as there is faculty and student interest. Across all IGERT projects responding to the 2003 web survey, 60 percent of the PIs report having created new inter/multidisciplinary courses as part of their IGERT project, and 27 percent report that other new courses have been developed. In addition, 64 percent of all PIs reported that new seminar series, workshops, and/or conferences resulted from their projects. (Table D.1 in Appendix D displays the institutional offerings related to IGERT projects.)

By opening inter/multidisciplinary courses to non-IGERT students, projects have begun expanding the pool of interest in their interdisciplinary theme among faculty and students. At one university, a non-IGERT Chemical Engineering faculty member requires all students who work in his lab to take one of the new IGERT Bioinformatics courses, even if students have no other involvement with IGERT. A new IGERT course at another university, taught by the co-PI, has become the most popular elective in the life sciences.

Some IGERT projects have also developed special purpose offerings not typically found in traditional programs. In keeping with IGERT program expectations, over half of the projects have implemented a course addressing ethics in research. These courses are sometimes expanded into what one faculty member titled “Life 101,” covering “things I wish I’d known early in my career.” One project is extending beyond the involved disciplines; its “Biotechnology Law and Ethics” course is taught by a Law School faculty member who finds the course revolutionary because it is the first time that a law school course has ever been open to students from other departments. Several projects also offered courses on writing. One IGERT has established a writing program in which students are required to take a sequence of three courses that focus on writing skills relevant to their research. The program will be continued after IGERT funding has ceased and has recently been opened to students across the university. Another IGERT’s faculty established four “ramp-up” courses designed to accelerate training because they felt that many of the incoming students, although of high quality, had deficits in one of the foundation disciplines.

Not only are IGERT projects encouraging interdisciplinary thinking through course offerings, but interdisciplinary research is encouraging the development of new and different types of courses. At one project, for example, one professor indicated that regular visits by an IGERT student from another field to his lab have resulted in valuable exchanges and is leading to a seminar-style course in the spring in which the students and the faculty member will explore problems that cut across their fields of study.

In some cases, the development of inter/multidisciplinary courses has spread beyond the IGERT project. In their web survey responses, 14 percent of all PIs reported that new, IGERT-inspired course offerings have emerged in other programs (Table D.1, Appendix D). Although this is not happening in a large number of institutions, it is compelling given the difficulties of developing and implementing interdisciplinary courses. This provides some evidence that the presence of IGERT projects, and the value they place on interdisciplinary learning, can have effects on how the institution at large views learning in this way.

The educational components of IGERT programs on many campuses have influenced their home institutions in other, more subtle ways as well. Many IGERT programs have developed seminar series, journal clubs and interdisciplinary conferences that attract participants from across the campus and which are likely to remain in place after the conclusion of IGERT funding. The highlight of one IGERT program, for example, is a weekly seminar series where trainees have the opportunity to meet and interact with prominent investigators in one of the areas represented by the program. These weekly seminars attract scholars from across the campus who relish the opportunity to meet with individuals on the cutting edge of research in a variety of fields. Another university has developed a similarly popular Distinguished Lecturer Series, and a third has established a yearly conference in conjunction with its IGERT program that attracts 75 to 100 attendees per year. This conference has generated so much international enthusiasm that it has spurred the formation of a professional association, with branches in the U.S., Japan, and Europe, that will sponsor the conference in future years, allowing more researchers to attend and raising the profile of the interdisciplinary work done through the IGERT program.

The relationships with both industry and international labs that have been developed with the use of the IGERT funds are also likely to have a lasting impact on the home institutions. Participants in one IGERT program cite the collaboration with a nearby national laboratory as extremely important for positioning the university as a major player in science education in the state. The relationships that faculty at another project have established with 14 different international internship sites in Europe, Asia, and the Middle East will remain long after IGERT funding has ended. At a third project, students have traveled to Brazil and Japan where they gained experience with a particular piece of equipment; they tapped this experience to construct their version, making it available at their institution.

In addition, the influence the IGERT program has had on many campuses by providing funds for the purchase of new equipment should not be overlooked. Many IGERT programs have used funds to purchase new technologies and to ensure that their laboratories are state-of-the art. Since research in the sciences is often driven by available technology, such upgrades will have a lasting impact on the research experiences of students for many years to come.

Finally, on many campuses the IGERT program has served as a model for other interdisciplinary programs that are trying to establish themselves and for thinking about graduate education more creatively. At one university, for example, an Institute has adopted lab rotations similar to IGERT's and, in the spring of 2003, the five faculty PIs of an Interdisciplinary Research Team will team-teach a multi-disciplinary course that they are modeling after IGERT's interdisciplinary course. Similarly, some of the existing inter-college programs at another university are now studying the key components of an IGERT program to see if they are more broadly applicable. An NSF-funded Center at that university incorporates a seed grant program modeled after a Research Credit Card that the IGERT there had established. At a third university, the areas of health, international studies, and ethics are all drawing on IGERT as an example of how interdisciplinary education might proceed.

Summary

In their first years of operation, the IGERT projects have affected their home institutions in a number of ways. Many institutions have acted to support inter/multidisciplinary programs. Such support may have been sparked by the arrival of IGERT projects or been part of an ongoing institutional initiative. IGERT projects at universities with a history of inter/multidisciplinary endeavors benefit from supportive institutional policies and from faculty readiness to collaborate across disciplines. Other universities have used IGERT projects as springboards to expand cross-disciplinary endeavors. We observed evidence of institutional support for IGERT projects in the form of funding, resources, space, and personnel. We also saw institutions putting changes into practice by modifying policies governing teaching credit, faculty appointments, and tenure. IGERT projects have sparked innovation in graduate education, including new courses, modified degree requirements, and even entirely new interdisciplinary doctoral degree programs. While the sites visited still had two years remaining on their grants, it is encouraging to note that the projects had begun altering their institutional landscapes, for it is in changing institutional culture and policies that IGERT projects have perhaps the best chance of initiating permanent change in graduate education.

Chapter 6. Project Development and Growth

Introduction

The National Science Foundation (NSF) initiated the Integrative Graduate Education and Research Traineeship (IGERT) Program to meet the challenges of ensuring that Ph.D. scientists and engineers have the inter/multidisciplinary backgrounds and the technical, professional, and personal skills needed for the career demands of the future. Just as the IGERT program has evolved, projects themselves evolve as they implement their plans and respond to changing circumstances and demands. Given the dynamic nature of the programs, it is useful to look at how projects develop over their years of implementation. This chapter looks longitudinally at how projects have:

- changed practices or offerings in response to feedback from participants;
- structured graduate education around inter/multidisciplinary research themes and professional growth experiences for students in various career environments; and
- promoted the development of a range of student abilities, including teamwork and oral and written communication skills across disciplinary, sectoral, and national boundaries.

Project Changes

Reflecting the dynamic nature of the IGERT program, IGERT projects experience modifications from year to year. Projects respond to external and internal feedback and pressures by adding or dropping components to help meet their goals. Site visits conducted to projects in their third year of implementation provided retrospective reports of how projects have changed. Further, the four years of web-based data that have been collected provide the opportunity to explore the level of change and the areas in which changes have occurred across all projects.

Implementation changes

A substantial number of projects report having made mid-course corrections in how they present multidisciplinary work. At one project trainees pushed successfully to replace dual, faculty-designed entry courses (one for biologists and one for physical scientists) they described as a “revolving door of lectures” with a common, student-directed multidisciplinary course in which they could fill each other’s deficits. At another, the initial plan had students spending a few weeks on each of the lab’s experimental rigs, rotating from one station to another. Experience showed, however, that the sophistication of each rig and the mathematical models used to explain the observations took most students a semester to master. Student feedback led the faculty to decide that full mastery of one system was better than superficial exposure to many.

Other changes made to address students’ needs include: moving a key course from fall to spring; revising the core course to include IGERT students only and refocusing its content, altering lab rotation requirements, and providing a laptop loaner program; developing a cohesive, required introductory course where there had previously been none; initiating a student mentoring program; and adjusting the selection criteria used to admit trainees in order to construct an advantageous cohort composition.

In several schools, faculty members have been notably open and willing to receive and act on student feedback. One project formalizes the process by having a Student Advisory Board that meets once a month with the project's Executive Board. Similarly, another project has a Student Panel that meets at least once a year and reports to the project's External Advisory Board. In any instance in which student feedback has been thoughtfully heard, and changes made, students have come to feel more like colleagues and collaborators in creating new fields than "students" in the more traditional, passive sense.

Occasionally, mid-course changes that respond to one set of perceived difficulties can generate other problems. For example, one project began with very prescriptive course requirements but revised them because the backgrounds of the trainees "made it tough" to meet the prerequisites of the required courses. They now have just one core course, which led a content specialist to conclude: "The main drawback to the curriculum is that at least one more general optics course should be added to the core to cover spectroscopy and other optical imaging and sensing approaches to the field. In addition, these two courses and seminars should be required and make up the 'core' for all IGERT students." One trainee observed, "There are very few collaborations here." Other trainees said they were too busy focusing on their individual lab work to collaborate just yet. As one explained, "[My discipline] first, then IGERT." It appears that addressing the discipline gap by retreating from strong cross-discipline experiences has weakened this project's multidisciplinary character.

Multiple factors stimulate the corrective action that has led to more tightly integrated cross-disciplinary programs. Some projects have the advantage of a strong prior interdisciplinary history that enables them more easily to identify weak spots. In several instances, a well-functioning internal formative assessment system has provided input for mid-course corrections. Sometimes the irritation may be sufficient to generate the activation energy necessary for change. Another factor might well be the energy of some trainees who push until changes are made. At one project, "Students who applied came with a vision of what they wanted graduate experience to be like, and the faculty gave them the room to do this," according to one trainee.

Change in Project Activities across Training Years

The IGERT web monitoring survey, which has been administered each spring beginning in the spring of 2000, provides the best source of information to track how projects change over their years of implementation. The data presented in this section come from the first four administrations. We have data on the first five cohorts of grantees (1998 through 2002). Because survey data collection began in the spring of the 1999-2000 academic year, we start with year 2 of the 1998 cohort. Information on the fifth grant year is available only from the 1998 cohort in the 2003 survey. We have four years of data on the 1999 cohort, three years of data on the 2000 cohort, two years of data on the 2001 cohort, and one year of data on those funded in 2002.

Because of the timing of the awards, projects often did not have trainees in the first year of their grant. In order to reflect project growth in those elements that relate directly to activities involving trainees, we have rearranged the projects to consider their sequential *training* years (as opposed to *grant* years). Training years count the number of years a project has been "active," defined as having at least two trainees, at least one of whom was funded within his/her first three years of doctoral study.

The 10 projects in year 5 are all from the 1998 cohort, while the 76 projects with data on the first training year include projects from each of the five cohorts. For all of the following analyses, it is important to keep in mind that the size of the sample considered differs for each training year (as illustrated in Exhibit 6.1).

Exhibit 6.1

Number of Projects Providing Data for Each Training Year

	Training Year				
	Year 1	Year 2	Year 3	Year 4	Year 5
Number of projects	76	71	53	32	10

In the sections that follow, we discuss changes in projects' use of education and training activities, followed by changes in PIs' assessment of their trainees' quality relative to their usual graduate students, and PIs' assessment of their projects' success in fostering trainees' growth toward project goals.

Last year was the first year there was enough information to begin looking at how projects change over time. This year, there is a large enough sample in each of the first four years to support an exploration of project features. While some differences observed are clear, others were less obvious, and their possible meaning was not always apparent.

PIs are asked each year whether particular activities associated with IGERT goals have been used in their projects. The activities are associated with six broad areas:

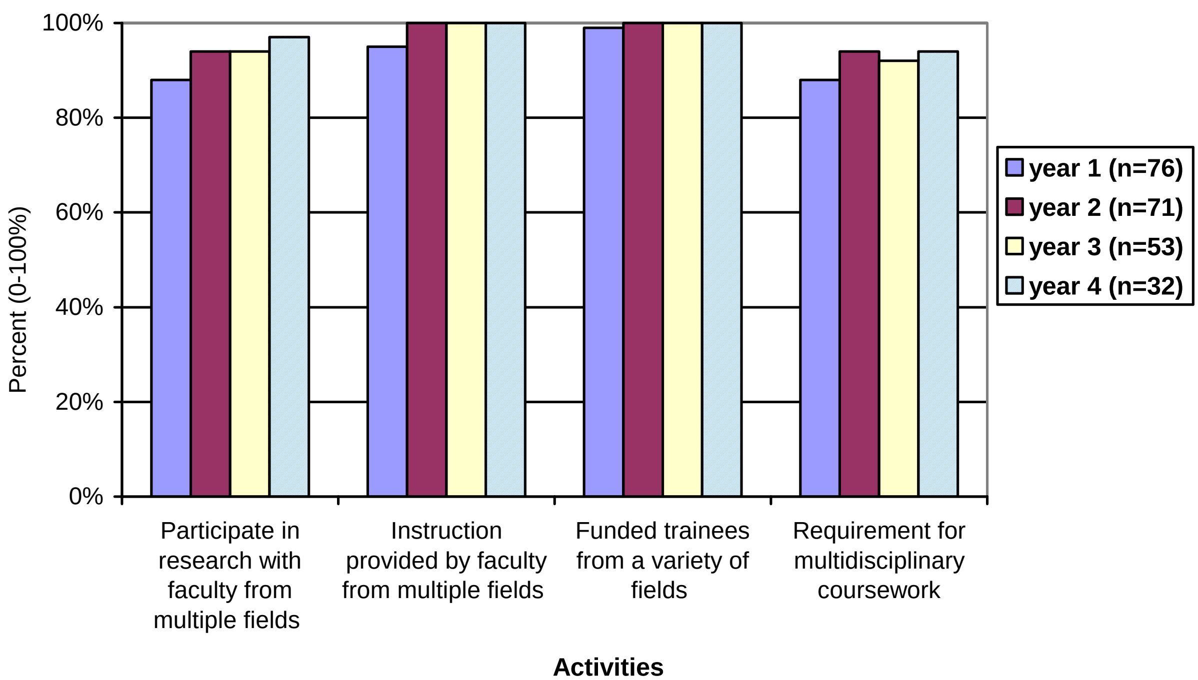
- Multidisciplinary/Interdisciplinary Training
- Preparation to Conduct High Quality Research
- Preparation in Communication and Teamwork
- Preparation for Careers in Industry, Government, or Public Sector
- Preparation for Faculty Positions
- International Opportunities

As most projects begin with trainees in the early stage of their Ph.D. training, projects initially focus on activities that are appropriate for this stage, such as coursework. The development of additional opportunities in later project years may be consistent with trainees beginning to concentrate on their own research as they advance through their training. As described below, some activities were more common in projects in their later years.

Activities associated with "multidisciplinary or interdisciplinary training" are consistently high across training years as shown in Exhibit 6.2 below. Even the activities reported least often by projects in their first year—*participation in research with faculty from multiple fields* and *multidisciplinary coursework*—are found in 88 percent of first-year projects and rises to over 90 percent in subsequent years. One hundred percent of projects in their second year and beyond report *funding trainees from a variety of disciplines* and *employing faculty from a variety of disciplines to instruct trainees.*

Exhibit 6.2

Percent of Projects Offering Multidisciplinary/Interdisciplinary Training Activities



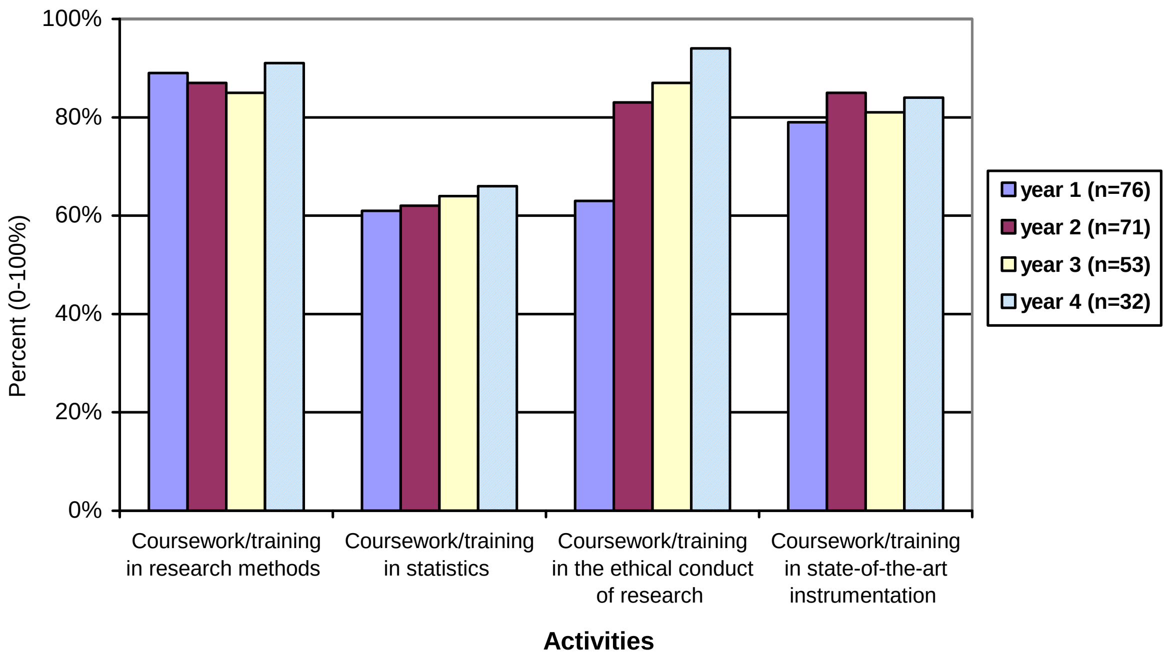
Source: OMB 3145-0136 EHR Generic Clearance: Survey of Principal Investigators, Survey Years 2000, 2001, 2002, 2003, Section "IGERT Multidisciplinary/Interdisciplinary Training"

Abt Table Production Date: February 2004 for IGERT 2004 Cross-Site Monitoring Annual Report

Most projects also offer various activities to prepare trainees to "conduct high quality research" across all years, although fewer require training in statistics than in other research topics. Exhibit 6.3 displays the proportion of projects that offer related activities. Over the course of the four training years, neither *training in research methods* nor *training in state-of-the-art instrumentation* showed any consistent pattern of change, with the first consistently offered by 85 to just over 90 percent of projects, and the second by just under 80 to 85 percent of projects. The large proportion of projects that offer these activities reflect the importance placed on quality research while maintaining a multidisciplinary focus. The IGERT Program Office specifically emphasizes training in the ethical conduct of research, and there was a consistent increase in projects reporting this activity over the first four training years.

Exhibit 6.3

Percent of Projects Offering Trainee Preparation to Conduct High Quality Research



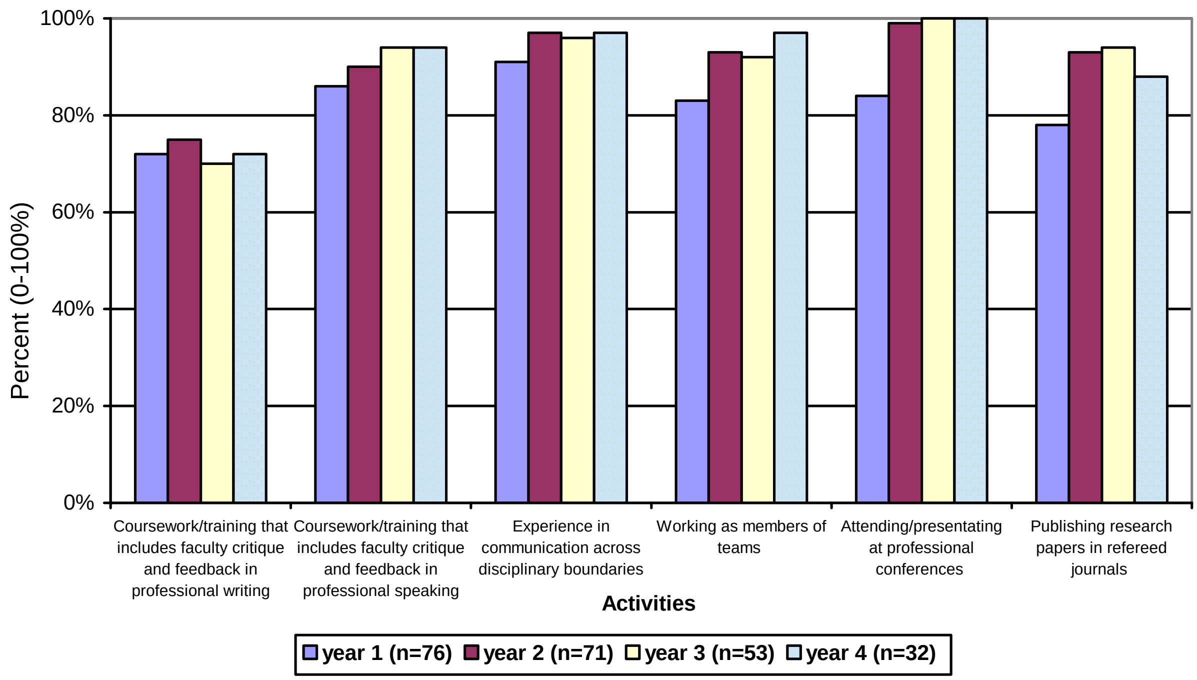
Source: OMB 3145-0136 EHR Generic Clearance: Survey of Principal Investigators, Survey Years 2000, 2001, 2002, 2003, Section "IGERT Trainee Preparation to Conduct High-Quality Research"

Abt Table Production Date: February 2004 for IGERT 2004 Cross-Site Monitoring Annual Report

There was some indication of growth from the first training year to later years in several activities related to "preparation in communication and teamwork" (Exhibit 6.4). *Attending and presenting at professional conferences,* and *publishing in refereed journals* were all more prevalent in projects beyond their first year. This may reflect the reality that, as their training advances, graduate students have research results to present or publish. In later training years, there are also more opportunities among projects for trainees to *work as members of teams*. This again, may reflect the concentration of individual course-work within the first year(s) of graduate training.

Exhibit 6.4

Percent of Projects Offering Trainee Preparation to Communication and Teamwork



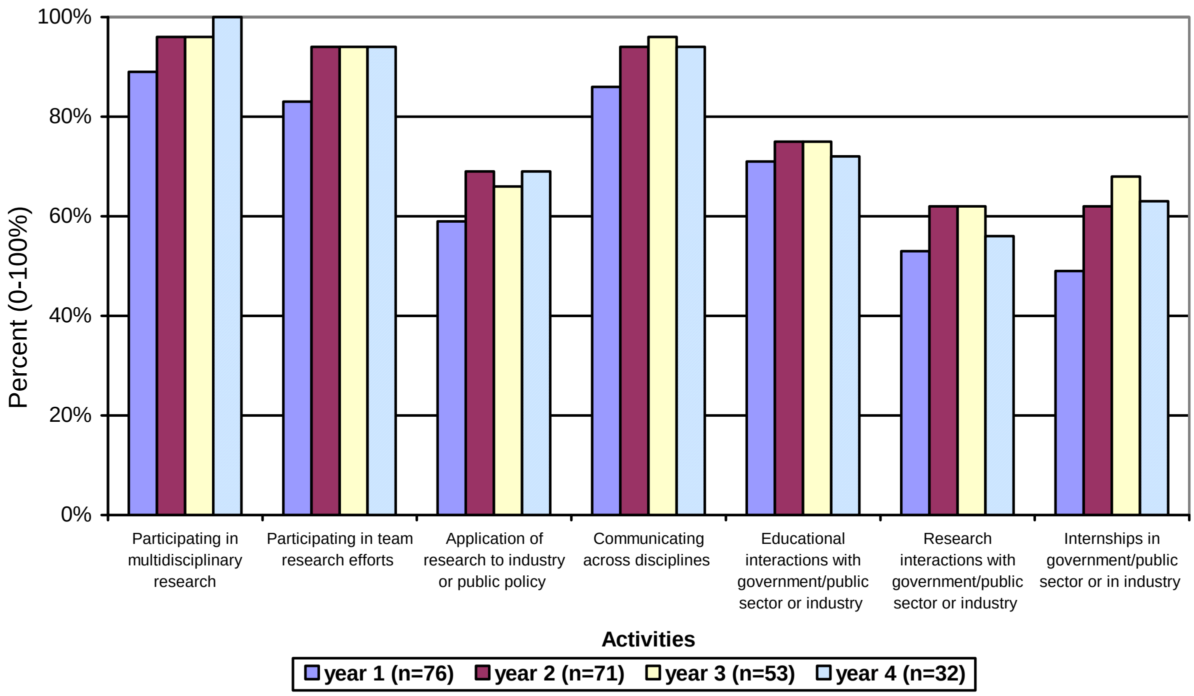
Source: OMB 3145-0136 EHR Generic Clearance: Survey of Principal Investigators, Survey Years 2000, 2001, 2002, 2003, Section "IGERT Trainee Preparation in Communication and Teamwork"

Abt Table Production Date: February 2004 for IGERT 2004 Cross-Site Monitoring Annual Report

In the area of "preparation of trainees for careers in industry, government, or the public sector," presented in Exhibit 6.5, only *participation in multidisciplinary* research shows consistent growth from year 1 to year 4. *Internships in government, public sector, or in industry*, which has been strongly encouraged by IGERT, shows evidence of growth in years 1 through 3, but a slight decrease in level in year 4 projects.

Exhibit 6.5

Percent of Projects Offering Preparation for Careers in Industry, Government, or Public Sector



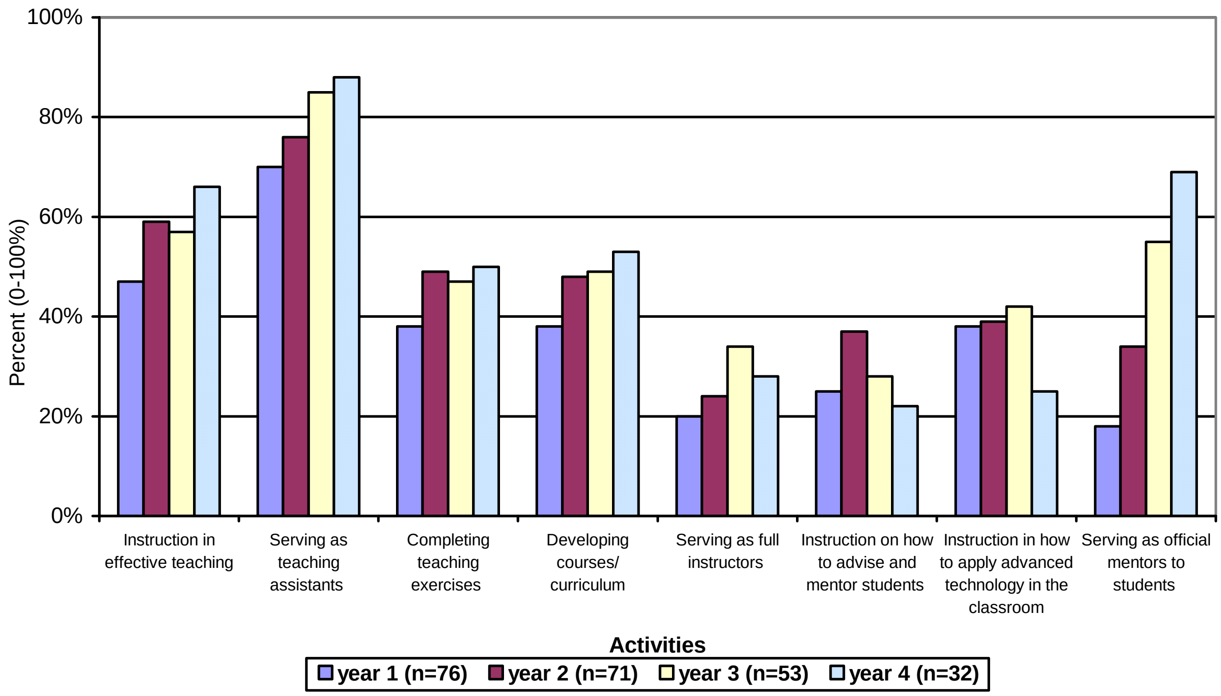
Source: OMB 3145-0136 EHR Generic Clearance: Survey of Principal Investigators, Survey Years 2000, 2001, 2002, 2003, Section "IGERT Trainee Preparation for Careers in Industry, Government, or Public Sector"

Abt Table Production Date: February 2004 for IGERT 2004 Cross-Site Monitoring Annual Report

In those areas in which PIs report fewer trainee activities, the activities most closely associated with traditional graduate education are generally most popular. In "preparation for faculty training" (Exhibit 6.6), for example, *serving as teaching assistants* and *serving as official mentors to students* appear more common in later years, expanding from 60 to 88 percent and 18 to 69 percent, respectively. Offering *instruction in effective teaching practices* also increased from 55 to 69 percent between first- and fourth-year projects. These increases may reflect the advancement of earlier students from course taking to teaching assistant positions.

Exhibit 6.6

Percent of Projects Offering Trainee Preparation for Faculty Positions



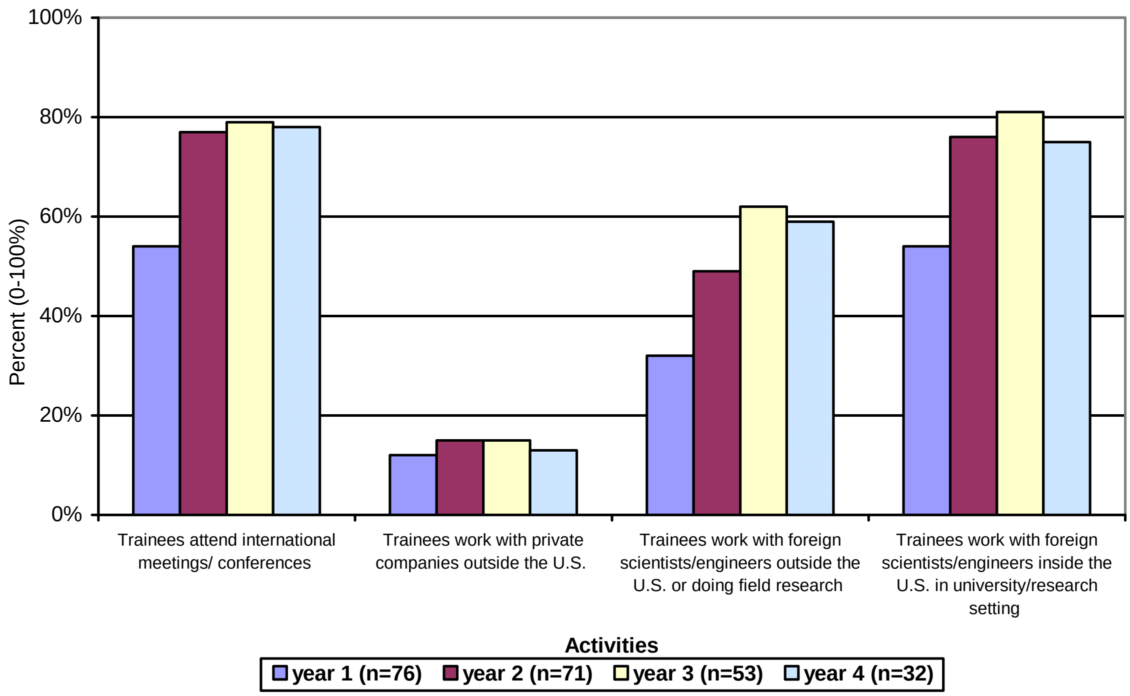
Source: OMB 3145-0136 EHR Generic Clearance: Survey of Principal Investigators, Survey Years 2000, 2001, 2002, 2003, Section "IGERT Trainee Preparation for Fellowship Positions"

Abt Table Production Date: February 2004 for IGERT 2004 Cross-Site Monitoring Annual Report

In "international opportunities" (Exhibit 6.7) *working with foreign scientists/engineers <u>inside</u> the U.S.* is the most commonly reported activity, closely matched by *attending international meetings/conferences*. Both of these are used by nearly 55 to nearly 80 percent of projects over the training years reported, with growth between years 1 and 2 but less consistent growth in later years. The less frequently provided *opportunities for trainees to work with foreign scientists <u>outside</u> the United States* (between 32 and 62 percent) is an activity that has received emphasis by the IGERT Program Office, and there has been some growth in the percent of projects using this activity through the third training year with a slight dip in the fourth (59 percent).

Exhibit 6.7

Percent of Projects Offering International Opportunities



Source: OMB 3145-0136 EHR Generic Clearance: Survey of Principal Investigators, Survey Years 2000, 2001, 2002, 2003, Section "IGERT International Opportunities"

Abt Table Production Date: February 2004 for IGERT 2004 Cross-Site Monitoring Annual Report

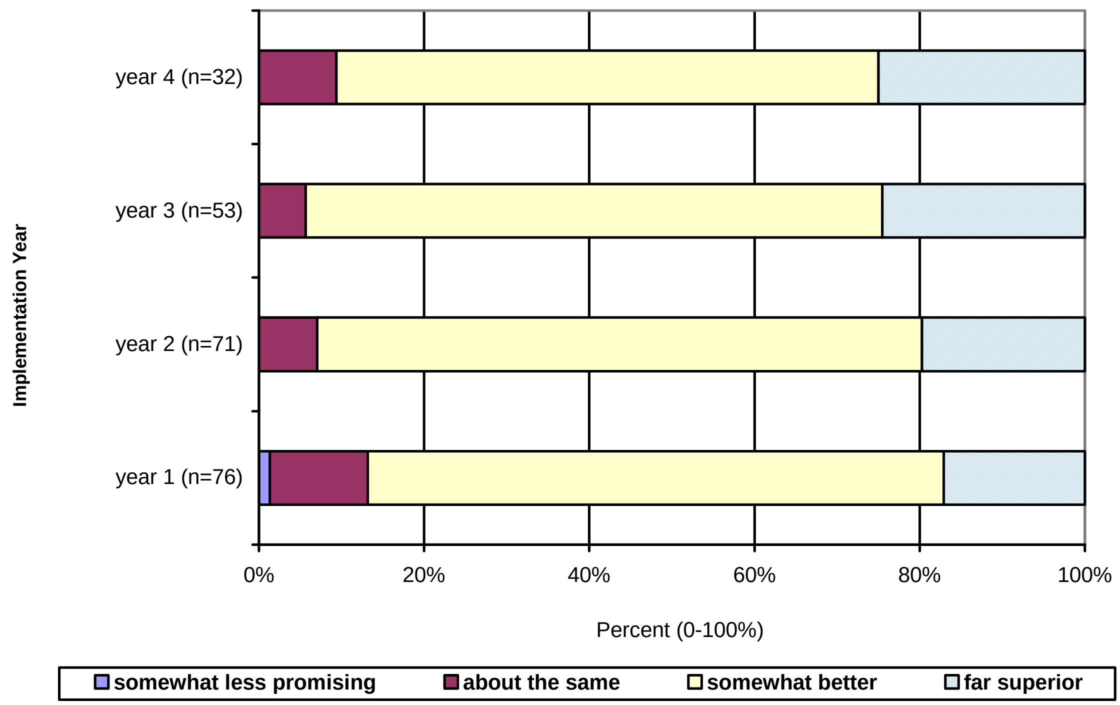
PI Assessment Across Training Years

While the previous section describes changes in the proportion of projects making use of given activities in their IGERT projects across training years, this section examines changes in PIs' assessments of their projects' progress toward goals. By and large, PIs' assessments of progress toward their goals reflect the percent of projects reporting activities of particular types.

Trainee Quality
In each of the four years of the survey, PIs were asked to assess the quality of their trainees (as a group) compared to the graduate students they usually see, in terms of their academic/research potential. PIs' assessments of their trainees' quality has not changed markedly across implementation years, as seen in Exhibit 6.8.

Exhibit 6.8

Changes in PI Assessment of Trainee Quality by Implementation Year



Source: OMB 3145-0136 EHR Generic Clearance: Survey of Principal Investigators, Survey Years 2000, 2001, 2002, 2003, Section "Assessment of Trainee Quality and Project Success"

Abt Table Production Date: February 2004 for IGERT 2004 Cross-Site Monitoring Annual Report

Project Goals for Trainees
PIs were also asked to rate their project as s*uccessful*, *somewhat successful*, *not successful*, or *not begun* in fostering trainee growth in each of 11 project goal areas:

Three basic graduate education goals:

- Success in *multidisciplinary*/interdisciplinary coursework
- Breadth and depth of knowledge
- Ability to conduct high quality research

Two professional skills in education goals:

- Teaching and/or mentoring
- Course development

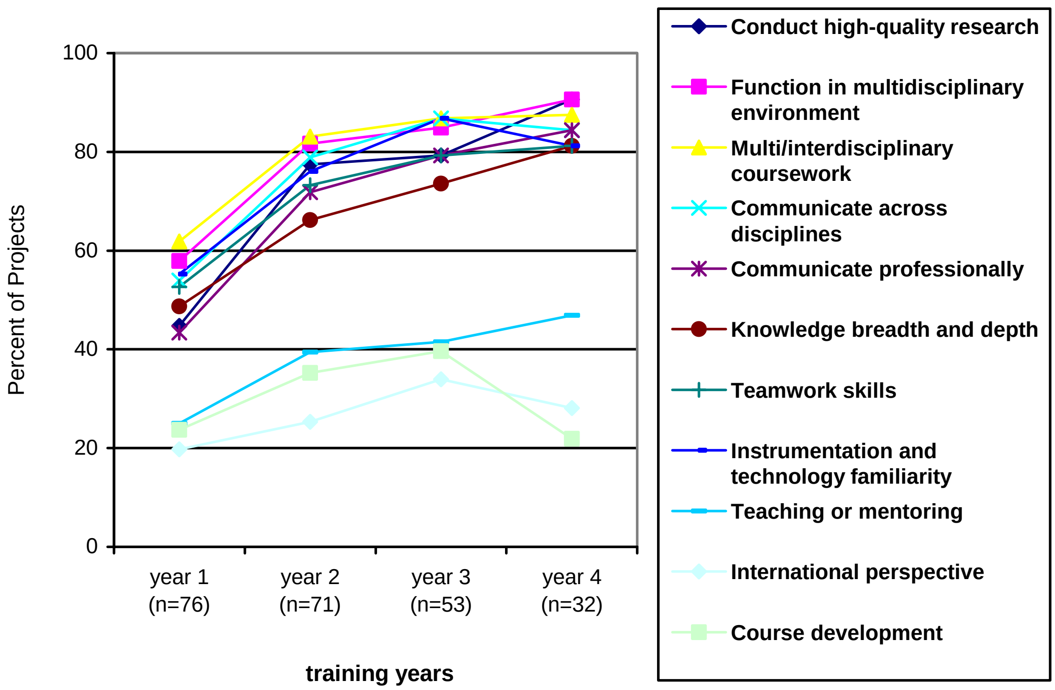
Six goals associated with the development of professional skills applicable to work in non-academic (public or private sector) employment:

- Ability to function in a multidisciplinary/interdisciplinary environment
- Ability to communicate across disciplines and with different audiences
- Teamwork skills
- Familiarity with state-of-the-art instrumentation/technology/modeling skills
- Ability to communicate professionally (e.g., give presentations, write scientific articles)
- International perspective (e.g., familiarity with different cultural perspectives, ability to work with scientists from different cultures).

Exhibit 6.9 displays the proportion of PIs who rated their project "successful" for each project goal. By year 4, at least 80 percent of the projects rated themselves successful in most goal areas. The two educational skills goals (teaching/mentoring and course development) and the fostering of international perspectives clearly constitute a separate group, with a smaller proportion of projects reporting them "successful." In addition, the greatest increase in the proportion of PIs who rate their project successful occurs between years 1 and 2.

Exhibit 6.9

Percent of Projects Reporting "Success" for Project Goals by Training Year



Source: OMB 3145-0136 EHR Generic Clearance: Survey of Principal Investigators, Survey Years 2000, 2001, 2002, 2003, Section "Assessment of Trainee Quality and Project Success"

Abt Table Production Date: February 2004 for IGERT 2004 Cross-Site Monitoring Annual Report

Summary

The IGERT program specified programmatic expectations, but allows individual projects considerable latitude on how to advance their goals. This provides individual projects the opportunity to implement their graduate training projects in the manner that best fits the needs of their students. As such, IGERT projects are not wedded to a particular formula, but instead, make mid-course adjustments in order to improve their graduate training.

As IGERT projects evolve, they change in response to internal and external influences. Site visits produced evidence of change in response to trainees' needs and feedback. Data from the annual web survey of IGERT PIs administered from 2000 through 2003 show that projects expand the activities they offer as they advance in years. Overwhelmingly, change occurs between the first and second years of implementation, with most projects offering features addressing each specific trainee goal by their second year of activity. There is little change in project offerings from years 2 through 4 partly due to the overwhelming number that are addressing a given goal or activity by their second year.

Chapter 7. Institutionalization and Future Impacts

In their first three years, the IGERT projects we visited have had a range of impacts on students, faculty, and institutions. Yet ultimately, in its desire to change the culture of graduate education, NSF hopes that projects will continue to thrive, grow, and expand after IGERT funding has ended, restructuring graduate education within and beyond their home institutions. Though only in their third year, we observed signs that many projects are thinking of and taking actions towards institutionalization, through two means:

- the more concrete programmatic elements developed by IGERT projects that are likely to continue as part of graduate training post-IGERT funding; and
- the less tangible changes in institutional culture, involving the institutionalization of IGERT-related ideas, practices, and relationships.

In this chapter, we describe the ways in which we observed IGERT projects becoming part of the fabric of their home institutions, as well as:

- the relationship between institutional and project factors which help or hinder institutionalization efforts; and
- the potential future forms institutionalization may take as projects continue to mature.

Institutionalization of IGERT Graduate Education Projects

The steps taken toward institutionalization vary across projects. In the web survey, 69 percent of PIs across all cohorts reported having planned for the continuation of IGERT initiatives, concepts, or collaborations. Not surprisingly, many more of the 1998 projects (88 percent) report such plans than younger, 2001 and 2002 projects (55 percent and 29 percent, respectively). More PIs expect continuation of initiatives and collaborations and report seeking funding (60 to 70 percent) than expect lasting changes in student entrance or advancement procedures (10 to 15 percent). Just 20 percent report having a written plan for continuation. Details of the steps projects have taken toward institutionalization are detailed in Table E.1 in Appendix E.

At the far end of the institutionalization spectrum is the option of making permanent entire IGERT projects. Such program institutionalization seems likely at 15 of the 57 IGERT projects visited, according to the site visit teams. Developing or identifying institutional "homes" for these projects has been one successful approach towards institutionalization.

- Faculty at one project focused heavily on developing a strong institutional foundation before developing specific program elements (courses, workshops). The resultant Institute for Computational Science and Engineering, which links computer science and other departments in science and engineering, is an ideal location for their IGERT project.
- The Office of the Vice President for Research at one university is considering formally chartering its 1998 IGERT project as either a Center or an Institute, created around the

project's research mission and responsible to the Office of the Vice President for Research (rather than to individual academic departments).

- Creation of a similarly focused program at the same time as the IGERT was funded led to the immediate institutionalization of the program at its university. Both IGERT project and interdepartmental program faculty have been aggressive and successful in pursuing additional support for students and for research.
- Participants at another project report they are likely to institutionalize their IGERT through a recently created interdisciplinary program.
- The IGERT project at another university is already part of a larger, pre-existing graduate group, which will continue after IGERT funding ends.
- At a university with a 2000 IGERT, the Vice Provost described ongoing efforts to establish an institute for interdisciplinary training, which would house the IGERT project as well as future interdisciplinary training efforts.

The establishment of new degree programs is another approach to permanence. Four universities with IGERTs have created new interdisciplinary degree programs. It took years for the new programs to pass through all the procedures at their universities, but as free-standing degree programs they and their constituent parts (courses, laboratories, degrees) are likely to remain part of graduate education at their institutions for the foreseeable future.

Other institutions have taken the intermediate step of obtaining approval to recruit directly into their IGERT project and/or to award a certificate in the research focus area, although trainees continue to receive their doctoral degrees from their identified home department. In the majority of the remaining cases, it is more likely that only selected elements of IGERT projects will remain.

Regardless of the magnitude of the changes IGERT projects have fostered, they have developed a number of new educational tools and mechanisms, such as courses or requirements. The anticipated institutionalization of IGERT courses or requirements post-funding is attributable both to their educational value and to institutional inertia—once new elements have been adopted by universities, they often remain.[33] Other activities or structures are not as likely to become a formal part of an institution's graduate education, such as IGERT-related conferences, internships, and student activities. Least likely to continue are characteristics of IGERT as a *traineeship* program; the most obvious of these is the unrestricted funding that projects offer students. Such funding creates such opportunities for students as the opportunity to experience varied research in a range of laboratories, as opposed to the traditional graduate education pattern of apprenticeship within a single faculty member's lab. It is here that projects that have taken the more challenging path of creating whole new educational mechanisms (interdisciplinary courses, lab rotations, degree requirements) are more likely to see truly interdisciplinary elements remain a part of the fabric of their institutions' graduate education.

How likely are these new educational tools and mechanisms to be institutionalized? Participants at 18 IGERT projects expect that their newly developed courses will remain post funding. One project has

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[33] This is true only of named courses that have been approved through appropriate institutional channels. A number of IGERT-specific courses have been taught under generic headings that do not require approval and have no place in permanent department course lists.

put in place a certificate program along with a core of interdisciplinary courses; both are expected to remain beyond the five years. The main curricular elements of another project have already been institutionalized in the creation of the two new Ph.D. programs. Other projects reported that IGERT courses will remain as part of their university offerings. One university's IGERT courses have been approved and cross-listed with established departments. Another university, in addition to continuing courses modified or added to the curriculum through IGERT, cited the increasing number of biologists who are taking computation courses as an outgrowth of the merging cultures.

While many projects cited course institutionalization, some expressed concern that newly developed, and especially team-taught, courses cannot be maintained in the long run if they depend on faculty willingness to accept a teaching overload.

There is a distinction to be made between project elements that have been attached to pre-existing institutional agencies (e.g., departments) and those that were newly invented solely for the benefit of IGERT participants. The latter are more vulnerable when IGERT funding is over. IGERT seminars, for example, may be less likely to remain than modifications to existing departmental courses. Elements of IGERT projects that are not tied to specific degree requirements but rather exist as novel or extra elements of IGERT graduate training are also less likely to remain when funding disappears. The annual Summer Institute hosted by one IGERT may disappear once the grant is over. Internship relationships with outside entities, funded by IGERT monies, may also end without funding.

Finally, there is the ability to continue offering students unrestricted funding. This is the hardest to institutionalize and yet perhaps most important characteristic of IGERT projects, according to many faculty and students. The cornerstone of each IGERT project we visited seemed to be the capacity for graduate students to explore research in multiple laboratories, with multiple faculty members, in multiple disciplines. The PI and program faculty at one project hope that the program will continue to be able to offer interdisciplinary traineeships. The director of an interdisciplinary research institute that houses one IGERT is just beginning an ambitious effort to build an endowment for fellowships, and is being supported in doing so by the institute's Board of Advisors. At another university, IGERT faculty have been aggressive and successful in pursuing additional support for students and for research. An industry partner contributed $500,000 for graduate student support, and participating faculty are confident that the program will continue.

Although it has sufficient research funds to support graduate students, one project has developed a particularly well-articulated plan for continuing unrestricted student funding, grounded in what are perceived to be important departmental needs. The IGERT's home department highly values U.S. students because of the recognized importance of a common language and culture in interactions with American industry, and they believe that the benefit of choosing their own research paths provided by unrestricted funds attracts U.S. students. To institutionalize these benefits of IGERT funding, they are considering an Institute model in which funds pooled from industry membership or, alternatively, from faculty grants would be used to support program activities and to provide an up-front guarantee of funding to students. A potential candidate for the industry approach is an Institute currently being developed in connection with the university's business school. The PI described this as a consortium based on the NSF CRC model.[34] He said they have seven companies on board, and they are pursuing

[34] A S/I/UCRC is a University-Based Research Center that receives base funding of an equal amount from NSF and the State Government. Industry contributions in cash and in kind are at least equal to the NSF or State contribution.

three times that many. The companies offer resources, and the institute looks at problems of interest to the companies, either collectively or as case studies, thus providing multiple opportunities for student projects and for industrial internships. The alternative approach, of pooling funds from a number of professors' individual research grants, would detach ownership of research assistantship slots and redistribute the money to students at the department level.

Corporate funding is being sought by other projects as well, although many of these projects focus more on infrastructure maintenance than on sustaining unrestricted student funding. One IGERT professor noted that it is now relatively easy for faculty to accept students in their labs because the students arrive with funding and there is little risk to the faculty member. In the future, even if faculty generate funding for interdisciplinary projects, students will be less free to identify and work on *their own* ideas.

Those IGERTs with a more academic than industrial focus naturally look elsewhere for funding. For example, one PI (and university Provost) set forth the following business plan:

- Fund *all* students in the first year while they are taking the multi-disciplinary course, doing the three 10-week rotations, and taking supplemental courses. To do that, the faculty must win training grants that build on similar themes.
- For the students' second year, access indirect costs to fund students and use TA lines. To date, the Provost has not yet dictated nor have department heads agreed that a specific number of TA lines belong to the IGERT program.
- For the students' remaining years, faculty support students on their own grant funds.

A number of other projects, on the other hand, are not so invested in seeking alternative funding. They report that it is unclear at the moment, and too soon to know, whether other funding will be available to support traineeships after IGERT funding. There was some feeling that because budgets are departmentally based, funding multidisciplinary trainees will be difficult.

At the time of the site visits, three IGERT projects indicated no current plans to institutionalize their IGERT graduate projects. At the first, there are no plans to institutionalize the program beyond the five-year funding period; as the PI puts it, they will "pull the plug after five years." At the second, difficulties in getting the project up and running have precluded attention to sustaining the effort past its original funding cycle. And at the third, the chairman of one participating department reported being anxious for the IGERT to end so that the PI could focus on his normal departmental responsibilities. However, as projects continue to evolve in the years beyond the site visits, the value of continuation or institutionalization may be realized, as evidenced by one university's successful grant application, for a project that built on its 1998 IGERT project work, for funding in the 2003 cohort.

Institutionalization of IGERT Ideas

Much less tangible than weaving new courses or degrees into institutional educational programs is the impact that participation in IGERT has had on the way faculty and students both within and beyond IGERT projects think about graduate education and cross-disciplinary collaboration. As discussed in Chapter 4, participating faculty's IGERT experiences have altered their own and the broader faculty's perceptions of the possibilities of inter/multidisciplinary collaboration in numerous ways. Ideas are not static, and as IGERT faculty adopts new perspectives and habits, they may begin to influence non-IGERT faculty and administrators. These changes include patterns of cross-disciplinary teaching and research among faculty brought together by IGERT and the adoption of IGERT activities by other departments or programs (e.g., lab rotations, internships).

Many IGERT faculty emphasize the project's influence on how they think about teaching and research, and they anticipate continuing to work with colleagues outside their own discipline with or without IGERT. IGERT funding has encouraged new linkages and collaborations among faculty members that will remain and continue to bear fruit post-NSF support. Thus, while one university IGERT plans to "pull the plug," the co-PIs and faculty on the Executive Committee feel that the social fabric created among faculty during IGERT is a legacy that will lead to other things. Faculty said that the IGERT experience has built "a base of trust that will lead to working together" and that "generally there [is] now more mutual respect" among the core group of IGERT faculty. Increases in cross-disciplinary faculty collaboration, grant applications, research, and publications have all contributed to changes in climate and culture that are much harder to measure. Faculty at another project attributed their strength in interdisciplinary research to the spirit of collaboration that was present prior to the IGERT award and has been strongly promoted through IGERT activities. They have been successful in developing joint projects that have been funded, and the joint research and publishing will continue into the future. Similarly, a professor at another project said that faculty interactions "almost always culminate in grant proposals." And a senior faculty member added, "I write very, very few grants by myself anymore. The thought of doing it now kind of scares me."

Thinking of the effects of IGERT beyond project boundaries, the PI and some institutional administrators at one project remarked that the presence of the IGERT project has enhanced the multidisciplinary culture at the University: that as IGERT faculty participate on university-wide committees, they promote a culture that supports multidisciplinary education across the entire university and makes it easier for other interdepartmental or interdisciplinary projects to be accepted at the university. Another PI commented that, "these IGERTs have transformed and continue to transform the campus. There is much more hustle and bustle across campus and trust of colleagues in different departments and new shared value systems vis-à-vis tenure and hiring, grad student projects, etc." In other places IGERT projects have drawn faculty with interdisciplinary interests to their universities, either as interdisciplinary hires or into traditional departments. These faculty members are likely to remain and continue the tradition of interdisciplinary research after the IGERT grants end.

Replication of program elements elsewhere in the university is another way IGERT ideas are spreading throughout campuses. The Vice-Provost for research at one university reports that a "copycat effect" is in operation on his campus, such that elements of the IGERT project are being mimicked across campus. At another institution, where interdisciplinary work is common at the undergraduate level, IGERT is credited with achieving interdisciplinary buy-in in the more individualistic and competitive graduate education culture. The fact that the PI has become an Associate Dean of Research and Graduate Affairs allows her to advance programs encouraging IGERT features such as team-based research, industrial internships, and multidisciplinary research. She has already instituted "Mentoring Workshops" to facilitate junior faculty interaction with senior faculty to develop research activities across disciplines. At two other universities, some new graduate programs have incorporated elements such as a multidisciplinary focus, internships, and an Advisory Board. At one of these universities, a new multidisciplinary master's program has several IGERT-inspired components: a common core of computational methods, an ethics course, and an internship. The new program is also making a concerted effort to recruit students from traditionally underrepresented groups.

New institutional forms are also spreading as a result of IGERT projects. Examples include a new Institute at a 2000 site that is expected to house interdisciplinary grants and programs in the future; an interdisciplinary Center at another university; the apparently seamless relationship between an IGERT and a similarly named Graduate Group, both housed in the IGERT, at a third university; and an interdepartmental program and its almost overlapping IGERT at a fourth university.

Factors Affecting Institutionalization

There is no magic formula that can guarantee institutionalization of an IGERT project, although a project's hopes for long-term viability seem to rest on four connected factors: institutional commitment, resources, leadership and faculty participation, and the project's conceptual base.

Institutional Commitment

To survive long-term, any novel educational program must find a way to fit within its supporting university's goals and mission. If the cross-disciplinary nature of IGERT projects fits conceptually within its home institution, it has a better chance of long-term survival. Some institutions hosting IGERT projects have a prior history of interdisciplinary work; others have new institutional initiatives supporting interdisciplinary research and education. University administrators at more than half of the IGERT institutions described how IGERT fits into their institutional plans to create more inter/multidisciplinary forms of graduate education. Selected examples are presented below:

- One university visited has a new provost who is operating with a strong hand, trying to build on university strengths. She has been focusing her efforts on interdisciplinary programs. This university is now home to two IGERT projects.
- Another university has a long tradition of attracting faculty interested in interdisciplinary work, and most are participating IGERT faculty. The Vice President for Research and Graduate Students said "IGERT fits beautifully" into the University's culture and priorities, and the university has been awarded three more IGERTs.
- University administrators attest to this third university's history of supporting interdisciplinary efforts. Currently, the Graduate School funds 12 interdisciplinary programs that span from two to six colleges each and report directly to the Dean's Office. The university's 1999 IGERT benefited from this history of interdisciplinary efforts on campus; the university now has two IGERT projects.
- Interdisciplinary work that involves multiple departments and schools also occurs at a fourth university in the sciences, social sciences, engineering, and humanities. Faculty may hold appointments in more than one department or program. Four IGERTs are among over 50 interdisciplinary programs. Faculty members and university administrators indicated that there are few barriers to conducting interdisciplinary programs, with many faculty members participating in more than one of these programs.
- At another university, the Dean of Graduate Students stated that the university is committed to creating the structure for flexibility that interdisciplinary work requires, and

IGERT is perceived as contributing to such cultural change on campus. Administrators have commented that having three IGERT projects on campus allows the university to take its interdisciplinary efforts to the next level by creating opportunities for faculty within different interdisciplinary projects to work together. As one faculty member said, "[This university] hires people based on its interest in creating collaborations not competition."

- Administrators at one state university are highly supportive of interdisciplinary programs, as evidenced by the university's four IGERT grants. In addition, the president created a special fund that gives competitive awards for interdisciplinary programs.
- A smaller private university has traditionally supported interdisciplinary endeavors. This university competes for faculty and students with much larger, wealthier institutions. For this reason, the administration believes that interdisciplinary efforts, especially in the sciences, provide a competitive advantage for attracting high quality students and faculty. This perception is echoed by faculty members.
- One university's Provost made it clear that bridging departments is a central institutional strategy, something that the university leadership believes may help distinguish this university from others. By combining faculty across departments, they can put together teams to work on interdisciplinary projects without growing in size. The message is: "[We] do not let departmental structure hold us back."
- At another university, the Vice-Provost for research discussed dedication to interdisciplinary training as the direction that graduate education should go. The administration sees the IGERT project as a model training grant, and he hopes it marks the beginning of an institutional shift towards this type of graduate education.
- The Dean of the School of Management at another university views their IGERT project as deeply strategic, a part of the fabric of the university. It fits with the university's strategic plan, one element of which is "leadership in technology transfer."

Some of the projects we visited face a university context less hospitable to interdisciplinary research and education. At one, for example, there is institutional acceptance of the concepts and framework of interdisciplinary work but less consensus about how to manage and carry it out. In spite of the explicit charge to secure extramural funding, interdisciplinary Centers receive no credit for grants they acquire; instead grants are administered through, and credited to, the single department of the PI. The Vice President for Research characterized the Deans as provincial and somewhat territorial and said the Deans believe interdisciplinary Centers are removing good faculty, and credit for the work they do, from their departments.

Resources

Along with institutional support, a second necessary (though not sufficient) factor for the longevity of an IGERT program is obtaining adequate resources (financial and otherwise) to sustain project activities. Their desire for grant extensions notwithstanding, financial resources are the most common barrier to institutionalization of IGERT graduate projects cited by PIs and participating faculty. Without money to support students independently of individual faculty grants, IGERT PIs fear that the core value of their IGERT projects will be lost. Based on the information we gathered in our third-year site visits, it seems that 18 of the 57 projects we visited might be able to sustain some level of unrestricted support for students. One university, for example, just received a $150 million gift to support (among other things) graduate students. Once NSF funding ends, another university's IGERT plans to request support for students from a recently announced NIGMS/NIH training grant program, and anticipates that the recent relationship developed with a National Center at NIH may be a source of support for the program's students. A state university has been aggressive and successful in pursuing additional support for students, both from private industry and through NIH and the U.S. Department of Agriculture.

Others have already used IGERT to leverage other grants. Being in a high-demand field can make fundraising from industry more successful. For example, one university plans to initiate major fundraising among the 100-plus companies in its area with an optics focus, in order to obtain adequate external support to keep the IGERT project going. Obtaining internal funding may pose a greater challenge for IGERT projects, especially those situated within public institutions. Convincing state legislatures to provide adequate funding in a time of shrinking resources is difficult. One state university's budget from the state is actually declining, leaving little or no room for new programs. Another state university does not provide its Organized Research Units or Graduate Groups (such as its IGERT projects) the same kind of direct state funds as traditional departments, so obtaining university funding after the grant ends will pose a challenge. At another university, funding for Biology labs has remained flat for over seven years, and they worry about maintaining levels of student support sufficient to attract/retain the same kinds of students.

A third source of funding is individual faculty grants. At one project, for example, the co-PIs have submitted applications that had netted $738,000, spread across 18 different grants. Money available for research varies by discipline, however, so some IGERT faculty are better placed to seek outside funding than others. IGERT faculty in the social sciences lamented that fewer funding opportunities are available in their fields. Further, unless these grants are interdisciplinary in nature, operating a graduate program solely off faculty grants not only leaves much to chance but also risks reversion to an apprenticeship model. It remains to be seen whether IGERT projects can successfully mount a funding strategy comprehensive enough to sustain the current level of activity.

Leadership and Faculty Participation

No IGERT project can continue without faculty leadership and support. The issues affecting faculty commitment discussed in Chapter 4 will play a significant role in the institutionalization of any IGERT project. Finding ways to support team-teaching of inter/multidisciplinary courses without faculty overloads will be critical. In addition, the challenges of supporting and rewarding inter/multidisciplinary research, navigating departmental degree requirements so that IGERT participation does not place too great a burden on students, and working out rules for joint advising all have to be met for IGERT graduate education to be sustained long-term.

In only a few cases is faculty support so uneven, for various reasons (e.g., disaffection of faculty, PI or faculty work overload, inequitable distribution of trainees or resources), that participants are already concluding that project activity is unlikely to continue in its present form once NSF funding ends.

- Currently, faculty at one university are minimally involved in the IGERT project (although supportive of students' thesis research), and hope for continuation of the project will depend on a revival of faculty interest after the PI departs for another institution.

- At one IGERT, the PI's department chairman is anxious for the IGERT to be over so the PI can refocus on his normal departmental responsibilities. The PI is an enthusiastic and motivated leader, yet lack of faculty or institutional support for the IGERT to date has left him overburdened. He does not plan to continue the project beyond the funding period.
- At another project, several of the original departments have not had trainees in the IGERT project. The unevenness of departmental participation and faculty buy-in is an ongoing issue, and raises concerns about some departments' continued involvement beyond the IGERT-funded period.
- The PI at a 2000 project expressed frustration when faculty participation declined drastically after the first semester of the project. The faculty, in turn, reported that it was not clear how they were expected to be involved and there was little incentive for their continued participation.

The Project's Conceptual Base

The most important factor for longevity may be a project's research area: the conceptual and intellectual base upon which all project activities are built. If faculty and students are not interested in a project's area of study, the project simply cannot be sustained. The viability of a project's research area plays out in multiple arenas: faculty, internal resources, students, and external funding. The conceptual base of each IGERT project is a necessary means of capturing and sustaining faculty interest. Institutional resources depend on the fit of the project's multidisciplinary theme with its university's academic mission. The Dean of a School that houses one IGERT, for instance, noted that the IGERT is "in our sweet spot," given its position at the intersection of social science, information technology/systems, and organizational behavior. Once the project has attracted faculty and garnered institutional resources, students must be drawn to the project. They must find the research focus area one in which they can envision both present intellectual excitement and a future career. In addition to recruitment into the IGERT, projects also need to maintain intellectual draw among students in general at their universities if they are to thrive. For example, one IGERT's courses have attracted only a few non-funded individuals; in the long run, the certificate program and the core courses will need to develop a constituency beyond NSF-funded students in order to sustain itself when IGERT funding ends. The operations research seminar at another project, on the other hand, is an example of project courses that have developed strong non-IGERT constituencies, and thus greater hope for institutionalization. Finally, the conceptual base of the project in part defines the external funding available—some topics are hot; others are not. For example, a faculty member at one project commented that they are probably still "two years away from success in obtaining research funding" because their field is so new. Alternatively, another project's graduates will fill a "critical shortage" of Ph.D. graduates in its field.

Multiple Project Locations

Few IGERT projects include multiple institutions, in part because of the difficulty of organizing and managing a graduate education/research collaboration across institutions, even with IGERT funding, let alone without external grant support. Six of the projects funded in 1999 and four of those funded in 2000 were co-located at more than one university from their inception. In addition, two IGERTs became two-campus projects when their PIs moved to other institutions. Among these 12, only two projects definitely see continued collaboration in their future. At the one project, pre-existing collaborative work among faculty from both institutions seems to have been strengthened by IGERT, and two new cross-institutional grants are in the works. Expectations for future shared graduate education, however, are less clear. Another dual-campus project is committed to maintaining the project across the two campuses. At the time of our visit, they had acknowledged some difficulties and were working towards solutions to be implemented the following year. The remaining projects in this group are less sanguine. In two cases, the planned collaboration between institutions never took root sufficiently to allow consideration of institutionalization. In others, the collaboration did work at some level but the PIs, although interested in continuing IGERT at the core institution, did not mention sustaining their IGERT in its combined form.

Judging from this sample, working across institutions to build a program is difficult. While simple geographic distance and other factors undoubtedly play a role in these difficulties, imbalances between partners might also complicate relationships. Among these planned cross-institutional collaborations, all but one are between what might be considered unequal partners. In four cases, the core institution has reached out to "more prestigious" universities, and in one case to a "less prestigious" minority university. While some level of faculty interaction undoubtedly preceded each of these IGERT connections and some partners have managed to work together during the funding period, none of these arrangements were able to strengthen ties to the extent that they see a future together worth including in their institutionalization plans. Even the equal partners, with their complementary studies of ecosystems in two contrasting environments, have struggled to engage students in the way they envisioned. They, however, do continue to look to a future of continued research collaboration.

The standout among multiple-campus projects is centered at the home institution's field biological station. Its structure is radically different from other IGERTs. The project was originally designed to engage students and their advisors from 12 universities in two summers of intensive interdisciplinary coursework and research at the biological station. The IGERT is now open to all comers, and is considering extending the program to three summers. The fiscal agent and home of the PI is one state university, the two project coordinators are from another university in the state system, and remaining faculty and trainees come from multiple other universities. While presenting a somewhat different challenge in terms of institutionalization, the IGERT appears healthy and eager to continue, assuming a continuing welcome from the field station and success in the more difficult issue of funding for students. At a minimum, the interdisciplinary research focus will be institutionalized at the biological station through the creation of a regular summer session course.

Of the two unplanned dual-campus IGERTs, only one had been divided long enough at the time of our visit to allow judgments about institutionalization. Both of these two institutions believe that two separate fully funded IGERTs would be better because "funding is too stretched now." One Dean commented, "The synergies haven't really worked out so well. It would be hard to make a case to continue the relationship."

Future Indicators of IGERT Projects' Impact

Many IGERT participants and interested parties believe that five years is too short a time in which to change the delivery and culture of graduate education. Still, IGERT projects have already had numerous impacts on their participants and home institutions, as indicated in earlier chapters. There is a good prospect for continuation in some form of many of the projects after IGERT funding ends.

It is too soon to assess broader changes across other universities, national fields, professional associations, etc. However, we have identified some indicators to watch as time goes on. These are listed below in the form of questions.

- Do the number of Ph.D.s (or certificates) awarded by the interdisciplinary degree programs increase over time?
- Do any of the IGERT graduate programs that are now certificate programs evolve into a "field," as chemical engineering did a number of years ago?
- How successful are IGERT trainees in getting employment, both in and out of academe?
- Do organizations that fund research, including NSF itself, fund more inter/multidisciplinary endeavors?
- Are there changes in journal article authorship (i.e., more departments and/or more interdisciplinary programs represented among the authors)?
- Are there changes in citation patterns in journal articles (i.e., more citations of references from other fields in discipline-focused journals)?
- Are new inter/multidisciplinary journals started to meet an increasing need?
- Does the pace at which new inter/multidisciplinary programs are started increase, and do some of these new programs adopt IGERT educational innovations (e.g., required lab rotations)?
- Do universities—both those with and without IGERT grants—accelerate the pace at which they change current policies that discourage inter/multidisciplinary teaching and/or research?
- Have there been modifications to tenure/promotion processes that allow for greater recognition of inter/multidisciplinary research and teaching, and what forms do these modifications take?

Finally, one cannot forget the anticipated impact of IGERT graduates themselves. While most students have not left their IGERT projects yet, as trainees complete their doctoral programs and become new faculty members or researchers they will bring interdisciplinary approaches to their own work and thus expand IGERT's impact long after the program funding has ended.

Summary

Institutionalization of IGERT projects occurs along two fronts: making permanent the innovative forms of graduate education developed by IGERT projects, and spreading IGERT-influenced ideas about collaboration across disciplines in research and teaching. The former is more tangible as it involves structural changes, although the latter may have a more significant impact because it affects faculty and institutional vision for future research and graduate education. Factors affecting institutionalization include institutional commitment (financial as well as ideological), resources, faculty interest and leadership, and the project's conceptual and intellectual base.

APPENDIX A

PROJECT CHARACTERISTICS

Appendix A

Table A.1
Percent of Projects Including Undergraduate and/or Postdoctoral Students

Type of Students Included in IGERT Training	**All** (N=100)	**1998** (N=17)	**1999** (N=21)	**2000** (N=19)	**2001** (N=22)	**2002** (N=21)
Neither undergraduate nor postdoctoral students	38%	24%	24%	42%	41%	57%
Undergraduate but not postdoctoral	32	35	33	16	46	29
Both undergraduate and postdoctoral	15	23	19	21	13	0
Postdoctoral but not undergraduate	15	18	24	21	0	14

Source: OMB 3145-0136 EHR Generic Clearance: Survey of Principal Investigators, Survey Year 2003, Section "IGERT Project Summary Characteristics"

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Table A.2
IGERT Project Characteristics

Departments/Schools Involved	***Program History***	***Multidisciplinary Focus Area***
Biomedical Engineering, Biology, Chemistry; plus, the Center for Biodynamics, the Center for Advanced Biotechnology, and the Bimolecular Engineering Center	existing collaborations	Bioinformatics
Applied Mathematics, Cognitive and Linguistic Sciences, and Computer Science	existing collaborations	Applied Mathematics, Cognitive Sciences, and Computer Science
Schools of Business, Liberal Arts, Engineering, and Science	new	Environmental Manufacturing Management
Chemistry, Materials and Aerospace Engineering, Biometry, Theoretical and Applied Mechanics, Mathematics, Sociology, Chemical Engineering, Physics, Neurobiology, Civil and Environmental Engineering, and Crop and Soil Science	new	Advancement and applications of non-linear systems in various fields
Economics, Government, Public Policy, and Sociology	existing collaborations	Inequality and Social Policy
Anthropology, Computer Science, Communication, Civil, Structural, and Environmental Engineering, Geography, Industrial Engineering, Philosophy, and Political Science	existing collaborations	Geographic Information Science
Biochemistry, Ecology & Evolutionary Biology, Mathematics, Molecular & Cellular Biology, Pharmacy, Physics, Physiology, Applied Mathematics, Biomedical Engineering, Genetics, Neuroscience	existing collaborations	Mathematics, Biology, and Physics
Institute for Transportation StudiesTrainees from: Agricultural Economics, Civil & Environmental Engineering, Chemistry, Chemical Engineering, Ecology, Economics, Mechanical Engineering, or the TTP graduate group	pre-existing program	Engineering and Public Policy fields related to transportation
Chemistry, Electrical & Computer Engineering, Physics	existing collaborations	Optical Science
Chemistry, Chemical & Materials Engineering, Electrical Engineering	existing collaborations	Chemical and Biological Sensors
Biochemistry, Molecular Biology & Biophysics, Chemical Engineering, Chemistry, Computer Science, Entomology, Mathematics, Medicinal Chemistry, Physics	existing collaborations	Computational Neuroscience
Six schools (Engineering, Policy, Planning and Development, Medicine, Business, Communications, and Education); as well as the College of Letters, Arts, and Sciences	new	Urban Sustainability
Botany, Chemistry, Chemical Engineering, Electrical & Computer Engineering, Mechanical Engineering, Physics, Zoology	existing collaborations	Optical Molecular Bio-engineering
Aeronautics & Astronautics, Astronomy, Atmospheric Sciences, Biochemistry, Chemistry, Genetics, Geological Sciences, Geophysics, Microbiology, Oceanography	new	Astrobiology
Primary departments: Rural Sociology, Limnology Secondary: Zoology, Forest Ecology & Management, Botany, Journalism & Mass Communication, Agricultural & Applied Economics, Environmental History, Civil & Environmental Engineering	new	Interaction of Social and Aquatic Systems

Table A.2
IGERT Project Characteristics

Departments/Schools Involved	*Program History*	*Multidisciplinary Focus Area*
Electrical & Computer Engineering, Chemical Engineering, Computer Science, Chemistry, Physics & Astronomy, Materials Science, Biomedicine	existing collaborations	Smart Sensors and Integrated Microsystems
Biochemistry, Biology, Chemistry, Computer Science, Neuroscience, Physics, Psychology	existing collaborations	Computational Neuroscience
Civil & Environmental Engineering, Electrical & Computer Engineering, Engineering & Public Policy, Industrial Administration, Computer Science, Social & Decision Sciences	pre-existing program	Computational Analysis of Social and Organizational Systems
Biology, Biomedical Engineering, Electrical Engineering & Computer Science, Mechanical & Aerospace Engineering	existing collaborations	Neuro-mechanical Systems
Chemistry, Chemical Engineering, Electrical Engineering, Applied Physics	existing collaborations	Nanostructural Devices and Materials
Agronomy, Animal Science, Molecular Biology, Biochemistry, Biophysics, Botany, Computer Science, Electrical & Computer Engineering, Genetics, Mathematics, Statistics, Veterinary Microbiology, Preventative Medicine, Zoology	existing collaborations	Computational Molecular Biology Training
Cognitive Science, Philosophy, Psychology	existing collaborations	Problem-centered learning
Industrial & Manufacturing Systems Engineering	pre-existing program	Manufacturing Logistics
Cell Biology & Neuroscience, Chemistry & Biochemistry, Mathematical Sciences, Microbiology, Veterinary Molecular Biology	existing collaborations	Complex Biological Systems
Chemistry, Physics, Electrical & Computer Engineering	pre-existing program	Photonics
Agronomy, Biochemistry & Molecular Biology, Civil & Environmental Engineering, Geosciences, Material Sciences & Engineering, Soil/Water/Environmental Science	existing collaborations	Biogeochemistry
Astrophysics, Computer Science, Geosciences	new	Program in Integrated Computer and Application Sciences
Basic Medical Science, Biomedical Engineering, Chemical Engineering, Electrical Engineering, Industrial & Physical Pharmacy, Mechanical Engineering, Radiology, Veterinary Physiology	new	Therapeutic and Diagnostic Devices
Chemical Engineering & Materials Science, Chemistry, Civil & Environmental Engineering, Environmental Toxicology, Geology, Land, Air, and Water Resources, Mechanical & Aeronautical Engineering, Neurology, Physics, Veterinary Medicine	existing collaborations	Nanophases in the Environment, Agriculture and Technology
Chemical Engineering, Computer Science, Medicine, Dentistry, Electrical Engineering, Materials Science, Mechanical & Aeronautical Engineering, Neurobiology, Psychology, Neuropsychiatric Institute, Physiological Sciences, Psychiatry & Biobehavioral Science	existing collaborations	NeuroEngineering

Table A.2
IGERT Project Characteristics

Departments/Schools Involved	***Program History***	***Multidisciplinary Focus Area***
Biological Sciences, Freshwater Ecology, Civil Engineering, Earth and Planetary Sciences, Geography, Geological Sciences	pre-existing program	Freshwater Sciences
Biological & Agricultural Engineering, Chemical Engineering, Chemistry, Civil Engineering, Computer Science & Computer Engineering, Educational Leadership/ Counseling & Foundations, Electrical Engineering, Industrial Engineering, Management, Mechanical Engineering, Microelectronics/Photonics, Physics, Sociology	new	Microelectronics-Photonics
Biophysics, Chemistry, Electrical Engineering & Computer Science, Environmental Health Sciences, Materials Science and Engineering, Physics	existing collaborations	Molecularly Designed Materials
Atmospheric & Oceanic & Space Science, Biological Sciences, Chemistry, Evolution & Ecology & Organismal Biology	existing collaborations	Biospheric-Atmospheric Research Training
Aerospace Engineering, Ceramic Engineering, Computer Science, Electrical & Computer Engineering, English, Mechanical Engineering, Metallurgical Engineering	existing collaborations	Variable Speed Electromechanical Drive System
Biology, Chemistry, Computer & Information Science, Plant Developmental Biology, Center for Genomics & Bioinformatics, Mathematics, Molecular Biology Institute	existing collaborations	Evolution, Development & Genomics
Center for Materials Research, Chemical Engineering, Chemistry, Electrical & Computer Engineering, Materials Science & Engineering, Mechanical & Aerospace Engineering, Physics	existing collaborations	Science and Engineering of Laser Interactions with Matter
Applied Geology & Geochemistry, Biological Systems Engineering, Biotechnology, Center for Multiphase Environmental Research, Chemical Engineering, Chemistry, Civil & Environmental Engineering, Crop & Soil Sciences, Environmental Microbiology, Geosciences, Microbiology, Soil & Water Engineering	existing collaborations	Education of the Next Generation of Environmental Scientists and Engineers
Anthropology, Biology/Life Sciences, Bioengineering, Kinesiology	new	Engineering, Anthropology, Kinesiology
Anthropology, Geography, Geology, School of Life Sciences (Biology, Plant Biology), Center for Environmental Studies, Sociology, Engineering, Horticulture, Public Affairs, History, Philosophy, Psychology	existing collaborations	Urban Ecology
Carnegie Mellon: Computer Science, Robotics, Psychology, Statistics, Biological Sciences, Center for Automated Learning & Discovery Pittsburgh: Mathematics, Psychology, Neurobiology, Neuroscience	pre-existing program	Cross-disciplinary training in the Neural Basis of Cognition
George Washington: Anthropology, Biology, Forensic Sciences, Engineering Maryland: Anthropology, Biology Howard: Microbiology, Anthropology	existing collaborations	Human Evolutionary Biology
Chemistry, Biological Sciences, Chemical Engineering, Mechanical Engineering, Textiles, Education	new	Macromolecular Studies

Table A.2
IGERT Project Characteristics

Departments/Schools Involved	***Program History***	***Multidisciplinary Focus Area***
Botany, Plant Pathology, Genetics, Zoology, Animal Science, Horticultural Science, Crop Science, Poultry Science, Environmental & Molecular Toxicology, Entomology, Molecular & Structural Biochemistry, Statistics, Physics, Mathematics, Chemistry, Molecular & Biomedical Sciences, Microbiology, Population Health & Pathobiology, Companion Animal & Special Species, Farm Animal Health & Resource Management, Computer Science, Chemical Engineering, Biomedical Engineering, Forestry	new	Bioinformatics & Functional Genomics
Chemical and & Biological Engineering, Engineering Sciences & Applied Mathematics, Mechanical Engineering, Biomedical Engineering, Electrical & Computer Engineering, Materials Science and Engineering, Neurobiology & Physiology, Physics & Astronomy, Mathematics, Physiology	new	Complex Dynamical Systems
Chemistry, Physics, Mathematics, Material Science, Chemical Engineering, Aerospace Engineering, Computer Science & Engineering, Polymer Science	new	Many-Body Problems
Biochemistry & Plant Biology, Agricultural & Biological Engineering, Computer Science, Electrical & Computer Engineering, Mechanical Engineering, Aeronautical & Astronautical Engineering, Botany & Plant Pathology, Chemical Engineering, Chemistry, Industrial Engineering, Medicinal Chemistry & Molecular Biology, Medicinal Chemistry & Molecular Pharmacology, Nuclear Engineering, Management, Economics	pre-existing program	Technology Transfer
Biophysics Graduate Group, Molecular & Cell Biology, Integrative Biology, Plant & Microbial Biology, Environmental Science & Policy Management, Bioengineering, Electrical Engineering & Computer Science, Physics, Chemistry, Psychology	pre-existing program	Physical Biosciences
Microbiology, Immunology & Molecular Genetics; Chemistry & Biochemistry; Biomathematics; Biostatistics; Molecular, Cell, & Developmental Biology; Human Genetics; Chemical Engineering; Computer Science	new	Bioinformatics
Biology, Physics, Psychology & Neuroscience, Cognitive Science, Salk Institute, Electrical & Computer Engineering, Neuroscience, Neurobiology, Anatomy, Mathematics	new	Computational Neurobiology
Chemical Engineering, Materials, Electrical & Computer Engineering, Physics	new	Materials Science and Engineering
Geological Sciences, Ecology and Evolutionary Biology, Political Science, Economics, Environmental Studies, Civil Engineering, and Journalism.	new	Carbon Cycle, Climate Change, and Societal Impacts and Societal Impacts
Tennessee: Materials Science & Engineering, Mechanical, Aeropspace & Biomedical Engineering Rutgers: Mechanical & Aerospace Engineering Lehigh: Mechanical Engineering & Mechanics	existing collaborations	Materials Science
Mechanical Engineering, Chemical and Fuels Engineering, Electrical Engineering, Materials Science Engineering, Bioengineering	existing collaborations	Thermal Fluid System

Table A.2
IGERT Project Characteristics

Departments/Schools Involved	***Program History***	***Multidisciplinary Focus Area***
Biochemistry, Bioengineering, Chemistry, Chemical Engineering, Electrical Engineering, Material Sciences Engineering, Molecular Biotechnology, Physics, Physiology & Biophysics	pre-existing program	Nanotechnology
Electrical & Computer Engineering, Industrial & Systems Engineering, Economics, Finance, Computer Science	existing collaborations	Internet/Global Communications Infrastructure
Chemistry, Computer Science, Chemical Engineering, Electrical & Computer Engineering, Mechanical Engineering, Mathematics, Molecular Medicine & Genetics, Neurosurgery	existing collaborations	High Performance Computing

Table A.3

Distribution of Active Consortial Arrangements across Partner Type

Partner Type	**Percent of projects having consortial arrangements with this partner type (Project N=28)**	**Number and percent of consortial arrangements with this partner type** (Arrangement N=78) N (%)
Institutions	68%	33 (42%)
Federal Laboratories	25	13 (17)
Corporations	18	8 (10)
State or Local Governments	14	8 (10)
Other	14	4 (5)
Federal Agencies	11	6 (8)
Foreign Governments	7	3 (4)
National Science Foundation	4	2 (3)
Foundations and other non-profits	4	1 (1)

Note: Percentages do not sum to 100% because projects have multiple consortial partners. Percentages are reported only for the 28 projects that reported external partnerships.

Source: OMB 3145-0136 EHR Generic Clearance: Survey of Principal Investigators, Survey Year 2003, Section "IGERT Consortial Arrangements"

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Table A.4
Distribution of Active Consortial Arrangements across Exchange Activity

Exchange Activity	**Percent of projects using this exchange activity** (Project N=28)	**Total number of exchange activities of this type across all partnerships** (Partnership N=78) N (%)
Combination of facilities, collaborative research/teaching, personnel exchange	64%	34 (44%)
Combination of collaborative research/teaching and personnel exchange	29	9 (12)
Collaborative research/teaching	18	16 (21)
Combination of facilities and collaborative research/teaching	14	12 (15)
Personnel exchange	11	3 (4)
Facilities	7	3 (4)
Combination of facilities and personnel exchange	4	1 (1)

Note: Percentages do not sum to 100% because projects have multiple consortial partners.

Source: OMB 3145-0136 EHR Generic Clearance: Survey of Principal Investigators, Survey Year 2003, Section "IGERT Consortial Arrangements"

Abt Table Production Date: February 2004 for IGERT 2004 Cross-Site Monitoring Annual Report

Table A.5
Distribution of Active Consortial Arrangements across Arrangement Type

Arrangement Type	Percent of projects having these consortial arrangements (Project N=28)	Total number and percent of consortial arrangements of this type across all projects (Partnership N=78) N (%)
Non-degree granting entity	54%	42 (54%)
Ph.D. granting institution	54	24 (31)
Minority enhancing and Non-degree granting institution	14	5 (6)
Minority enhancing	7	3 (4)
Minority enhancing, Ph.D. granting institution and Non-degree granting institution	7	3 (4)
Minority enhancing and Ph.D. granting institution	4	1 (1)

Note: Percentages do not sum to 100% because projects have multiple consortial partners.

Source: OMB 3145-0136 EHR Generic Clearance: Survey of Principal Investigators, Survey Year 2003, Section "IGERT Consortial Arrangements"

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Table A.6
Additional Funding Sources across Donor and Donation Types

Donor Type	Percent of projects receiving funds from this source (project N=44)[a]	Total number of direct donations from this source	Total number of in-kind donations from this source
Institutions	50%	51	10
Corporations	27	17	10
State or local governments	20	21	3
National Science Foundation	23	25	0
Federal agencies	20	32	4
Foundations and other non-profits	16	13	4
Federal laboratories	7	3	2
Foreign governments	5	2	1
Other	14	8	2
TOTAL – ALL DONOR TYPES		172	36

[a] Includes only projects reporting at least one additional funding source. Percentages sum to more than 100 percent because projects received funds from multiple sources. In-kind donations came from donors who also provided direct support, with three exceptions: (a) a federal lab providing trainees with internships; (b) a university center which provided "supplies and samples" for a research project; and (c) administrative support from a university department.

Source: OMB 3145-0136 EHR Generic Clearance: Survey of Principal Investigators, Survey Year 2003, Section "IGERT Additional Funding Source"

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Table A.7
Distribution of Additional Funding Amounts across Donor and Donation Types by Donor

Donor Type	Median Dollar Amount of Direct Donations from this source (Donation N=172)	Donor n	Direct Donations Range	Estimated Median Dollar Value of In-Kind Donations from this source (Donation N=36)	Donor n	In-Kind Donations Range
National Science Foundation	**$99,994**	25	**$5,250-$800,000**	**-**	**-**	**-**
Federal Agencies	**$84,316**	32	**$6,262-$1,200,000**	**$3,150**	4	**$300-$30,000**
Foundations and other non-profits	**$75,000**	13	**$20,000-$300,000**	**$11,673**	4	**11,600-$1,000,000**
Federal Laboratories	**$45,000**	3	**$1,800-$55,000**	**$17,500**	2	**$15,000-$20,000**
Institutions	**$44,000**	51	**$1,326-$473,000**	**$42,500**	10	**$10,000-$828,158**
Other	**$36,008**	8	**$765-$140,000**	**$32,500**	2	**$15,000-$50,000**
Foreign Governments	**$27,000**	2	**$5,000-$50,000**	**$17,000**	1	**$17,000**
State or Local Governments	**$25,000**	21	**$5,000-$2,600,000**	**$18,000**	3	**$16,000-$105,000**
Corporations	**$18,000**	17	**$4,000-$150,000**	**$8,250**	10	**$1,000-$160,000**

Source: OMB 3145-0136 EHR Generic Clearance: Survey of Principal Investigators, Survey Year 2003, Section "IGERT Additional Funding Source"

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Table A.8
Distribution of Additional Funding Amounts across Donor and Donation Types by Project

Donor Type	Median Dollar Amount (n) of Total Direct Donations from this source	Direct Donations Range	Estimated Median Dollar Value (n) of In-Kind Donations from this source	In-Kind Donations Range
National Science Foundation	**$938,745**	**$153,800- $1,404,923**	**-**	-
Federal agencies	**$770,631**	**$132,025- $3,048,162**	**$1,300**	**$300- $35,000**
Foundations and other non-profits	**$265,944**	**$80,000- $705,000**	**$517,473**	**$34,946- $1,000,000**
Federal laboratories	**$50,900**	**$1,800- $100,000**	**$35,000**	**$35,000**
Institutions	**$471,000**	**$69,430- $2,491,128**	**$218,724**	**$10,000- $1,122,384**
Other	**$157,016**	**$125,000- $165,765**	**$32,500**	**$15,000- $50,000**
Foreign governments	**$27,500**	**$5,000- $50,000**	**$17,000**	**$17,000**
State or local governments	**$249,937**	**$146,600- $2,863,932**	**$69,500**	**$16,000- $123,000**
Corporations	**$168,500**	**$102,000- $248,000**	**$51,193**	**$19,000- $163,500**

Source: OMB 3145-0136 EHR Generic Clearance: Survey of Principal Investigators, Survey Year 2003, Section "IGERT Additional Funding Source"

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Table A.9
Recruitment Strategies Used by IGERT Projects, Overall and by Cohort

	Percent of Projects					
Strategy	**All** (N=100)	**1998** (N=17)	**1999** (N=21)	**2000** (N=19)	**2001** (N=22)	**2002** (N=21)
Use faculty personal contacts to identify and attract prospective trainees	99%	100%	100%	100%	100%	95%
Offer competitive stipends and other support to prospective trainees	96	100	100	95	100	86
Distribute non-electronic media citing IGERT funds	94	100	90	100	95	86
Invite prospective trainees to campus	91	88	100	89	100	76
Promote NSF-IGERT at national meetings/graduate student fairs	86	94	95	95	95	52
✓ Ensure that entry requirements do not unnecessarily exclude prospective students	80	94	91	74	86	57
Place advertisements in scholarly journals or electronic media citing IGERT funds	73	76	86	74	86	43
✓ Recruit through minority science organizations	73	76	100	58	82	48
✓ Offer research experiences for undergraduates (REU) at IGERT institution	68	71	90	68	73	38
Informational visits to undergraduate institutions	49	53	76	37	50	29
✓ Recruit through national institutional initiatives (e.g., McNair, AMP)	43	65	76	26	41	10
✓ Informational visits to minority colleges	47	59	67	26	59	24
✓ Recruit through women's science organizations	41	53	57	32	41	24
✓ Recruit through initiatives that focus on minority enrollment in graduate programs (e.g., QEM, GEM)	41	35	62	37	55	14
Recruit through regional institutional initiatives	40	35	48	58	41	19
Recruit from summer programs around the country	30	41	48	26	27	10
✓ Undergraduate exchange programs with historically black colleges and universities	25	24	38	11	36	14
✓ Informational visits to women's colleges	18	18	29	11	18	14

Notes: Items marked with a check (✓) are particularly important in recruiting underrepresented groups.
Frequencies reported for those projects that had begun funding trainees.

Source: OMB 3145-0136 EHR Generic Clearance: Survey of Principal Investigators, Survey Year 2003, Section "Recruitment Strategies"

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Table A.10
Percent of Projects Citing Factor Among *Most Important* to IGERT's Admission Process

Admission Factors	ALL (N=86)	1998 (N=17)	1999 (N=21)	2000 (N=19)	2001 (N=22)	2002 (N=7)
Recommendations	72%	71%	67%	63%	86%	71%
Undergraduate GPA	50	71	43	47	45	43
Student's Goal Statement	44	35	48	42	50	43
Background and Experience	40	12	52	37	50	43
GRE Scores	29	47	24	26	27	14
Quality of Undergraduate School	12	12	14	16	5	14

Note: Column percentages do not sum to 100 percent because projects may use multiple factors.

Source: OMB 3145-0136 EHR Generic Clearance: Survey of Principal Investigators, Survey Year 2003, Section "Admissions Criteria"

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Table A.11
IGERT Assessment: Who Performed Assessment?

Person or group	ALL (N=86)	1998 (N=17)	1999 (N=21)	2000 (N=19]	2001 (N=22)	2002 (N=7)
Principal Investigator of IGERT project performed project assessment	60%	65%	52%	58%	73%	43%
An individual or group of IGERT participants (other than the PI) performed project assessment	51	65	52	58	46	14
An individual or group from outside of your university (e.g., an external evaluator, an Advisory Committee of peer scientists)	35	41	48	32	32	0
An individual or group within your university, but not in a department that is a part of the research focus of your IGERT project	21	0	29	26	23	29

Note: Figures reported only for *active* projects.

Source: OMB 3145-0136 EHR Generic Clearance: Survey of Principal Investigators, Survey Year 2003, Section "IGERT Assessment"

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Table A.12
IGERT Assessment Methods

Method of Project Assessment	ALL (N=86)	1998 (N=17)	1999 (N=21)	2000 (N=19)	2001 (N=22)	2002 (N=7)
Informal feedback from trainees and faculty to the PI or faculty serving on an assessment or management committee	87%	94%	100%	74%	86%	71%
Annual or more frequent surveys of trainees to learn about their concerns	73	76	76	79	73	43
Annual or more frequent meetings of project participants to discuss project management and problems in program implementation or function	59	65	67	58	59	29
Annual or more frequent meetings of project faculty members serving as an assessment committee	55	53	62	58	59	14
Annual or more frequent surveys of participating faculty members to learn about their concerns	35	35	43	32	41	0
Annual or more frequent site visits by an Advisory Committee or external evaluator that includes interviews of trainees and faculty and observations of classes, seminars, and laboratories	34	29	52	42	23	0

Source: OMB 3145-0136 EHR Generic Clearance: Survey of Principal Investigators, Survey Year 2003, Section "IGERT Assessment"

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APPENDIX B

IMPACTS ON STUDENTS

Appendix B

Table B.1
Educational Elements of IGERT Projects: 1998, 1999, and 2000 Cohorts

Thesis/Degree	Courses/Seminar	Lab/Research	Advisor/Mentors	Internships	Other Offerings
1998 Cohort					
Integrated thesis degree in project research focus	Core courses seminar	Lab rotations (2 to 4)	Dual advisors (experimental and computational)	Optional internships	Student lounge links to outside labs
"Discipline-plus"[a] some students earn Master's in non-home department	2 courses outside department bridge courses for non-specialists ethics lunches	Publishable interdisciplinary paper		Not available	Travel support
"Discipline-plus"	4 core courses student led seminar		Interdisciplinary committee	Required internships leading to thesis project	Shared office space
"Discipline-plus" in addition to their Ph.D., students must earn a minor in a different field	2 core courses weekly seminars	Year-long team interdisciplinary research project		Internships available; required	
"Discipline-plus" multidisciplinary dissertation prospectus and dissertation	3 semester proseminar (team taught) bridge courses for non-specialists weekly seminar series summer institute research ethics workshop	Faculty research apprenticeship (summer or term)		Optional	
"Discipline-plus"	A set number of required courses from a menu	3 lab course requirements	Within students' home departments	Industrial internship listed in proposal and 2002 Management Plan, but not implemented thus far.	
"Degree-plus" certificate available	4 core courses (one is ethics) plus two electives from designated research areas student-run weekly colloquia	Research experience one-on-one with faculty from another department	Dual advising	Required internship	Conference funding designated IGERT student offices
"Discipline-plus" certificate	Biomathematics seminar	Semester-long interdisciplinary lab experience		Not available	Professional training opportunities

Table B.1
Educational Elements of IGERT Projects: 1998, 1999, and 2000 Cohorts

Thesis/Degree	Courses/Seminar	Lab/Research	Advisor/Mentors	Internships	Other Offerings
"Discipline-plus" either through home department or pre-existing interdisciplinary graduate group	Transportation seminar	Submit research plan and carry out self-defined, transportation-related project		Optional Internships available	Variety of courses have been developed Travel funds
"Discipline-plus" certificate	Weekly seminar (industry input) team-taught advanced optical laboratory plus 2 other optics courses mini-courses	Lab rotation (one out of department)		Required industry internship – three months. Industry assesses on employable quintet.	
"Discipline-plus" certificate	2 core courses Weekly seminar (take for three semesters) 1 credit professional ethics	1 core lab course	One main advisor and one or more co-advisors from multiple departments	Required internships (usually summer) other industrial collaborations	Travel opportunities
"Discipline-plus" minor in project focus area	Bridge courses for non-specialists courses (flexible) 5-week summer retreat seminar annual symposium ethics workshops	Lab rotation as lead in to thesis interdisciplinary research requirement	Four member advisory committee, two from outside home department	Not available	Career skills class
"Discipline-plus" certificate available	3 courses (8 units) colloquium series	3 courses of directed research (first 2 with faculty from home department, last with students and faculty from three different disciplines)		Work closely with community agencies (supervised by faculty), but no internships per se.	
"Discipline-plus"	Weekly seminar series 4 courses in 3 of 4 core areas one day seminar in Jan		Co-advisors from at least two departments	Optional industrial internship	State-of-the-art User Facility

Table B.1
Educational Elements of IGERT Projects: 1998, 1999, and 2000 Cohorts

Thesis/Degree	Courses/Seminar	Lab/Research	Advisor/Mentors	Internships	Other Offerings
“Discipline-plus” certificate	Joint interdisciplinary courses one designed by students and one by faculty – each a quarter long 3 winter quarter seminars one cognate area course Annual 3-day off-site workshop five lecture ethics courses	One quarter of research outside major field (and preparation before)		Optional internships available	New “extremophile” lab
Dissertation must be interdisciplinary “discipline-plus”	One course each year (composed of a seminar and group project). spend 20 hrs per week on IGERT related activities and research	Conduct interdisciplinary research	Have an interdisciplinary graduate committee	Optional internships are available	Attend cross-disciplinary professional meetings
“Discipline-plus”	9 core courses, 4 include labs two-semester colloquium series	Project-based learning, multidisciplinary teams of students, faculty, industry researchers. shared lab space.		Not available (research takes place in the lab)	State-of-the-art equipment conference support
1999 Cohort					
“Discipline-plus”	Both required courses and seminar	4 lab rotations first year	Dual advisors informally. May become formal	Not particularly relevant	Travel funds
“Discipline-plus” students earn a certificate; separate Ph.D. is under review by university College Council	4 core courses ethics/professional development modules added to existing courses	Lack of physical space for all computing equipment	PI advises or co-advises about half the students (trainees + associates)	Industry or federal agency internship required	Travel funds laptop computer with simulation software given to all students
“Discipline-plus” Students earn degree through entering department	Weekly seminar series with guest speakers Students must take one interdisciplinary course, one course in ethics	Summer lab rotation- students work in teams to solve interdisciplinary problems		Limited participation in internships	Travel funds
Ph.D in Nanotechnology or related discipline	Introduction to nanotechnology, advanced weekly seminar, special mini-courses	Student assigned to mentor lab – rotates to other labs on limited basis	One or two advisors	No formal internships	End of year seminar

Table B.1
Educational Elements of IGERT Projects: 1998, 1999, and 2000 Cohorts

Thesis/Degree	Courses/Seminar	Lab/Research	Advisor/Mentors	Internships	Other Offerings
Degree awarded by university with "graduate major" in a department or an interdisciplinary program (IDP)	One core course in computational biology (choice) Workshops required Ethics Workshop and bioethics courses or course modules required	First year requirement: three "research exploration" rotations for Ph.D. students and two for Master's students. One "wet" lab and one computational lab required. State-of-the-art facilities, with university matching the NSF equipment funds.	Joint mentoring is required – one a biologist & one a mathematician, computer scientist or statistician. A Program of Study (POS) Committee is established to track progress.	Available, not required.	Stipends are supplemented by university, and summer stipends provided from COE funds. University provides computer hardware and software to students. Students access individual accounts of excess COE to support research and travel.
Discipline-based	Students take 15 different semester courses some of which are team-taught, plus an annual semester-long seminar, also invitational meetings	All students engage in lab-based research –some more clinical in nature than others (e.g., working with patients), all students spend time in multiple labs	Across departments and sometimes institutions	Not applicable	Conference support and regular rigorous critique of presentations by faculty and students Also, very intensive recruitment weekend – mentioned by several trainees
"Discipline-plus"	Weekly seminar taught by PI (students must take twice)	Work with primary advisor	Single advisor in Industrial Engineering department	Mandatory international internship Industrial internships available	Distinguished Lecturer Series
Traditional disciplines	Series of research writing courses developed for IGERT.	Primary component of this IGERT is multidisciplinary research teams.	Single department, but work with multiple faculty in research teams	In proposal, but now optional. Trainees receive experience working with industry through their research teams.	Conference travel $750 for books and supplies

Table B.1
Educational Elements of IGERT Projects: 1998, 1999, and 2000 Cohorts

Thesis/Degree	Courses/Seminar	Lab/Research	Advisor/Mentors	Internships	Other Offerings
"Discipline-plus" Students (from 11/02 on) will also receive a certificate.	2 one-semester lecture courses and related 2 one-semester lab courses. 1 course in Bioinformatics, one ethics course, attendance at seminar series.	3 10-week laboratory rotations in first year, in state-of-the-art facilities	Dual advisors from two different departments	None	Travel funds. Each student gets a laptop computer. Out of state research or training experience. Intensive summer 1 week workshops.
"Discipline-plus"	Mandatory seminar taken first fall of IGERT involvement, which introduces students to the faculty, methods, and languages of all IGERT departments. Course rotates through various IGERT faculty members' labs. Students must enroll in 12 credit hours of coursework from a specified list of courses, and must spread coursework out over three broad categories.	Different lab project most weeks of IGERT seminar. Research Credit Card: Provides students freedom to pursue interdisciplinary and sometimes exploratory research. Students are required to apply for the RCC at least once, and may receive up to two years of RCC support (up to $4,000 each year).	Dual advising: Typically, one advisor is in the student's home department and the second is from another department. If both advisors come from the same department, then the PhD committee must include at least one other IGERT faculty from an outside department.	None	Teaching Credit Card: Supports students' development of a biogeochemical instructional "module," either to introduce a new angle into a pre-existing class or to create a new opportunity on campus or in the community. Each TCC may be funded up to $1,800. Students are required to apply for the TCC at least once.
"Discipline-plus"; no certificate	Four courses, trainees must take at least 2; Monthly seminars; Periodic tutorials; Student-run seminars.	State-of-the-art facilities; Students work in at least home department lab and are encouraged to work in a lab in another discipline (CS if they're non-CS, other discipline if they're CS).	Encouraged to have dual advisors from 2 different disciplines (but not required)	Optional internships are available	Travel funds Retreats (twice per year)
Trainees earn degrees from existing departments.	Required to take 4 of 7 IGERT courses. Trainees also attend a weekly seminar.	Required to take 3 of 4 newly developed lab modules that introduce students to state-of-the-art research methods.	Two thesis advisors from different fields	Internship required	Trainees have access to a $5,000 individual account for equipment and supplies. Conference attendance (1/year)
"Discipline-plus"	Weekly seminar (team-taught); special topics course; ethics course.	2 lab rotations (1 outside main field) completed over graduate career	2 or more advisors from different departments	Optional	Provide $3000 in travel and supply funds for conferences, equipment, etc.

Table B.1
Educational Elements of IGERT Projects: 1998, 1999, and 2000 Cohorts

Thesis/Degree	Courses/Seminar	Lab/Research	Advisor/Mentors	Internships	Other Offerings
PhD from one of two participating IDPs An *interdisciplinary-plus* model	Weekly NET journal club (co-facilitated), 4 core courses in first year, ethics course in second year	Lab rotations encouraged and time spent in each advisor's lab State-of-the-art facilities Access to leading researchers and research centers	Dual advisor structure – one from BioMedical Engineering and one from Neuroscience	Optional, internships not required	$500 a year to trainees for educational expenses Summer Research Program for undergraduates
Discipline (w/ potential for "discipline-plus" certificate	Students take a core set of 4 courses together in a 4-semester sequence; annual workshop attended cross-institution, seminar at each university, ethics course	All students engage in field-based research (which eventually leads to a lab component, including comparative analysis/research using samples from other areas).	Across departments and sometimes institutions	There is an externship requirement written into the proposal, but so many of the students enter directly from work that the PIs seem to be rethinking this requirement.	
Interdisciplinary PhD in Microelectronics-Photonics w/emphasis in photonics, micro-electronics, or materials and processing	Required to take ethics, organizational management, in addition to required hours of science and engineering Students meet weekly in cohort groups and attend monthly IGERT seminars	Students have research groups they meet with regularly, however most students' research is individualized and most work independently Students have access to a variety of labs, including a cross-disciplinary research facility, HiDEC (high density electronic fabrication facility)	1 major advisor from "home" department (physics, chemistry, or any engineering) In addition, one of the microEP directors sits on each student's committee	Optional, not required-some students have found their own internships; Students are encouraged to do internships, but this has been difficult to enforce mainly due to economic downturn	Entrepreneurship class This project emphasizes applicability of the degree and "soft skills"
"Discipline-plus"	Trainees take three of four core courses and meet additional course requirements. Weekly brown bag	3 rotations required during first year. One rotation must be outside of home department. Rotations in industry or government labs are possible	Opportunities for advisors from multiple disciplines but not required	Optional	Funds for work in overseas labs are available. Only 3 of 43 trainees have availed themselves of the opportunity.

Table B.1
Educational Elements of IGERT Projects: 1998, 1999, and 2000 Cohorts

Thesis/Degree	Courses/Seminar	Lab/Research	Advisor/Mentors	Internships	Other Offerings
"Discipline-plus" Students earn a degree from department at their home institution. There is no official recognition of their participation in this program besides their transcript, cv, and thesis research.	Two summers—The first summer's "Cornerstone Experience" includes: 6 Fundamentals workshops (on the interdisciplinary research areas); 6 Data-Intensive workshops (hands-on research experience); and 3 Perspectives workshops (global climate change, international, and industrial perspectives on biospheric-atmospheric interactions).	The Data Intensive workshops are intended to introduce key lab and analytic techniques in connection with the research areas addressed in the fundamentals workshops. At the end of the first summer and for the majority of the time during the second summer, students are expected to conduct innovative field research at the biostation with support/advice from peers and from project faculty.	Each trainee is assigned one biospheric science faculty mentor and one atmospheric science faculty mentor in addition to the two coordinators (one biospheric, the other atmospheric) who help guide the trainee through designing and conducting the field research and later analysis. In addition, second-year trainees mentor the first-year trainees, and because students enter at different points in their graduate careers, those who are further along in their degree work also mentor those who are at an earlier stage.	Not a part of this program.	Funds are available for trainees to travel to attend conferences, and they are encouraged to attend a conference in whichever field (a or b) is not their department's field. For example, an atmospheric chemist would be encouraged to attend an ecology conference, and a geochemist might be encouraged to attend an atmospheric science conference. Also, a portion of the COE funds is used to support travel of the students' home institution advisors to the field station during the summer to facilitate their playing an active role in the IGERT portion of the trainees' research.
PhD in Biology	One core course, weekly journal clubs, ethics course	3 lab rotations required in first year – both institutions have state-of-the-art facilities	Dual advisor structure: one from evolutionary biology, one from developmental biology	Internships are not required	IGERT funds post-docs, whom trainees report are "quite significant", and the university sponsors a summer experience for undergraduates.
Students earn a departmental degree only	Ethics workshop	State-of-the-art facilities Connection with the Jefferson Lab FEL	N/A	N/A	Travel funds

Table B.1
Educational Elements of IGERT Projects: 1998, 1999, and 2000 Cohorts

Thesis/Degree	Courses/Seminar	Lab/Research	Advisor/Mentors	Internships	Other Offerings
"Discipline-plus;" students have option for graduate certificate.	3 required courses (team taught) Weekly brown bag seminars (covering ethics and other topics) Five seminars outside of home department each semester	3 lab "rotations" (abbreviated) in 3 years	Single advisor who is participating IGERT faculty member One committee member from another department	Required of all trainees in industry, state or federal agency, or higher education	Funds to support conference travel and presentations Expected to have mentored teaching experience Expected to mentor undergraduates in research
2000 Cohort					
Discipline-plus	Weekly IGERT seminar with guest speakers 3 core courses (new for IGERT) 2 additional courses outside student's major field	1 lab rotation (outside major field) (not enforced) Lab work integrated into core courses	Dual advisors (one from field outside major) during first two years (not enforced)	2 internships required (not enforced)	$3000 annually for travel, supplies, research
Discipline-plus	1-credit seminar each fall 3 other courses	2 collaborative workshops with other students		Required but not enforced	Travel and research funds
Discipline – plus additional coursework and a year-long training in a lab in another discipline.	All IGERT students must satisfy the CNBC program of study, consisting primarily of coursework and seminars.	One-year cross-over training in a lab different from the students home discipline	Advisors from home department plus practicum advisors from the cross-over discipline	Optional	Travel funds
Discipline-plus	Core Courses Problem Based Learning Tutorial Capstone Seminar in fifth semester	Lab Rotations (must take Molecular biology as either course or rotation, & one rotation outside home specialty)	Single advisor in home department (IGERT PI conducts annual review of each student)	Public Understanding of Science Internship (work with an organization that presents science to the public)	
Home department awards degrees	Summer ethics course 3 required core courses (team-taught)	2-6 weeks of lab work side-by-side with a faculty member	Students have a single advisor, but work with faculty from other disciplines through their research projects	Internships occur at the final stage of training, just before the student finishes his/her dissertation	Minigrants—students apply for them to fund a variety of research activities and travel.

Table B.1
Educational Elements of IGERT Projects: 1998, 1999, and 2000 Cohorts

Thesis/Degree	Courses/Seminar	Lab/Research	Advisor/Mentors	Internships	Other Offerings
Traditional PhD	Interdisciplinary Seminar in Nonlinear Science Weekly lectures by outside invited speakers Bi weekly grad student seminar organized by grad students Nonlinear Science Course – required 2-quarter sequence		Two advisors from different departments	Encouraged	
Discipline-plus; option to get HPC minor	Core course (offered every 2 years) Biweekly seminars at which students present their research	Core course includes both theory and HPC applications, which students do outside of class but submit	Dual advisors from 2 different departments, CEMBA participants	Not required	Funds for travel, research support (software, specialized equipment, laptops)
Discipline – plus additional coursework	Five day Orientation Program; Multidisciplinary Course Sequence (taught by Management faculty and outside speakers); “Bridge” courses for trainees and interns; Case Development in Technology and Innovation Management Innovation Realization Lab Discussion seminar during which teams meet to discuss project progress, challenges and objectives. Outside speakers are used for specific skills development such as patent searching and library database training.	Course for EPICS students to receive credit for collaborating with IRL students on commercialization feasibility analysis for EPICS team developed products.	Advisors from home department plus practicum advisors from school of Management	Optional some internships are available; required - Product Commercialization Practicum all students have to complete a practicum	Travel funds
Discipline-plus or IDP degree in Biophysics	Faculty-led and student-led seminars Intensive, non-credit 1-2 week workshops developed as needed for “concentrated investigation” Assessment and customized program of study	3 lab rotations in the 1st year Wide open access at UCB and at Lawrence Berkeley National Lab	1st year – mentored by graduate advisor; then, committee	Not required but internships, jobs, rotations at LBNL offer exposure to work in a national lab setting	Annual Biophysics Retreat IGERT = a passport to the campus and Lab

Table B.1
Educational Elements of IGERT Projects: 1998, 1999, and 2000 Cohorts

Thesis/Degree	Courses/Seminar	Lab/Research	Advisor/Mentors	Internships	Other Offerings
Discipline-plus Students earn letter of completion	IGERT seminar 3 core courses plus three minor courses	Have major advisor Get support from area advisor in choosing minor courses	Optional – typically in industry		Funds for travel and conferences
Degree in Biology with focus on CN	6 core courses (waived if pass exam w/o it) 3 elective courses Journal club 3 quarters 1st year	3 lab rotations Links to The Salk Institute and Neuroscience IDP	Co-advisors, but one will do if advisor has both computational and experimental methods	Optional	Two week Boot Camp before 1st year $1000 travel funds Exchange program in Germany
Discipline-plus	3 core courses including an engineering management course Special ethics course Speakers series	At the university and international conferences and/or research experiences	No co-advising of trainees Trainees are required to be mentors to undergraduates or high school teacher interns	Required unless industry experience	Travel funds Participation in outreach and mentoring activities Competitive grant program for trainees
Discipline-plus enhanced offerings from what is offered the respective departments	Two-year sequence. First semester consists of a lecture course, second semester a lab course and third and fourth semesters student seminars that focus on group projects.	As part of second semester.	Not specified	Short 2-4 week internships are available.	
Discipline-plus	Bi-weekly meetings, seminar course, one week short-course in the summer	Nothing systematic, but many students are trained on state-of-the-art equipment at Oak Ridge National Lab	The PIs advise most or all of the students in the program	Students are encouraged to participate in both industrial and national lab internship experiences	International student exchange and opportunities to visit other campuses associated with the program
Discipline-plus A certificate is planned for the future	3 core courses are cross-listed plus Communication, Creativity, and Teamwork (CCT) course for PhD students	Lab that has been refurbished with IGERT, University and industry support	Co-advisors from two departments	2 trainees placed at Sandia National Labs	REU students work in Lab Trainees receive a supplement of $7500 at PhD and $3750 at MS level
Dual PhD in Nanotechnology (option)	1-credit seminar meets weekly three of four quarters 1 core course 3 other courses (2 outside of major field)	1 laboratory rotation with someone other than primary advisor			Funds for travel, supplies and books
Home department confers degrees					

Table B.1
Educational Elements of IGERT Projects: 1998, 1999, and 2000 Cohorts

Thesis/Degree	Courses/Seminar	Lab/Research	Advisor/Mentors	Internships	Other Offerings
Discipline-plus Students earn a certificate in Scientific Computing	Four courses required to obtain Certificate Required IGERT seminar (student presentations)	No rotations – work within home laboratory group	Co-advisor in complementary field	Required - 12-week industrial internship at industrial research facility or national lab	Trainees must include a high-performance computing application in their thesis

[a] The term “discipline-plus” is used here and throughout this report to refer to IGERT projects where students earn a Ph.D. in their home department, experiencing IGERT as additional courses, laboratory research, and other opportunities and requirements. Students in some “discipline-plus” projects earn an additional certificate or minor.

Table B.2

Percent of Projects Offering Multidisciplinary/Interdisciplinary Training Activities

Training Activity	ALL (N=86)	1998 (N=17)	1999 (N=21)	2000 (N=19)	2001 (N=22)	2002 (N=7)
Funded trainees from a variety of disciplinary fields	100%	100%	100%	100%	100%	100%
Instruction provided by faculty from multiple disciplinary fields	99	100	100	100	100	86
Trainees participated in research projects with faculty from a variety of disciplinary fields	95	100	100	89	95	86
Required courses that drew on two or more disciplinary fields	93	94	95	95	91	86

Note: Figures reported only for *active* projects.

Source: OMB 3145-0136 EHR Generic Clearance: Survey of Principal Investigators, Survey Year 2003, Section "IGERT Multidisciplinary/Interdisciplinary Training"

Abt Table Production Date: February 2004 for IGERT 2004 Cross-Site Monitoring Annual Report

Table B.3

Percent of Projects Offering Preparation for Careers in Industry, Government, or Public Sector

Training Activity	ALL (N=86)	1998 (N=17)	1999 (N=21)	2000 (N=19)	2001 (N=22)	2002 (N=7)
Trainees participate in research projects involving multiple disciplines	93%	100%	100%	95%	86%	71%
Trainees participate in team research efforts	92	100	90	95	91	71
Trainees have experience in communicating across disciplines and/or with different audiences (including the general public)	90	100	91	95	86	57
Trainees have educational interactions (e.g., courses, workshops, seminars) with government/public sector or with industry professionals	74	71	81	68	86	43
Trainees participate in any application of research to industry or public policy	66	59	71	74	73	29
Trainees have internships (off-campus work experiences of one month or more) in government/public sector or in industry settings	62	65	67	68	64	14
Trainees have research interactions with government/public sector or with industry professionals (other than internships)	57	59	71	47	64	14

Note: Figures reported only for *active* projects.

Source: OMB 3145-0136 EHR Generic Clearance: Survey of Principal Investigators, Survey Year 2003, Section "IGERT Trainee Preparation for Careers in Industry, Government, or Public Section"

Abt Table Production Date: February 2004 for IGERT 2004 Cross-Site Monitoring Annual Report

Table B.4

Percent of Trainees Who Have Experienced Activities Aimed at Improving Communication Skills during Their Time as an IGERT Trainee

	ALL (N=1685)	1998 (N=498)	1999 (N=525)	2000 (N=352)	2001 (N=270)	2002 (N=40)
Presentations made at the IGERT institution	74%	74%	74%	76%	77%	43%
Professional conferences attended	65	72	66	66	53	33
Oral presentations outside the IGERT institution	47	53	48	44	39	35
Training/coursework in professional speaking/presentation skills	41	42	45	35	42	18
Poster sessions presentations outside the IGERT institution	39	37	48	39	29	23
Training/coursework in professional writing	33	35	36	24	39	13
Other activities to develop their ability to communicate professionally	25	29	26	23	23	5

Source: OMB 3145-0136 EHR Generic Clearance: Survey of Trainees, Survey Years 2000, 2001, 2002, 2003, Section "Ability to Communicate Professionally"

Abt Table Production Date: February 2004 for IGERT 2004 Cross-Site Monitoring Annual Report.

Table B.5

Percent of Trainees Who Have Experienced Activities Aimed at Developing Professional Skills Applicable to Careers in Industry, Government, or the Public Sector during Their Time as an IGERT Trainee

	ALL (N=1685)	1998 (N=498)	1999 (N=525)	2000 (N=352)	2001 (N=270)	2002 (N=40)
Participation in any research project involving multiple disciplines	74%	78%	74%	73%	71%	63%
Participation/experience in team research efforts	74	78	72	73	76	48
Training/experience in communications across disciplines and to different audiences	53	63	53	48	45	38
Educational interactions with industry professionals or with government or other public sector professionals	42	49	39	41	40	28
Participation in any interaction between academic research and industrial applications or between academic research and public policy development or application	36	47	33	33	30	23
Research interactions (other than internships) with industry professionals or with government or other public service professionals	32	41	30	31	24	18
Other activities to enhance your professional skills applicable to careers	6	9	5	6	4	0

Source: OMB 3145-0136 EHR Generic Clearance: Survey of Trainees, Survey Year 2003, Section "Professional Skills Applicable to Careers in Industry, Government, or Public Sector"

Abt Table Production Date: February 2004 for IGERT 2004 Cross-Site Monitoring Annual Report.

Table B.6

Percent of Projects Offering Trainee Preparation in Communication and Teamwork

Training Activity	ALL (N=86)	1998 (N=17)	1999 (N=21)	2000 (N=19)	2001 (N=22)	2002 (N=7)
Trainees receive experience in communication across disciplinary boundaries and with different audiences	97%	100%	95%	100%	91%	100%
Trainees attend and/or make presentations at professional conferences	97	100	100	100	100	57
Trainees participate as members of teams engaged in joint educational and/or research efforts	92	100	95	95	91	57
Trainees take coursework/training (e.g., brown bags, seminars) that include regular faculty critique and feedback in professional speaking/ presentation skills	92	88	100	100	82	86
Trainees publish research papers in refereed journals before receiving their doctorate	87	76	100	95	91	43
Trainees take coursework/training that includes regular faculty critique and feedback in professional writing	69	65	86	53	77	43

Note: Figures reported only for *active* projects.

Source: OMB 3145-0136 EHR Generic Clearance: Survey of Principal Investigators, Survey Year 2003, Section "IGERT Trainee Preparation in Communication and Teamwork"

Abt Table Production Date: February 2004 for IGERT 2004 Cross-Site Monitoring Annual Report.

Table B.7

Percent of Projects Offering Trainee Preparation to Conduct High-Quality Research

Training Activity	ALL (N=86)	1998 (N=17)	1999 (N=21)	2000 (N=19)	2001 (N=22)	2002 (N=7)
Trainees have coursework/training in research methods	88%	82%	90%	95%	91%	71%
Trainees have coursework/training in the ethical conduct of research	83	94	90	84	77	43
Trainees have coursework/training in state-of-the-art instrumentation	79	76	90	84	86	14
Trainees have coursework/training in statistics	64	65	71	68	59	43

Note: Figures reported only for *active* projects.

Source: OMB 3145-0136 EHR Generic Clearance: Survey of Principal Investigators, Survey Year 2003, Section "IGERT Trainee Preparation to Conduct High-Quality Research"

Abt Table Production Date: February 2004 for IGERT 2004 Cross-Site Monitoring Annual Report.

Table B.8

Percent of Trainees Who Have Experienced Activities Aimed at Improving Research Skills During Their Time as an IGERT Trainee

	ALL (N=1685)	1998 (N=498)	1999 (N=525)	2000 (N=352)	2001 (N=270)	2002 (N=40)
Participation in research projects within their own discipline area but outside their dissertation research	67%	75%	66%	63%	60%	53%
Training/coursework in research methods	58	61	59	54	57	40
Training/coursework in responsible conduct of research	55	60	57	47	56	40
Training/coursework in state-of-the-art instrumentation	51	47	58	49	47	45
Training/coursework in statistics	38	46	35	38	30	33
Other activities to develop or increase professional skills to conduct high-quality research	17	23	14	19	12	8

Source: OMB 3145-0136 EHR Generic Clearance: Survey of Trainees, Survey Years 2000, 2001, 2002, 2003, Section "Professional Skills to Conduct High-Quality Research"

Abt Table Production Date: February 2004 for IGERT 2004 Cross-Site Monitoring Annual Report.

Table B.9

Percent of Projects Offering Trainee Preparation for Faculty Positions

Training Activity	ALL (N=86)	1998 (N=17)	1999 (N=21)	2000 (N=19)	2001 (N=22)	2002 (N=7)
Trainees serve as teaching assistants	74%	71%	100%	74%	64%	43%
Trainees serve as official mentors to students (grad, undergrad, or high school)	59	41	81	68	64	0
Trainees receive instruction (e.g., courses, workshops) in effective teaching practices	50	59	71	32	50	14
Trainees develop course and/or curriculum materials	47	47	57	53	41	14
Trainees complete teaching exercises supervised by IGERT or other faculty	43	41	52	53	36	14
Trainees receive instruction in how to apply advanced technology in the classroom	41	41	38	42	55	0
Trainees serve as full instructors (i.e., unsupervised preparation, teaching, and grading for a course)	24	35	29	32	14	0
Trainees receive special instruction (e.g., courses, workshops) on how to advise and mentor students	21	12	24	26	27	0

Note: Figures reported only for *active* projects.

Source: OMB 3145-0136 EHR Generic Clearance: Survey of Principal Investigators, Survey Year 2003, Section "IGERT Trainee Preparation for Faculty Positions"

Abt Table Production Date: February 2004 for IGERT 2004 Cross-Site Monitoring Annual Report.

Table B.10

Percent of Trainees Who Have Experienced Activities Aimed at Developing Professional Skills in Education During Their Time as an IGERT Trainee

	ALL (N=1685)	1998 (N=498)	1999 (N=525)	2000 (N=352)	2001 (N=270)	2002 (N=40)
Mentoring of High School, Undergraduate, or Other Graduate Students	41%	43%	43%	41%	37%	25%
Teaching Assistantships	37	40	46	32	21	43
Participation in multidisciplinary educational effort	24	30	21	24	24	15
Participation in Any Group Education Efforts	21	23	21	21	21	5
Courses Developed and/or Major Teaching Roles	15	23	13	14	9	5
Other Activities to Develop or Increase Professional Skills in Education	14	19	11	15	13	0

Source: OMB 3145-0136 EHR Generic Clearance: Survey of Trainees, Survey Year 2003, Section "Professional Skills in Education"

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Table B.11

Percent of Trainees Who Report Benefits from Their Internship Experiences Activities (for those who completed the internship N=310)

	ALL (N=310)	1998 (N=132)	1999 (N=76)	2000 (N=55)	2001 (N=45)	2002 (N=2)
Experience communicating and working with people from different disciplinary or professional backgrounds	86%	90%	83%	84%	80%	100%
Experience with applied research	79	75	78	91	78	50
Experience with team approaches to problem solving	72	73	72	67	71	100
Increased awareness of non-academic job opportunities available to people with your education and interests	71	70	72	65	80	50
Likelihood of a job offer after graduation	43	42	45	49	31	100
Development of a thesis and/or dissertation research topic	40	40	30	51	42	50
Financial or equipment support to complete thesis research	29	27	22	40	33	50
Other benefits	18	23	9	22	11	50
No benefits resulted from internship(s)	14	16	18	13	4	0

Notes: Figures are reported only for those trainees who have conducted an internship of at least one month in length.

Source: OMB 3145-0136 EHR Generic Clearance: Survey of Trainees, Survey Year 2003, Section "Off-Campus Internships/Industrial Rotations"

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Table B.12

Percent of Projects Offering International Opportunities

Training Activity	ALL (N=86)	1998 (N=17)	1999 (N=21)	2000 (N=19)	2001 (N=22)	2002 (N=7)
Trainees attend international meetings/ conferences	76%	76%	86%	84%	73%	29%
Trainees work with foreign scientists/engineers (e.g., students, faculty, other researchers) inside the U.S. in university/research setting (public or private sector)	70	71	95	68	55	43
Trainees work with foreign scientists/engineers outside the U.S. (e.g., in a university/research setting (public or private sector) or doing field research)	58	59	67	79	45	14
Trainees work with private companies outside the U.S.	14	24	19	11	9	0

Note: Figures reported only for *active* projects.

Source: OMB 3145-0136 EHR Generic Clearance: Survey of Principal Investigators, Survey Year 2003, Section "IGERT International Opportunities"

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Table B.13

Percent of Trainees Who Have Experienced Activities Aimed at Broadening Their International Perspective during Their Time as an IGERT Trainee

	ALL (N=1685)	1998 (N=498)	1999 (N=525)	2000 (N=352)	2001 (N=270)	2002 (N=40)
Experience communicating and working with people of different cultures, nationalities, or backgrounds	85%	85%	86%	82%	83%	88%
Experience working with scientist(s) of other nationalities within the United States	74	74	73	76	70	73
Experience, outside of your studies, living and/or working in a foreign country	13	17	11	12	12	8
Internships or other experience working with scientist(s) of other nationalities, in their own countries	13	16	12	13	10	5
Other internationally oriented educational/professional activities	10	13	9	8	9	3

Source: OMB 3145-0136 EHR Generic Clearance: Survey of Trainees, Survey Year 2003, Section "International Perspective"

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Table B.14

Project Success in Fostering Trainee Growth as Reported by Principal Investigators (n=86)

Project Goals for Trainees	Successful	Somewhat Successful	Not Successful	Not Begun
IGERT Specific Goals				
Success in inter/multidisciplinary coursework	79%	16%	0%	5%
Ability to communicate across disciplines and with different audiences	77	15	0	8
Ability to function in an inter/multidisciplinary environment	74	20	1	6
Teamwork skills	73	17	0	9
Breadth and depth of knowledge	67	28	0	5
International perspective	29	42	2	27
Traditional Graduate Education				
Ability to conduct high-quality research	72	17	0	10
Ability to communicate professionally (e.g., presentations, articles)	70	21	0	9
Familiarity with state-of-the-art instrumentation/technology/modeling skills	69	26	0	6
Teaching and/or mentoring	42	37	1	20
Course development	30	26	1	43

Notes: Row percentages may not sum across to 100 percent due to rounding. Figures reported only for *active* projects.

Source: OMB 3145-0136 EHR Generic Clearance: Survey of Principal Investigators, Survey Year 2003, Section "Assessment of Trainee Quality and Project Success in Fostering Trainee Growth"

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APPENDIX C

IMPACTS ON FACULTY

Appendix C

Table C.1

IGERT Institutional Impacts: Impacts on Faculty

Type of Institutional Impact	ALL (N=86)	1998 (N=17)	1999 (N=21)	2000 (N=19)	2001 (N=22)	2002 (N=7)
Faculty are sharing mentorship of students (other than membership on dissertation committees) across discipline boundaries	79%	82%	71%	68%	86%	100%
Faculty are teaching new courses that cross traditional disciplinary boundaries	65	65	62	53	86	43
Faculty are participating on multidisciplinary dissertation committees more often	64	77	57	68	64	43
Faculty increased their participation in non-home-discipline meetings, conferences, etc.	57	65	57	53	64	29
Faculty are members of multidisciplinary teams winning new grant support more often	55	59	67	58	45	29
Faculty are team-teaching courses across disciplines more often	55	35	57	58	68	43
Faculty are jointly authoring papers across disciplines more often	55	71	52	53	50	43
Faculty are using new pedagogical approaches	27	24	29	32	27	4

Note: Figures reported only for *active* projects.

Source: OMB 3145-0136 EHR Generic Clearance: Survey of Principal Investigators, Survey Years 2000, 2001, 2002, 2003, Section "IGERT Institutional Impacts (Impacts on Faculty)"

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APPENDIX D

IMPACTS ON INSTITUTIONS

Appendix D

Table D.1

IGERT Institutional Impacts: New Course Offerings and Requirements

Type of Offerings	ALL (N=86)	1998 (N=17)	1999 (N=21)	2000 (N=19)	2001 (N=22)	2002 (N=7)
New seminar series, workshops, and/or conferences resulting from the IGERT project	64%	53%	62%	63%	82%	43%
Inter/multidisciplinary courses developed for the IGERT project	60	47	52	63	77	57
New course requirements, specifically for the IGERT PhD program	34	12	24	16	64	71
Other courses developed for the IGERT project (e.g., ethics, statistics, reinforcement in particular disciplines)	27	24	19	47	27	0
New, IGERT-inspired, multidisciplinary offering in university programs other than the IGERT program	14	6	19	11	14	29

Note: Figures reported only for *active* projects.

Source: OMB 3145-0136 EHR Generic Clearance: Survey of Principal Investigators, Survey Years 2000, 2001, 2002, 2003, Section "IGERT Institutional Impacts (New Offerings, Requirements)"

Abt Table Production Date: February 2004 for IGERT 2004 Cross-Site Monitoring Annual Report.

APPENDIX E

INSTITUTIONALIZATION

Appendix E

Table E.1

IGERT Institutional Impacts: Institutionalization

Type of Activities	ALL (N=86)	1998 (N=17)	1999 (N=21)	2000 (N=19)	2001 (N=22)	2002 (N=7)
Plans for continuation of IGERT initiatives, concepts, collaborations	69%	88%	86%	63%	55%	29%
Work with administration and/or funding sources	60	88	57	53	64	14
New procedures or activities that reduce barriers to multi/interdisciplinary training and research	43	29	48	47	50	29
New paradigms for integrating research and education at the graduate level	27	24	29	26	36	0
New paradigms for graduate student assessment or advancement to candidacy	13	12	10	26	9	0
Written plans for continuation	20	24	33	21	9	0
New entrance requirements	8	6	14	0	9	14

Note: Figures reported only for *active* projects.

Source: OMB 3145-0136 EHR Generic Clearance: Survey of Principal Investigators, Survey Years 2000, 2001, 2002, 2003, Section "IGERT Institutional Impacts (Institutionalization)"

Abt Table Production Date: February 2004 for IGERT 2004 Cross-Site Monitoring Annual Report.