Craft-Based IGERT Experiment in Graduate Macromolecular Studies

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The Teaching Craft for Macromolecular Creativity project at Louisiana State University is an experiment in graduate polymer education. With support from the National Science Foundation’s Division of Graduate Education, in the form of an IGERT grant, it has affected 36 Ph.D.-intending graduate students from 6 departments using an Apprentice-Artisan-Craftsperson training ladder adapted from the trade arts. After research-driven lecture and lab-based coursework in the synthesis, characterization, processing, and theory of macromolecules, recruits joined an interdisciplinary team including other students, faculty, and off-campus participants. Based on merit, students were elected as Apprentices, who worked side by side at the bench with professors and other on- or off-campus “research craftspersons” for 2–6 weeks. Upon completion of a written report and advancement to Ph.D. candidacy, Apprentices became Artisans. Among other privileges and responsibilities, Artisans were permitted to write minigrants to explore original ideas. Successful Artisans were declared Craftspersons and became eligible for up to six months of “predoc” at another site, often international. The core curriculum continued to evolve for an interdisciplinary clientele to emphasize team study and cohort teaching opportunities. Other features included training in ethics and group dynamics, community service, student self-government, leadership and formative/summative evaluation. Successes and shortcomings of this approach will be discussed in the dual contexts of creating a student-driven, self-sustaining program and exploring new models of graduate training.

Keywords integrative graduate training, macromolecular science and engineering, apprentice-artisan-craftsperson ladder, student leadership, minigrants, cohort teaching

1. Introduction to IGERT

Concern for American graduate education dates at least to the 1970s, but the launch in 1998 of the National Science Foundation’s Integrative Graduate Education Research...
Training (IGERT) program may be the most concerted effort across the spectrum of the sciences to “do something.” IGERT can be traced to certain perceived deficiencies in the status quo of traditional graduate education. While acknowledging the many successes of American graduate education, a 1995 report from the National Academy of Science’s Committee on Science, Engineering, and Public Policy (COSEPUP) found American Ph.D. graduates too closely tied to a single specialty, inexperienced as team players, in need of months if not years of on-the-job training (even for academic careers), insufficiently prepared for a global economy, wanting in communications skills, not well versed in applied science, confused about ethics, poorly skilled in business practices such as cost analysis and project management, sometimes lacking in interpersonal skills and sensitivity, and a poor representation of the ethnic, racial, and economic diversity that characterizes the US population. At the time of the COSEPUP report, the end of the Cold War and the resulting shift in emphasis of science caused concern for the adaptability of the science and technology workforce. Additionally, it was widely recognized that graduate school classroom activity did not accurately reflect real-world problem solving (a malaise that also besets undergraduate and K-12 education), nor was leadership training for the 10– or 15-year horizon always provided. In short, the holistic aspects of graduate education were missing.

No panacea exists for these problems, but the COSEPUP report made this recommendation:

“To foster versatility, government and other agents of financial assistance for graduate students should adjust their support mechanisms to include new education/training grants to institutions and departments.”

Against this backdrop, NSF created IGERT. The guidelines for 2008 read:

The Integrative Graduate Education and Research Traineeship (IGERT) program has been developed to meet the challenges of educating U.S. Ph.D. scientists and engineers who will pursue careers in research and education, with the interdisciplinary backgrounds, deep knowledge in chosen disciplines, and technical, professional, and personal skills to become, in their own careers, leaders and creative agents for change. 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 is also intended to facilitate diversity in student participation and preparation, and to contribute to a world-class, broadly inclusive, and globally engaged science and engineering workforce.

NSF gave principal investigators wide latitude to try creative approaches, but interdisciplinary and team-based research are two prominent themes running through the 195 IGERT sites funded so far. The guidelines also require a significant change in the flow of capital, discussed further below, and suggest an emphasis on the soft skills. Although IGERT is now more than ten years old, there remains justifiable concern whether students trained around these themes are placed at risk. Whatever its deficiencies, traditional graduate education—working on a tightly focused, usually single-discipline project guided by a principal advisor, with almost all of the emphasis on technical proficiency—sits atop an evolutionary process and must be accorded a certain amount of respect. Learning to learn and learning to solve are its main attributes, along with the character developed through that
process. The sound fundamentals associated with deep disciplinary training can prepare at least some percentage of Ph.D. scientists for sudden changes in the job market, shifts in national needs and new trends in science. Looking back to the volatile mid-1990s, the science Ph.D. who converted to another area, such as investment analysis or law, often remained a useful national asset. It can be argued that the traditional graduate education system, in training such adaptable persons, does its job most of the time. It is not a foregone conclusion that team-based, interdisciplinary study can match this versatility. Similarly, pushing the skills of interpersonal relationships, group dynamics, project management, team building and more into graduate school is not guaranteed to result in better performance than developing these abilities later in a career. These elements could distract the immature student from the benefits derived from a strong focus on independently solving a detailed scientific problem. The extra activities will almost certainly divert attention away from the advisor’s research agenda. Some educators embrace the idea of teaching these life skills in graduate school, but think the end user (usually industry) should pay for it. While the notion that what is good for academe is good for industry has surely died, it does not follow that the short-term interests of industry are always good for the nation, scientific advancement or even for industry itself if one takes a sufficiently long view. Despite these considerations, interdisciplinary and team-based activities remain central to most IGERT experiments, as do various soft skills.

The study of polymers and biopolymers provides a natural and comparatively “safe” stage on which to conduct interdisciplinary experiments in education. Polymers may be produced by organic chemists or by nature. Macromolecular characterization methods come from physics, chemistry and biology, while chemical, mechanical, or biological engineers are engaged in producing, processing, and isolating polymers. From drug delivery to polymer light-emitting diodes, bendable batteries, or lab-on-a-chip substrates, the invention of new polymer-based devices requires a mixture of experts well trained in their home disciplines and conversant in the language of others. In other words, polymer science is already a highly interdisciplinary endeavor. It is no wonder that a search of the IGERT National Recruitment Site (www.igert.org) returns at least ten programs related to polymer or macromolecular science. In the pantheon of approved IGERT projects, which may tempt such seemingly odd bedfellows as astrophysicists and biologists or chemists and journalists, polymer-based IGERTs pose comparatively small risks to their trainees. Graduates join an easily recognized group: polymer scientists.

The mechanism of IGERT matters. An old saying goes, “Don’t mess with people’s money or their kids.” IGERT does both. As a traineeship program, the flow of cash differs greatly from that associated with grants to single-investigators or focused research groups (Fig. 1). The cash flow also differs from that streaming through large centers, such as NIH Program Projects or Materials Research Science and Engineering Centers. Although NSF Traineeships are distinguished from NSF Fellowships by the extra emphasis on interdisciplinary activity and the aforementioned holistic aspects, the cash flow through the university resembles that of a fellowship program. The IGERT guidelines ensure that almost all funds go to the students. Beyond stipend support, about $10,500 direct costs per year per student is applied to activities that directly benefit trainees. The actual support beyond stipend will vary from institution to institution depending on tuition rates and the presence of a supportive administration (see below). At the core, stipend support means trainees are financially independent of their advisors while still reliant on them for intellectual support (a familiar reality in the arts and humanities for different reasons). Some universities take a slice out of the cost of education funds (or all of it at institutions with high tuition). Mechanisms to return any tuition and fees collected to the program vary. Standard indirect cost returned
to the university is capped at 8% for most expenditure, but an allocation can be made for a staff coordinator. Postdoc support is virtually nonexistent, as is faculty summer salary (disallowed when this IGERT was written; now capped at one month for the lead PI). Under typical circumstances, only about 3% of an IGERT award would go to faculty summer salary, including fringe benefits and indirect costs. Yet a typical IGERT involves 20 or more financially uncompensated faculty members in team-based research. Can a program divert the normal cash flow associated with academic research, give students substantial autonomy, fill their spare time with holistic training, and still find incentives for professors to participate?

2. The Polymer IGERT at LSU

This article describes observations from a macromolecule-based IGERT project at Louisiana State University, titled “Teaching Craft for Macromolecular Creativity.” Any area of macromolecular research was eligible, although several projects were designed by the initial faculty participants and set forth as examples in the original application for the two review panels (pre-proposal and invited full proposal). These sample projects were considered eligible immediately upon the recruitment of trainees interested in them; new projects had to follow the basic format outlined in the approved samples (a template was designed to simplify startups). Criteria included: qualifications of investigators; other resources available to those investigators; ability to identify and make good use of off-campus
resources; cross-disciplinary nature of the student and faculty team; and, likelihood that new
research would be catalyzed that was typically not possible outside of an interdisciplinary
team. The three co-PIs of the award—from Chemistry, Biological Sciences, and Chemical
Engineering—decided whether or not to launch new teams. Rejected groups were permitted
to reapply. Teams always included at least two experienced Ph.D.s with complementary tal-
ents and backgrounds (usually LSU faculty, but sometimes professors at other institutions
or senior staff members at national laboratories). There was often more than one student;
if this proved difficult for an otherwise worthy project, students were usually assigned a
“research buddy.”

Unlike many IGERT projects, there was not a highly specific technical theme (e.g.,
polymers for medicine or polymers at interfaces); rather, this IGERT can be considered an
experiment in rapid launch of new, small teams, including those pursuing curiosity-driven
research, with the only stipulation being that the research be macromolecule-related. Instead
of the usual “launch on a shoestring” approach, a new IGERT macromolecular project was
well supported in terms of students, resources, availability of national and international
labs, and internships. Implicit in an approach based merely on the size of molecules,
without regard for technical application or even requirement of a technical application, is
a certain diffuseness of impact. On the plus side, the plan featured inclusiveness and the
retention of a number of traditional NSF values: “small science” spirit; freedom to invent
and discover; and, close contact between faculty directors and students. It was hypothesized
that a community of macromolecular students could grow up around the IGERT, bound
by the relatively weak forces of a common curriculum in “large molecules” and shared
opportunities, rather than common technical objectives. It was further hypothesized that
this community would become self-sustaining after 5 years, especially in terms of traditions
and established policies.

The LSU Teaching Craft for Macromolecular Creativity program commenced in 2000
and will cease operations in July, 2008. No-cost extensions were granted on the original five-
year plan, which was found to be unrealistically short to effect lasting change and achieve
self-sustainability. The program has touched 36 graduate students in some way (Fig. 2).
Its last students should graduate in 2011. All IGERT sites are experiments, both in the lay
sense of the word (different things were tried) and as scientists speak (hypotheses were
tested, controls were applied). IGERT sites have provisions for internal evaluation, both
formative (changes in a feedback loop) and summative (outcomes for students, faculty and
university). Additionally, NSF surveys faculty and student participants on an annual basis.
Intermediate results are discussed at an annual workshop. The 2006-7 (tenth anniversary
report) is particularly informative 7.

3. Scope of this Report

A polymer scientist thinks of an instrument as a device (e.g., a rheometer) but to a social
scientist, an instrument can be a survey, a questionnaire, or an interview. Another difference
is the time span of measurements. Very long experiments are known in polymer science,
especially in rheology,8,9 but the discipline has developed workarounds in some cases. Sadly,
there is no equivalent to time-temperature superposition10 for the kind of social research
pertinent to IGERT. How nice it would be to have a time-emotional stress superposition
principle to predict the response of graduate trainees to extra effort in holistic training! In this
article, the reader will encounter informal descriptions of our experiment, plus preliminary
experimental data from instruments as social scientists understand them. New forms of
data, not welcome in the traditional physical sciences, include allegories and paraphrased
Figure 2. Apprentice-Artisan-Craftsperson ladder, with trainee benefits shown at left and number of trainees who achieved each rung shown at right. Some trainees remain in the program, and it is expected that 21 will complete all phases through Ph.D. Of those who departed, 6 switched to a traditional Ph.D. program.

quotations. The authors apologize at the outset that many questions cannot yet be answered; perhaps future results will appear as better data (and the last graduates) emerge. Meanwhile, it is hoped that a description of the program and certain observations will provoke thought and discussion, and that specific and general suggestions distilled from our program will aid in the design and evolution of further experiments in macromolecular education.

4. General Design of this IGERT Experiment

This IGERT falls into a category known as “discipline plus,” meaning that students have a home department and work towards a degree in a traditional major. As further evidence of the respect for traditional education, students had to meet all requirements of their home departments, in addition to any imposed by the IGERT program, either at
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the national level or locally. This IGERT’s specific, local requirements were a core curriculum of 3–4 polymer/biopolymer classes, a weekly seminar, summer training in ethics and other subjects, and service to the community. These elements were intended to be the glue that bound multidisciplinary research and disciplinary formal training within departments.

Aware of the risks to students, the principal investigators (PIs) based the project on a traditional model of education, the Apprentice-Artisan-Craftsperson ladder usually associated with trade arts, such as plumbing or carpentry. Students rose through four stages: recruit, apprentice, artisan, and craftsperson; see Fig. 2. IGERT relieves professors from having to fund students, at least temporarily. It was felt the best use of that time would be to spend it working side-by-side with apprentices. The U.S. Department of Labor defines Apprenticeship as “a combination of on-the-job training and related classroom instruction in which workers learn the practical and theoretical aspects of a highly skilled occupation.” It was hypothesized that four years of support (later reduced to two years) for a graduate student would entice even the most deskbound professor to return to the lab to teach research by direct example. The time commitment was flexible; it was suggested that each professor think realistically about how long it takes to find funding for a single student, then devote that much time in concentrated form to one-on-one training. Ideally, the project should satisfy some new curiosity of the professor. Spending every morning with a student for a period of ten days to try some new idea was envisioned. We wanted students to see research as a lifelong enjoyable pursuit, not a gateway to a future of writing proposals and e-mails (not to mention other tedious minutiae of academic life, such as all-important meetings of the Committee on Committees). We hoped that professors would be seen by the students as more than mere financiers of research. The side-by-side experience was to end with professors helping the students prepare a document similar in length and scope to a monthly report in industry. This document was to transfer technical writing skills from senior scientist to trainee at an early stage, before bad habits form. Ideally, the faculty member would start the document (to show how one starts writing a document, as students often languish over this step).

Artisan rank was granted to students who were declared by the Graduate School to be candidates for the Ph.D. (having passed a General Exam typically given in year 2 or 3) while keeping faithful to IGERT program requirements. At this stage, students were rewarded with an opportunity to write minigrants to exercise creativity and critical thought. One purpose of this was to relieve the tensions and constraints of performing research in a team environment. Another was to build confidence in the “ask and ye shall receive” system. In this IGERT, a minigrant originated by a single student could request up to $10,000, and several pushed right up to this limit.

Craftsperson status was reserved for impressive students in the last few months of their graduate career; students achieving this rank were encouraged to apply for an off-site “finishing school” experience in a prominent off-campus laboratory.

A number of other elements adorn the apprentice-artisan-craftsperson ladder model. For example, students were obliged to attend a science ethics course and perform a community service project. Additional embellishments were added as the program continued, most notably student governance and leadership training.

5. Preliminary Results, Discussion, and Suggestions

This section will cover structural and behavior issues first and then turn to observations arranged in the training ladder sequence through which IGERT trainees advanced, and
continue with some of the embellishments. Suggestions are offered for investigators, program managers directing or planning IGERT or similar programs, and university administrators.

5.1 Is This Really Anything New?

During the course of review and in describing the program to various audiences, the plan outlined above drew responses ranging from “revolutionary” to “so what?” The former was definitely not our intent; as stated, this experiment was intended to adopt the tried-and-true training ladder of the trade arts to a new Ph.D. training mission. The “so what?” crowd were about equally split between individuals who wanted little to do with IGERT because they did not see anything new in it besides extra demands on their students and investigators who at least recognized IGERT’s extra resources to accomplish what they were already trying to do with their graduate students. From the point of view of the project director, there were happy moments, as when a “doubting Thomas” professor announced, after one of the external panel reviews, that he finally “got it.” There were less happy moments when a professor was irate about poor communication—e.g., not being told about some required group activity or a student’s independent interests as expressed in a minigrant. Also, it is possible to create the impression in the students that they can be independent of their advisors and fail to transmit the importance of using (and crediting) those advisors appropriately. The admonition allegedly given to automotive pioneer Preston Tucker applies to education explorers as well: “You can’t have Falstaff and have him thin.”

5.1.1 Suggestion. 1) Integrate everything: The I in IGERT instructs us to merge activities whenever possible. Not only does this often work, it may be the only way to survive a program with such lofty intentions as IGERT (or any grant which requires “broader impacts”). The reason the doubting Thomas mentioned above came around to the point of view held by our IGERT site was because he was required (to the extent the word applies to faculty) to attend an external advisory panel meeting, at which the students and faculty alike were asked to explain the program (not just their own results, but also the core curriculum, seminar program, minigrants and so on) to outsiders. This simple example of scientific, managerial and cultural integration generally leaves a good impression.

5.2 The Professoriate Holds Strong Beliefs

The names of two original co-PIs do not appear atop this article. One departed for another university; this would not normally limit participation—IGERT favors science without borders—but associated with the move were additional administrative duties. Time and distance also made it difficult to recruit students (the more important because attracting students to IGERT resembles a Sadie Hawkins dance, with students often making the overture to professors to let them participate in the project). The other co-PI grew uncomfortable with the autonomy given to the students and the perceived burdens of the holistic training regimen relative to the skills, ambition, and intensity of the trainee. This experience was not unique, nor is it confined to this IGERT site. The IGERT PI should expect to hear some variant of “I have my own training scheme” from faculty participants.

5.2.1 Suggestions. Accept that not everyone belongs in the program; in particular, faculty who are highly possessive about students will be unhappy in IGERT. Such professors often
have a good system of training, but if not consistent with the objectives of the IGERT experiment, they may not be able to participate. 2) Eager faculty can be found within and without the university. 3) The IGERT experiment has to be explained again and again, especially as it evolves based on feedback from the internal evaluation panel and other IGERT projects... and even feedback from disgruntled professors. It is OK to evolve. 4) A program placing heavy demands on students requires truly great students. At any time, NSF supports about 30,000 graduate students; of these, perhaps 5–10% are IGERTians. It is imperative they be the top 5-10% of the local population in terms of desire, integrity, responsibility, and ambition. Working exclusively with energetic students ameliorates the lack of other incentives for faculty in the IGERT. Identifying such students is reserved for the Summary.

5.3 The Assistant Professor Problem

We experienced uneven results with assistant professors. Some saw the program as a way to attain new research skills, while others wondered why the holistic aspects of the project were taking the students away from their research. The former group produced some of our most successful students, which may be provisionally attributed to their ability to supply a meaningful apprenticeship experience, encourage internships, and support participation in the program despite its cost in terms of time. Concerning less enthusiastic assistant professors, it is tempting to think that reassurances from administration might have eased any fears they might have about establishing a unique career while participating in interdisciplinary, team-based research. It is probable, though, that these individuals were simply more inclined to follow a traditional educational program, without external interference. It is understandable that assistant professors might be more insecure about such apparent meddling. After long training as graduate student and postdoc, they are nearing their goal of having the human resources necessary to implement their unique ideas. Many enter the professoriate having known only a traditional style of research—with professor firmly in control. In addition, they must deal with the very real problem of gaining tenure. The “ideal” IGERT publication, a student-originated project with at least two collaborating faculty authors, is not typically considered the ideal type of publication in a tenure package.

5.3.1 Suggestions for PIs. 1) It is just as important to interview the professors as the students when forming an academic working group. 2) If the prospective faculty candidate seems especially worried about tenure, they probably do not belong in the program. 3) No amount of communication about the rigors and requirements of the program, either during the writing phase of the proposal or post-award period, is excessive. 4) The participants should understand that the experiment deserves a level of commitment, discipline, and integrity similar to one’s devotion to a traditional research grant. 5) To avoid unintended alienation of potential future contributors, attempt to explain the limitations of assistant professor participation in the program as a career advancement mechanism (because in many institutions such participation will be weakly rewarded). 6) Try to emphasize that a training program, despite the time demands placed on the trainees, alleviates the need to pay for students, and frees the students from time-consuming duties associated with a teaching assistantship. Letting a program such as IGERT do the heavy lifting of student training liberates cash for speedier postdocs, who can propel the assistant professor’s career. This bit of advice can be used to motivate senior faculty, too.

5.3.2 Suggestions for Institutions. Some institutions have adopted a “point system” which does credit participation in interdisciplinary efforts (e.g., 100 points for a student on an
individual research grant, 50 points for working with a student in an interdisciplinary project, etc.). The formula (or lack thereof) varies; assistant professors just need to know where they stand, and should not be pressured to participate.

5.3.3 Suggestion for NSF. A parallel faculty fellowship program for faculty incentives might be considered (e.g., holders of an IGERT grant could apply for supplemental funds to reward participation, especially for assistant professors who are ideal for skills training). Close scrutiny of the university’s plans to plow tuition and fees back into the program is also recommended.

5.4 The Underperforming Student Problem

Some students will blame low research productivity on IGERT. While it is true the program makes extra demands of students (all IGERTs do this) it equally provides opportunities for efficient conduct of science (in our case, no one who ever wanted to visit a national or international lab was turned down). A student who blames IGERT for low research output is making excuses.

5.4.1 Suggestions. 1) This type of behavior can be thwarted best by frequent communication between the faculty team members. As with their dissertation committee meetings, a requirement of IGERT students is periodic “project team meetings.” 2) As with parenting, the least permissive parent should win any disagreement. 3) This agreement should be established before the team is commissioned. 4) Consider manipulation of space to keep students accountable. One faculty participant was reluctant to rearrange desks to keep a better eye on a problem trainee, saying graduate students ought to have the self-discipline as adults to make such a cheap trick unnecessary. The other partner in that team felt it was OK to manipulate space—i.e., that discipline could be taught by enforcing good habits. The result, which cannot be laid quite at either professor’s doorstep, was that the student was unaccountable for too long and left the program. 5) Accept that even good “parents” eventually have a rogue “child”; a way to minimize the damage to the program is discussed in the Summary.

5.5 IGERT Creates Inequities

Even the best trainees may not be demonstrably better than other students, especially well-trained and strongly motivated internationals. Yet all IGERTians receive a handsome stipend and, depending on university policy, may receive extra benefits derived from Cost of Education funds. In some cases at LSU, these factors could result in up to a $15,000 annual salary difference between two benchmates at equal time points in their graduate careers.

In the first place, is the risk of such inequities warranted? One argument in favor of incentives for American students to pursue a Ph.D. in science, math, or engineering boils down to “seeing is believing,” meaning that prospective scientists need to visualize a technically-oriented peer group whose members look like them. In this view, the term “role model” does not imply that behavior will be modeled after someone now in the role; it just means prospective scientists making visual connections or similar realizations that people not so different from themselves choose science. Making this happen more often in the United States is a challenging problem. Americans are among the few citizens of the globe to believe that mathematical prowess is something to which one is born, rather than a skill to be acquired.12 Although other factors may enter into the low mathematical abilities
of American students, the relative absence of “normal” Americans in math creates the perception that we just are not born to it, except for the occasional geek. For such a belief to propagate to science in general could lead to a devastating reduction in support for American science, technology, engineering, and mathematics (STEM) education.

It seems reasonable to take steps to ensure a healthy representation of American faces in the STEM Ph.D. community, even if it means painting with a broad brush by requiring the small percentage students served by IGERT to hold citizenship or permanent resident status. Trouble may ensue when that broad brush swishes across individual research groups, though. Some faculty could not tolerate the inequity within their groups: Two professors asked their students be removed from the program, citing such inequity.

5.5.1 Suggestions. 1) To make the Americans-only nature of IGERT more digestible to faculty concerned about fairness to international students and/or harmony within their research laboratories, some strategies were adopted to make certain IGERT benefits available to all. For example, an international student can “tag along” with a traveling IGERTian, as long as the costs are distributed appropriately. Using other resources, we were able to include international students in certain IGERT activities; however, nothing can be done about the stipend. Only American students can receive it and the amount must be $30,000 (unusual among IGERTs, we were allowed to combine funds from other sources to reach $30,000, but this required special authorization). 2) After the traditions and bylaws of student governance have been established by the IGERTians, they can be asked to make the operations available to all, including internationals. We spent one full year preparing for this transition. As some American students will be coming off the $30,000 annual stipend and others not yet receiving it, a sufficient number can be found who have the moral authority to ask sacrifices from the international students to help establish a broad-based, permanent program. 3) To add incentive, we were fortunate to be able to develop a small parallel program, sanctioned by the Louisiana government, based on industrial work and student entrepreneurship (and intrapreneurship, defined as marketing products or services within the university). All students, domestic and international, are participating in this program.

5.6 Recruits

Many pages could be devoted to recruitment and student selection. The limited objective of this paragraph is to describe the life of the LSU CMC-IGERT “wannabe.” First, who were they? Some came to LSU explicitly for the program, others expressed interest in their first semester, and still others were encouraged to join by faculty. Most were first-year graduate students. In addition to courses required by their home departments, they enrolled in a required team-taught, two-semester series with integrated lab and lecture. These courses were titled Macromolecular Studies I and II (MS-I and MS-II). Usually at the end of the first semester, students who expressed interest in and potential for the program (as evidenced by coursework performance and efforts to join the groups of IGERT-compatible faculty) were considered recruits. Beginning in their second semester of residence, recruits were obliged to attend the Macromolecular Studies seminar program if they were not already doing so, take the second core course, MS-II, and continue to meet all requirements of their home department. Recruits and their principal Ph.D. advisors began to form teams involving other highly experienced Ph.D. advisors (faculty member in the same or a different department, national lab staff member, or a research coach at another university). Trainees with two
On-campus advisors were still encouraged to find an off-campus co-advisor, thus integrating career networking, research breadth, and even recruiting (some off-campus advisors were from schools known to produce strong students, some were from industry). The end of the recruitment phase, and for successful candidates the beginning of apprenticeship, was marked by completion of two forms specifying the nature of the project and available faculty-supplied resources and commitments to the program. The only major problem encountered with this stage of the project was that some teams had a hard time expressing the nature of their plan. Even so, the recruiting stage is an area which we would drastically alter; as will be apparent from the Summary, a better alternative can be found right in the graduate programs offered by most universities.

5.7 Apprenticeship

This part of the plan was sometimes spectacular, sometimes troublesome. On one hand, an intense period of close contact working on a project—just watching how the professor attacks it, rebounds from errors, and does not accept impediments—did seem to help some students who were afraid of research. On the other hand, proper side-by-side apprenticeships could not be executed by some faculty members. The same professors who could find time to work with somebody else’s students during a six-month sabbatical were unable to find six unfettered days (or twelve unfettered half-days) working on-site with their own students, even though most would agree that it is not certain to fund a student for two years through traditional grants after only six days’ worth of proposal writing. Some of the apprenticeships judged to be most effective were conducted off-site. Visits to national and international labs were particularly successful.

Other faculty forgot the details of the commitment they made by joining the program. Although not all IGERT sites have an apprenticeship experience, all require extra efforts from the faculty participants (beyond the PIs). As noted by others,15 few professors object to their students’ participation in career-advancing programs such as IGERT, but most managed to launch their careers without such advantage and reckon experience may be an adequate teacher, if not the best one.

Compounding literal lapses of memory, IGERT’s concentration of benefits on students creates an “incentive gap” for faculty participants. Faculty wanted to do the planned side-by-side experience with their IGERT apprentices, but given the declining success rates of proposals over the active period of our IGERT experiment, it is not surprising that truly effective apprenticeships with faculty were sometimes sacrificed for proposal writing or other activities. It is suspected, though, that the problem transcends the current difficulties in science funding and goes directly to the very nature of incentive. IGERT is not able to change human nature. There is a certain irony here. While the COSEPUP report expressed concern that young Ph.D.s in industry do not understand profit motive, it is pretty clear that university professors, including young ones, do: A typical $1M NIH grant brings in almost twice as much indirect cost to the university as a $3.3M IGERT award, not to mention summer salary for the PI. Professors who win the former awards are recognized and rewarded for them. By contrast, an IGERT site resembles somewhat a Soviet collective, complete with high ideals, five-year plan, fearless leader (PI), well-paid apparatchiks (trainees), and underpaid (during summer anyway) professorial proletariat. These problems are common to some if not all IGERTs. Although apparently no other declares specific ranks, such as apprentice or artisan, all must somehow grapple with the essential feature of the program, to wit: Students own the traineeships, faculty are liberated temporarily from grant-writing and should spend the extra time with students.
Most trainees did get a side-by-side experience with senior Ph.D. craftpersons, defined here as five or more years past graduate school, through work at the national laboratories or with LSU’s own scientific staff (which was effectively boosted by one FTE devoted to macromolecular studies in answer to the growth of the program). Whenever a student did not get an effective apprenticeship experience at all, we have the opportunity for an internal control experiment (e.g., IGERT benefits but without effective apprenticeship). Comparing these students to those who did receive a proper apprenticeship is how we suspect that good side-by-side experiences benefit students. This may seem obvious, but in discussions with various professionals over the years we learned that it is not. Some thought placing students in contact with professors could diminish their opportunities to figure out for themselves how to do research.

During their time as apprentices, students were able to write “microgrants” by filling out a simple, one-paragraph web form, requesting up to $1,000 in direct costs. This feature was not originally proposed, but added as a recruitment incentive. Most microgrants supported travel to meetings. Over 60 microgrants were awarded to 16 different trainees, at a direct cost exceeding $60,000.

The last act during apprenticeship was for student and professor to co-write a report on the activities. Early in the program, this acquired the name “minithesis,” signifying a practice run for the Ph.D. dissertation to come. Thus, the minithesis had the look of the real thing—requisite thanks to the advisor, dedication to loved ones, list of figures and acronyms, scientific background, results, references, etc.—but lacked the deep scholarship expected of a fully fledged Ph.D. scholar. The minithesis was judged to be an effective way to intervene early to shape the student’s writing style towards the norms desired by the supervising faculty member. As the projects were usually small and curiosity-driven, few minitheses developed directly into research articles, but some led to enhanced industrial interaction or proposals. An idea better than the minithesis will be presented in the Summary.

5.7.1 General Suggestions. 1) Getting away from campus seems to be helpful for effective apprenticeship. 2) No amount of communication with faculty participants about the nature of the program could be considered excessive. 3) Early intervention catalyzes the development of technical writing skills.

5.7.2 Suggestion for Agencies. 1) A program similar in spirit to IGERT is operated through National Institutes of Health and the Howard Hughes Medical Institute (HHMI-NIBIB Interfaces Initiative for Interdisciplinary Graduate Research Training). In that program, universities compete for a smaller award and then proceed to the main objectives after a stage of intensive faculty planning. While a faculty participant might have a casual attitude towards contributing a section to an IGERT proposal with less than ten percent chance of success, winning funding for the planning grant stage seems likely to produce a more intensive effort and deeper participation. This start-slow approach seems like a valid idea; indeed, the latest IGERT guidelines have a provision to support the extra faculty effort in the early stages, but it is still limited in scope. 2) Agencies might consider how to set aside provisions to ensure faculty incentives; for example, a faculty fellowship program running parallel to IGERT could be established to speed the development of IGERT apprentices (as already mentioned above). 3) In an age of accountability, NSF should try to ensure that some tuition and fees collected work their way back to supporting the program directly. Matching is no longer allowed on IGERT proposals, but institutions should nevertheless be required to demonstrate a strong level of commitment; for example, university administrators might be required to serve as co-investigators.
5.7.3 Suggestions for Universities. Adapting the existing mechanisms of a university may often be better than changing them. For example, it would be easy enough for most universities to offer a team-taught summer or intersession course with a title such as “Learning Research with the Pros.” This class would be team-taught by participating faculty, thereby funneling some of the IGERT tuition back into the side-by-side experience in a conventional way. To make it possible to include (and reward financially) more faculty, separate sections could be offered (e.g., one for engineers and one for chemists). Scheduled at the same time, these classes would meet separately on some days to cover disciplinary aspects of the research but meet together on others to discuss shared or interdisciplinary aspects, with one faculty member leading the discussion and the others serving as counterpoint. We call such concurrent scheduling “group swim,” and in standard lecture courses it has proven to be an effective way to work around the financial accountability issues of separate colleges and departments while integrating the content in a transparent way for the students.

5.8 The Artisan

The “gateway” in most universities is the Ph.D. candidacy exam, as administered by the Graduate School and home department. Students who successfully completed this exam were elevated to Artisan status. In the trade arts, someone at this stage is sometimes called a “journeyman,” indicating a student who tries various jobs. Too many journeys could delay completion of the degree, and that is one reason we did not choose the word journeyman for our intermediate rank; nevertheless, the artisan rank was intended to let students take some journeys, literal and figurative, to exercise creativity while building confidence in the notion of writing for funds, learning to critique their own work, plan projects, and contemplate budget constraints. The main vehicle for this was minigrants of up to $10,000 for any legitimate purpose. The minigrant program is one of this IGERT’s most treasured assets and will be described further below.

5.9 The Craftsperson

As indicated above, craftsperson status was awarded to students who, about six months before their planned dissertation defense, had undergone a rigorous data defense and impressed a faculty panel. Such persons were eligible to apply for “finishing school.” The idea originally sold in our IGERT proposal was a paid excursion to a prestigious laboratory to be taken after the data defense but before the dissertation defense, or after the dissertation defense but before formal graduation. By the time we had any students eligible for it, this kind of experience was called “predoc” by other IGERTs, but “pre-sabbatical” also applied in our case (except for the implication that it should take seven years to achieve the necessary status). Of the 14 IGERT trainees who completed their Ph.D.s while the program retained sufficient funds to support the predoc option, only three applied for this specific opportunity; however, the large minigrant cap allowed many others to take long internships as artisans. From practical training and financial points of view, such internships and the predoc option blurred into each other. One predoc used the time for writing while visiting a foreign lab. Another student won the right for a stay of several months in a prestigious lab, but after visiting the host at a minigrant-supported international conference, was offered a prestigious postdoc there instead. A third student used the mechanism instead to train at, and learn the ins and outs of, a government-based applied pharmaceutical research organization in a developing nation. This was in preparation for establishing a not-for-profit AIDS applied research program. The “finishing school” aspect of the program, although infrequently
used, may serve students by its very presence. If one thinks back to the last, hectic days of graduate school, just the possibility to chart one’s future in some other setting might relieve some stress. No problems were observed with this phase of the program; the probable lessons are that well-vetted students pose few risks, and other aspects of the program prepare students sufficiently well that the predoc experience is not badly needed.

5.10 Minigrants

Turning now to the embellishments on the AAC ladder, the two most important were minigrants and leadership training through student governance. The minigrants program was first implemented as a simple website requesting a one-paragraph description of the proposed activity, the amount requested and dates. This was OK for amounts less than $1,000, but it became apparent that larger requests should be accompanied by more detailed development from the student. Our advisory panel pointed out that a significant opportunity for writing, critical thought, and integrated internal evaluation was being missed by not asking the students to write anonymous peer reviews. This review mechanism was quickly implemented, and soon became the primary review process for minigrants. Proposal guidelines and forms were set up, borrowing heavily from the American Chemical Society’s Petroleum Research Fund (Type G, but with a 2000-word limit). Many young faculty in the macromolecular area begin the proposal-writing stage of life with this agency, so it was an appropriate choice. Merit criteria were altered appropriately for this IGERT (e.g., emphasis on professional development, curiosity-driven research, integration with the training effort for other students). Projects to enhance teamwork or individual efforts to combat team fatigue were equally welcome. Proposals were submitted to the student leadership (see next section) which selected anonymous reviewers and evolved its own set of guidelines. Reviews came back through the student government to the faculty co-PIs, who stripped them of remarks that might lead the student investigator to the identity of the reviewers. The co-PIs would have stricken any unprofessional remarks, too, had any been made. The faculty also prepared a “panel summary” to help the student investigator understand the reviewer’s comments and/or add any comments from the faculty perspective. The co-PIs then decided whether to fund the proposal in full or part. Student government also provided information on the applicant’s participation in the program before a funding recommendation was formalized. A student who was not fully participating (in program seminars, team meetings, meeting their apprentice-to-artisan-to-craftsman milestones, etc.) could not access their minigrant funds until the situation was rectified. This practice will be familiar to any faculty member who has endured a delay in receipt of NSF funding caused by a tardy report. Altogether, 38 minigrants were funded for a total of almost $230,000.

In the early phases of the project, the interdepartmental nature of the award caused some consternation because the home department (Chemistry in this case) had to manage benefits for students in other academic units. Enthusiasm for this was not universal among the several chairpersons who served Chemistry while this IGERT was active. To paraphrase one: On this travel authorization you want me to sign, how would I know if Joe Student in another department should attend a meeting in South America? I don’t know Joe, and I don’t even know his major professor. A traditional university structure, in which much research authority and financial responsibility is ensconced with departments, does not necessarily serve the interdisciplinary age well. Although the staff in various units eventually came to work together smoothly, it is easy to imagine organizational structures that might serve
interdisciplinary research better than departments and colleges separately empowered to control research resources.

A pervasive theme of the IGERT experience is that twiddling the controls of graduate education sometimes produces surprises, and so it was with minigrants. Any faculty member who looked at the proposals authored by the students would wonder what happened to the students’ writing. Almost without exception, the writing went far beyond what the same students seemed capable of when authoring, say, a monthly report. It made us believers in the transforming power of peer pressure; apparently, students who are quite inured to having professors bleed red ink all over their papers are less comfortable with their friends anonymously doing the same.

5.11 Student Government

The desirability of a student governing structure quickly became apparent; it was motivated by the need to establish lasting traditions and program identity, despite the relatively short duration of the program. A few cynics notwithstanding, most students responded positively to having such a leadership opportunity integrated into their graduate education. Like the apprentice-artisan-craftsperson ladder itself, there is nothing revolutionary here. We are merely adapting a system used in other settings to the culture of graduate education. Specifically, we tried to implement a kinder, gentler and looser version of the cadet system adopted by the military academies, military schools, and even the Reserve Officer Training Corps. The student governance structure recognizes no such thing as rank, but leadership, leadership training, and succession are firmly established in the organization’s bylaws. On an annual basis, the faculty meets to nominate students who seem to have the right qualities to serve as President of the Macromolecular Studies Group Student Association (MSGSA, which the students themselves incorporated as a registered student organization, complete with separate Tax ID number and bank account). Nominees are asked to choose a running mate, who will serve as vice president. Nominees will normally be familiar with the MSGSA’s standing committees (See Table 1) and will be informed of new directions and opportunities charged to the MSGSA for the upcoming academic year. After presentations during a special session of the weekly seminar meeting, student members are allowed to vote. The winning ticket selects chairpersons for standing and ad hoc committees, and every student—from recruit to craftsperson—serves on at least one committee as a condition of eligibility for micro- or minigrants. This system is more democratic than a military school, where a regimental commander is appointed, but in either system the selection criteria for the leadership role includes “holds the respect of peers” and “leads by example.”

The membership of the MSGSA is 20–30 students. The overseeing faculty organization, the LSU Macromolecular Studies Group, numbers about 20 professors. A lateral communications system is appropriate in such an organization; there is no strict “chain of command.” Even so, other important cues are taken from the military school organizational system, where the cadet regimental commander and selected others receive extra coaching. The MSGSA President and Vice President are the first to be invited to special functions, such as lunch with a visiting speaker. Separately, the leaders arrange for the students to meet the visitor without faculty present, and provide advance literature about the visitor’s research. Faculty attempt to help the student leaders delegate duties and figure out how to deal with unresponsive members. Special care is taken to ensure the leaders are including new students in the activities. This is especially important when the group is undertaking a new direction; not only do beginning students have greater staying power to see initiatives
through to completion, the new activity registers as part of their sense of tradition. The MSGSA leader is charged with conducting three meetings each month. The first is a meeting of each committee; occasionally, the MSGSA leadership and/or faculty will sit in on a portion of committee meetings, keeping a low profile. The second meeting is convened with the committee chairpersons and the MSGSA leadership; a faculty representative might be asked to attend. Finally, the MSGSA leadership meets with the faculty leadership to report progress. About once a year, some sort of special event is held. Once, the students elected to organize presentations by professional development/teamwork experts at a nearby beach hotel. Another year, the students helped schedule visits to campus in association with a nearby national meeting, leading to international training opportunities. It is too soon to say whether a student governance system produces effective leaders, but with certainty it can be said that students are developing skills often needed later in life. In practice, the system is virtually noninvasive, as the governing meetings are integrated with the normal weekly seminar.

6. Summary

If traditional graduate education represents the best result of an evolutionary process, an IGERT site can be considered a series of small mutations. Which of these survives is not yet certain, but there is no question that some mutations can be lethal to the Ph.D. candidacy of some students. Some trainees—often those who were either academically weak or defocused—did not fare well in our program. The number who abandoned graduate school as a result was small. Although it is uncertain whether they would have fared better in a traditional program, we suspect they might have. Again, this reinforces the notion that experimentation is best reserved for very ambitious and well-trained students. For great students, the writers remain profoundly enthusiastic about creating perturbations and about the IGERT program in general. Nevertheless, it is our duty to remain skeptical about tinkering with the system. It is too soon to tell which practices will provide a competitive advantage for graduate students generally. In addition to program-wide evaluations, NSF has authorized a competition for an IGERT Resource Center to help establish the overall outcomes. Meanwhile, based on the above experiences, we feel comfortable providing a few impressions.

*Integrating one activity with another is a faculty-time-efficient way to educate students technically and train them for a long, varied career.*

Integration is a big part of the answer to the question posed at the end of the Introduction. Opportunities abound; for example, when every seminar visitor is given a short survey to complete about the program, one both disseminates the nature and progress of the program.

### Table 1

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<th>Standing Committees of the Macro-molecular Studies Group Student Association</th>
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<td>Executive Committee</td>
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and fulfills part of the self-evaluation requirement. The same seminar speaker might send some data from his or her talk which soon becomes an in-class discussion or a problem set example in the core curriculum. This has the effect of keeping the curriculum up-to-date and more interesting to the students. If those seminar speakers are chosen from schools or industries of like interests, recruiting or placement objectives, respectively, are achieved.

Integration and interdisciplinary activity does not need to be centered on the research.

NSF’s main mission is to support research, but there are some dangers associated with using research—especially targeted research—as the centerpiece of an interdisciplinary effort. Our experience is consistent with the notion that students can work together in teams on activities such as outreach, curriculum, governance, and so on without sharing a research mission or even a highly specific theme. These activities are sustainable through tradition development for the program as a whole, while the ever-changing research landscape makes that more difficult. One of the major objectives of interdisciplinary activity—respect born of common activity—can best be accomplished when the students involved are not very closely bound by specific research interests. Central to this is the role of curiosity. While discussing interdisciplinary education, an accomplished senior colleague opined that he did not know what made it work, but in his travels across the globe, it seemed the most successful programs were found where the faculty and students remained curious—the kind of people who would put down their research to hear a great talk in another field, for example. By contrast, one of us just returned from a prestigious research institute where the focus on targeted research caused students to feel it would be a poor use of time to walk to an adjacent building to hear a lecture by a Nobel laureate in their same field. One must always be on the lookout for cats that kill curiosity. Centering the group on program development, outreach, and education (which is necessarily thematic but not highly specific), while imposing as little structure as possible on research direction, provides flexibility to encourage curiosity, creativity, and discovery. A program such as IGERT should be amenable to these traditional NSF core values. In discussions of this point, we have heard it argued that discoveries include better solutions to a targeted problem for the whole group, but this seems too narrow a definition for NSF. As almost the last agency to support pure, fundamental science, it is felt that NSF should cozy up to mission-defined science with great care.

Side-by-side apprenticeship can work for students, but like other activities, it would benefit from strong faculty incentives.

Such incentives can be integrated (what else?) into the mainstream of university activity; in particular, a team-taught “Learning Research with the Pros” class taught by paid faculty during intersessions or summer could launch students in the right direction.

Student governance enormously helps the program.

Most of our student leaders would report that they made some mistakes learning “on the job,” but the point is: they were not on a real job yet; instead, with faculty and peer inputs they were shaping the traditions of an educational social network and helping it attract and serve engaged students in the future. In the proposal guidelines to integrative, interdisciplinary programs of the future, we hope to see a required section for student governance as part of the overall project management description. Good examples exist, and we are so satisfied with the “softened” cadet program adapted from the military tradition that we hope to use more of it, especially cohort teaching. Many IGERTs adopt a cohort teaching model—students teaching students under faculty supervision—without realizing
its full potential or long tradition elsewhere. The Air Force Academy claims almost all
glider pilot training is handled by the cadets themselves; if cohort teaching works in a
life-and-death situation, it ought to be possible for students to train peers to run a gel
permeation chromatograph. This should not liberate faculty from side-by-side research
experiences with students, though, and faculty must assume responsibility for the training
guides and standards.\textsuperscript{16}

\textit{The most important “changes” may simply require development of underutilized university
assets.}

In particular, Ph.D. training has too often neglected the value of the MS thesis. In 1995, the
COSEPUP authors wrote:

“At the beginning of the research phase, departmental advisers should help
students to choose among three distinct options: first, to stop with a master’s
degree, in light of their aspirations and projected employment demand; second,
to proceed toward a PhD and a position in research; or third, for a student
interested in working in nontraditional fields, to design a dissertation that meets
high standards for originality but requires less time than would preparation for
a career in academic research. We believe that the first option is typically
undervalued and the third option often neglected.”

Despite the availability of this commentary, and the emergence of other programs to
promote MS degrees,\textsuperscript{17} we did not appreciate the utility and importance of the MS degree
until faced with some difficult realities. For example, the mandated stipend was raised from
$15,000/year to $30,000/year in the middle of our program. The extra largesse made it
more important than ever to award IGERT stipends only to students selected on the basis
of demonstrated aptitude. At this point, it occurred to some of us that the “minithesis”
ought to be a Master’s thesis and that stipend support should only follow its successful
defense. Not only would students wanting to enter the IGERT have to write and defend a
thesis, proving their bona fides, they would have about two years to understand the program
and its objectives, learn its traditions as recruits and apprentices, and begin thinking about
improvements to the program. Faculty would have a better opportunity to assess the potential
trainee’s abilities and aptitudes. The program is placed at less risk by supporting only tried-
and-true students, but trainees are also protected: a student who suffers a debilitating illness
in, say, year 3 will at least have received a degree to help reenter the science workforce
when health permits. The importance of the MS degree transcends IGERT. The written
general exam, which has often been used as the gateway to Ph.D. at least since the 1960s, is
an inferior substitute to the MS degree. Such a document might yet be required to advance
to Ph.D., but: a) it would be a breeze for students to write after having completed an MS
degree; and, b) implicit in the general exam, but too often lost in its execution, is the
notion that the Ph.D. must go beyond previous accomplishment and technical competence
to demonstrate innovation, critical thought and a philosophy of science.

7.5 Future Outlook

While it is now possible to renew an IGERT site once, the challenge implicit in the original
guidelines—a self-sustaining program without expensive training wheels—still beckons.
Our advisory panel pointed out that the main features of the program—integration of
research, teaching, recruiting, assessment, minigrants, student government, leadership
training, communication, and group dynamics—required about $100,000/year. Other activities, such as international travel, can be funded through existing mechanisms. Can such a program survive without the incentive of high stipends? After all, we argue in favor of incentives for faculty. The evidence suggests that financial support at a normal level of funding may suffice. While some students did come to the IGERT because of its large stipend, an equal number of high achievers worked hard for the program even after their stipend expired. This suggests that students are motivated by the fun of self-determination and engaging ideas, plus the opportunity to work with energetic peers. Working with sister universities in Louisiana’s higher educational system, many of which have polymer strengths, plans are being executed to integrate revenue-generating activity with entrepreneurship training (primarily for undergraduate students, through the innovative Student Entrepreneurs as Active Leaders program\textsuperscript{18}). At the graduate student level, the focus is on intrapreneurship (compensated service to the universities), which is coordinated by the MSGSA. It is hoped that postdocs can be attracted to this endeavor, serving primarily as consultants and entrepreneurs in training. These developments are direct outgrowths of our IGERT program; however, they were not planned developments. Just like other forms of research, experimentation with graduate education can produce serendipitous surprises.

8. Conclusion

It is not possible to operate a program of this nature without wondering what the future holds for graduate education. Some trends seem likely, such as lessening of the control exerted by departments and even colleges over research resources in favor of a more consolidated, university-wide approach, but graduate schools resemble living entities, and these tend to perfect themselves through an evolutionary process. As IGERT moves into its second decade, it will try to identify the best practices, but mutations should continue. While only some lead to competitive advantage, all inform and instruct. The IGERT program is well timed to new “environmental” stresses placed on graduate education by the increasingly interdisciplinary nature of research, among other factors. It is a fascinating time for graduate students and faculty to set forth on new journeys, but a potential outcome was stated by T. S. Eliot in \textit{Little Gidding}:

\begin{quote}
We shall not cease from exploration \\
And the end of all our exploring \\
Will be to arrive where we started \\
And know the place for the first time.
\end{quote}

Our journey at LSU suggests that the Master’s degree, far from a consolation prize, is a fine old idea whose time has come again. We also seem to know the value of side-by-side apprenticeships and, equally, the importance of incentives for faculty to take part in them. We find exceptional value in creativity-stimulating minigrants, leadership training integrated with student government, and opportunity for students to experience new cultures while performing research at national and international sites, but it is too soon to say whether trainees exposed to these features obtained an advantage over their counterparts. If we did not revolutionize graduate training, that was never the point and perhaps evolution was more appropriate anyway.

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