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An "IGERT" Model for Interdisciplinary Doctoral Education in Water-Related Science and Policy

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Abstract: Most doctoral programs in the U.S. remain "stove-piped" in traditional single-discipline fields, while scientific progress increasingly occurs at the boundaries between multiple disciplines. In response, the U.S. National Science Foundation has been funding projects in Integrative Graduate Education, Research, and Training (IGERT) to train a new generation of interdisciplinary scientists. The IGERT Ph.D. program in "Watershed Science and Policy" at Southern Illinois University (SIU) builds each year's student class as a diverse "cadre" who work intensively together on one hot-button river basin. The structure of these projects, and other program elements, are reviewed here along with successes and challenges to date. One challenge is the seeming tradeoff between (1) the development of tightly focused expertise versus (2) the breadth that characterizes interdisciplinary research. We conclude that interdisciplinary scientists must have disciplinary depth, but so too should they be trained in collaboration and integrating their results to address the challenges that face today's complex world.

Keywords: *Watersheds, doctoral education, interdisciplinarity*

What is IGERT and why? "IGERT" is the U.S. National Science Foundation's (NSF's) flagship program for fostering interdisciplinary doctoral education. The acronym stands for "Integrative Graduate Education, Research, and Training," and these terms succinctly capture some of the key goals of the program. Traditional graduate education, and much of NSF's budget, involves research and related activities within single scientific disciplines. Water-related research occurs within at least seven different NSF Directorates: Biological Sciences; Computer and Information Science and Engineering; Education and Human Resources; Engineering; Geosciences; Mathematical and Physical Sciences; Social, Behavioral, and Economic Sciences (NSF 2011), and numerous different programs within each of these Directorates. Graduate education, probably not coincidentally, largely follows the structure of research funding, with degrees, coursework, and research typically following one single disciplinary track. The problem with such a discipline-specific model, it's been suggested, is that a growing proportion of cutting-edge scientific questions and applications now occur at the boundaries and areas of intersection of multiple traditionally different fields. NSF (2011) advises that successful IGERT proposals "should provide a framework for integrating research and education and for promoting collaborative efforts within and across departments and institutions. Students should gain the breadth of skills, strengths, and understanding to work in an interdisciplinary environment while being well grounded with depth of knowledge in a major field."

NSF's IGERT program is designed to train top U.S. doctoral students through new educational models that cross the disciplinary pigeonholes that characterize most university science programs. More than just "inter-disciplinarity," the program's goals are education, research, and training that are "integrative." Whereas five researchers from different departments sharing lunch at the same table could be considered "inter-disciplinary," truly "integrative" science implies an activity that purposefully assesses the key elements of a problem and addresses them with information, measurements, analyses, and insights from all relevant fields. For the five researchers above

to have an "integrative" meal, they would need to work together in the kitchen, combining their different and complementary culinary skills into a new fusion menu that none of them alone could prepare. The overarching target of integrative science, and the IGERT program, is research and education in which the sum of the interdisciplinary elements is greater, much greater potentially, than the summed problem-solving potential of their disciplinary parts.

NSF seeks to spark integrative science by funding new IGERT doctoral science programs with student fellowships (stipends and cost-of-education allowances for university fees, textbooks, etc.), student field and laboratory research expenses, student conference travel and expenses, development of interdisciplinary curricula, acquisition of research equipment, and other costs associated with building and running such a "transformative" new program. Allowable program elements are outlined in NSF (2011), although specific details and activities within this structure vary widely from program to program. In addition to the basic structure and elements of most IGERT programs, NSF further recognizes "that globalization of research and career opportunities require students to acquire an international perspective [which] may be gained through … collaborative research experiences and/or fieldwork at foreign institutions and sites" (NSF 2011). Universities applying to the IGERT program may request supplementary funding from NSF's Office of International Science and Engineering (OISE), awarded competitively, in order to weave meaningful international research activities into the broader IGERT program fabric. In addition, a new opportunity (implemented after the SIUC IGERT program was funded) provides "Competitive Innovation Incentive Funds," for enabling and encouraging technology transfer by student trainees (e.g., prototyping costs, pilot studies, and patent filing fees; NSF 2011).

Need for Interdisciplinarity in Watershed Science

The late 20th century brought a new era in water-resources management, emphasizing collaboration and involving stakeholders in consensus-building and adaptive management. In a 2002 letter from the American Water Resources Association (AWRA) to President Bush, AWRA identified problems including: conflict among municipal and industrial water users and environmental requirements, 470,000 km of rivers and streams assessed by EPA that do not meet water quality standards, and impairment of 44 percent of estuarine areas in the U.S. The American Society of Civil Engineers' (2009) Report Card for America's Infrastructure graded the conditions of our dams, drinking water systems, and wastewater facilities as a "D." The importance and need for multidisciplinary scientific input to watershed issues is further highlighted by the large number of National Research Council panels currently and recently convened to address national river-basin challenges: the Colorado River basin (NRC 2007), the Mississippi River and Basin (NRC 2004a; 2005; 2008a; 2009), the Missouri River Basin (NRC 2002; 2011), the Klamath River Basin (NRC 2004b; 2008b), the Columbia River Basin (NRC 2004c), the Platte River (NRC 2004d), the Florida Everglades (NRC 2003; 2005b), and many other river- and basin-related studies.

Recent survey data (Bourget 2006) show that traditional single-discipline graduate education has failed to provide the type of professionals needed to meet the diverse and complex issues of water and watershed management in the 21st century as outlined by the National Research Council's (1999) New Strategies for America's Watersheds. NSF's 10-year outlook (NSF 2003) in environmental research and education highlighted the "demand for collaborative teams of engineers and natural and social scientists that go beyond current disciplinary research and educational frameworks." Instead, this new era demands inter-disciplinary approaches that integrate scientific research with resource management and policy-making, with the goal of creating science-literate leaders and policy-literate scientists for placement in government, academia, and the for-profit and non-profit private sectors.

Current issues in water, rivers, and watersheds are among the most cross-disciplinary of any science or scientific applications today. Our group at Southern Illinois University agreed from the start that the broad need for interdisciplinary, integrative science in water-related issues was well matched to the research and educational goals of NSF's IGERT program. Indeed, research groups at other universities also recognized this same need, and several water-related IGERTs have been funded in recent years. In addition, a similar, multi-institutional river- and watershed-focused doctoral program – the Erasmus Mundus

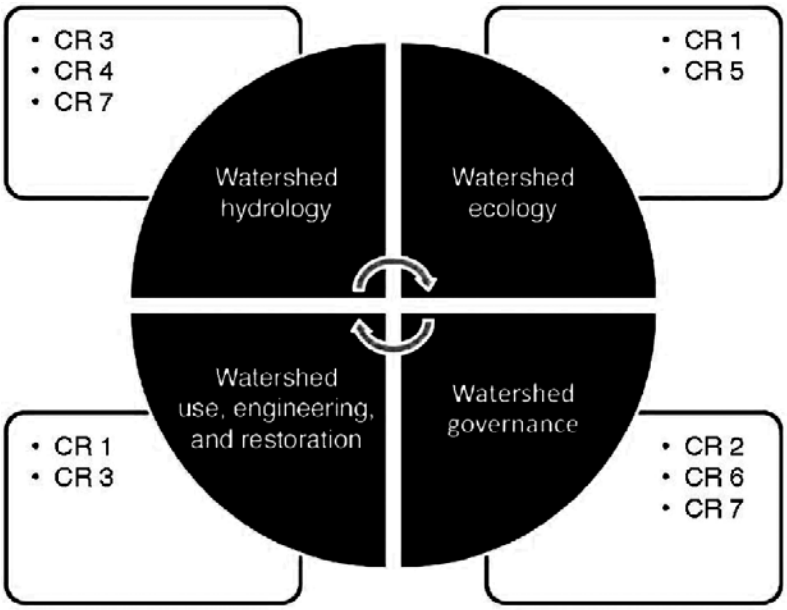


Figure 1. Research and applications in the areas of watershed science and policy cut across many different disciplines, including the four categories schematically grouped together here. The SIU IGERT program identified seven Core Research (CR) questions. Addressing these questions in meaningful ways, we contend, must draw information and insight from many, perhaps even all, of the relevant areas of watershed science.

SMART ("Science for MAnanagement of Rivers and their Tidal Systems; http://www.riverscience.eu) program – has also been implemented by the European Union.

The SIUC Watershed Science & Policy Ph.D. Program

The SIU IGERT program identified seven core research (CR) questions that cross-cut the many different disciplinary approaches to, and applications of, watershed science:

CR 1. How can the ecological health of watersheds be objectively assessed and related to the dynamics of physical systems and human impacts upon them?

CR 2. How do demographic and economic forces, legal frameworks, policies and practices at state, national and international scales influence on-the-ground and in-the-water conditions in watersheds?

CR 3. How do we document anthropogenic impacts on river and watershed systems and then set socially and economically viable biological, ecological, and geomorphic benchmarks for rehabilitating those systems?

CR 4. Can engineering modifications of natural systems be designed to maintain sound physical dynamics and the effective delivery of ecosystem services, including provisioning services?

CR 5. Under what circumstances of local culture, human capital, social networks, institutional capacities, and physical settings do effective and locally significant watershed governance institutions develop?

CR 6. How can watersheds be better governed on the basis of scientifically-sound, participatory watershed planning and adaptive management?

CR 7. How can models be constructed that capture nature-society interactions in a space-time framework to help guide watershed management and policy development?

The structure, curricula, and research activities of our IGERT program have been designed to help answer these questions by promoting doctoral education, research, and training that helps lower the barriers between traditional watershed disciplines.

Program Structure: The premise driving the design and structure of the SIUC IGERT program has been that student training in multidisciplinary watershed science cannot be meaningfully multidisciplinary without meaningful collaboration between students and advisors from different disciplines. The central approach in this program has been to train each year's IGERT class as a collaborative, interdisciplinary cadre. A "cadre" is defined as: "a nucleus or core group of trained personnel able to assume control and to train others" (Merriam-Webster's Dictionary).

Each year, we admitted 5-7 new IGERT fellows, each from a different disciplinary area, to collaborate as a team in constructing a research-driven assessment and management plan for one river basin. Our three cadres have worked in river basins that increased in size, complexity, and logistical challenges through the duration of this project:

Cadre 1: Cache River Basin – a Ramsar Wetland of International Significance located in southernmost Illinois.

Cadre 2: Atchafalaya River Basin – part of the distributary system of the Mississippi River into the Gulf of Mexico, located in Louisiana.

Cadre 3: Tisza River Basin – located in Central Europe, the Tisza is the largest tributary of the Danube River.

Further details about these systems, and the IGERT research projects in each, are provided below.

Admission of each cadre was a challenge each year, but simultaneously one of the great rewards of participating in this program. Our group recruited heavily throughout the year in order to maximize the size, breadth, diversity, and quality of our applicant pool. In general, the IGERT applicants have been among the best Ph.D. applicants on the SIU campus, and the program has increased the number and quality of applications to all of the participating doctoral programs. Selection of applicants for admission to the IGERT was done by the Principal Investigators (PIs) as a whole and was a challenging multivariate optimization function that attempted to maximize both the quality and the diversity of the resulting cadre. Diversity was a central element of the selection process, simultaneously emphasizing disciplinary background, ethnicity, gender, specific analytical skills, and other secondary factors.

A new cross-disciplinary watershed curriculum was developed at SIU to serve the IGERT program. This new curriculum consisted of three new courses: (1) Watershed Science, (2) Watershed Policy, and (3) Integrative Watershed Research and Internships. The watershed science and the watershed policy classes have been particular successes on campus because they have drawn large audience, serving what appears to have been pent-up demand on campus for multidisciplinary training in these areas. Our new Watershed Science class has been developed and coordinated by Prof. Matthew Whiles in the Dept. of Zoology. This course is a multidisciplinary exploration of watershed science and stream ecology, including lectures and discussions of the primary literature led by faculty members from four different colleges at SIUC (Science, Engineering, Liberal Arts, and Agriculture). Topics range from basics of the physical template, including stream flow generation, channel morphology, and water chemistry, to basic ecological concepts such as quantifying energy budgets and conceptual models of stream continua. More applied issues, such as methods for biological assessment and watershed conservation, are also covered. Students are assigned a discussion paper each week, which is usually a "classic" paper on the topic of the week, combined with related papers in the field.

Our new Watershed Policy class was developed and coordinated by Prof. Christopher Lant in the Dept. of Geography and Prof. Sara Baer in the Dept. of Plant Biology. The class explores socioeconomic driving forces in watersheds from a neoclassical, institutional and ecological economics perspective and how these can be incorporated into integrated watershed models, for example by linking crop prices to land use to soil, C, N, and P retention as an ecosystem service. Principles of the U.S. legal system are presented as the foundation for watershed governance. Finally, these are applied in in-depth case study papers of particularly interesting watersheds, with the IGERTs focusing on the Yangtze which they visited. Our Integrative Watershed Research class was designed to serve

each of our IGERT cadres during the semester when they were off campus, serving internships or otherwise engaged in research in their team's study basin. Profs. Pinter and Chevalier developed a week-to-week schedule of guided readings, data gathering and analysis and, most importantly, a series of milestones to guide each group towards completion of its final collaborative study product.

International Activities: Our group applied for and received a supplement from NSF's Office of International Science and Education in order to weave international research and training into the fabric of our IGERT program. This international element was one of the most appreciated elements of our IGERT, by our student fellows and by the participating faculty as well. Each IGERT student and PI worked in one international watershed, with the culmination of these international activities being our program's project in the Tisza River Basin (see below), during which Cadre 3 will live in Europe for 6 months, working with university, government, and NGO partners in four different countries.

Our first IGERT cadre worked in the Panama Canal watershed, in the end spending a total of 2-3 weeks touring, meeting stakeholders, and gathering data in the region. During their first voyage to Panama, IGERT students examined issues in the watershed from headwaters to the Canal. Students explored the Canal Zone, learning about the history and inner workings of the Canal, as well as the current expansion project and related conservation issues. In the headwaters, students learned about disease-driven amphibian declines, urbanization, and other threats to the integrity of the watershed, as well as challenges to developing ecotourism and related forms of sustainable economic development. The trip culminated in a journey up the Chagres River to an indigenous village, which explored additional benefits of watershed protection, including conservation of biodiversity and protection of indigenous culture. After the original Panama trip in 2011, its leader (PI Whiles) was so frugal that a second trip was schedule in 2012, focusing on re-survey of a long-term study stream that experienced a catastrophic amphibian decline in 2008 and is undergoing suburban development. Along with documenting long-term changes in physical and biological aspects of this stream, comparisons were made with similar streams draining more sustainably developed areas in southern Costa Rica.

Our second IGERT cadre spent two weeks in the spring of 2012 touring, meeting stakeholders, and gathering data along the Yangtze River in China. A particular focus was the interaction between the Three Gorges project, the length of which was explored by ferry boat, and Dongting Lake, formerly China's largest, which was explored by bus and small motorboat. The attenuation of high summer monsoonal flows, combining with incision of the Yangtze channel downstream of Three Gorges, are conspiring to drain Dongting Lake, one of the few high quality wildlife habitats remaining in China. The diversion of Yangtze water to the Yellow River basin and the sinking Yangtze Delta near Shanghai were secondary foci. Led by SIU faculty Dr. Wang Guangxing, students interacted with faculty at Central South University of Forestry and Technology and Beijing Forestry University. Together these international basin activities have significantly enhanced the exposure of our IGERT fellows to watershed-related research questions, tools, issues, and colleagues outside of the borders of the U.S. Although not always possible for every Ph.D. student, we consider such exposure to be a valuable asset in training the next generation of researchers and educators.

Other IGERT activities: NSF allows a range of other IGERT activities to broaden and enrich the education, research and training of the fellows enrolled in an IGERT program. Our watershed program has taken advantage of a number of these opportunities, we feel with significant benefits to our students. Among these many activities, we have brought a number of key watershed scientists and policy-makers to SIU for workshops, field trips, and other personal interactions with our IGERT students, as well as with others on campus. For example, our students did an intensive two-day workshop with David Conrad, Senior Water Policy Analyst with the National Wildlife Federation, who provided readings and guided the group through detailed seminar discussions of several hot-button political and environmental issues. We also hosted Carl Bruch, who is Senior Attorney and Director of International Programs for the Environmental Law Institute. Another major IGERT initiative was the "World Rivers in the 21st Century" symposium that

we convened in Carbondale in November of 2011. Speakers and attendees came from across the U.S., and the event was highlighted by a keynote presentation from Philip Weller, who is Director of the International Commission for the Protection of the Danube River.

In addition to in-coming watershed experts, our IGERT student fellows have travelled to a number of field locations and met with a number of outside experts. Such program travel has included numerous presentations of student research at conferences, meetings with governmental agencies and national NGOs such as The Nature Conservancy, and research and educational trips. Our 3rd cadre, for example, did a two-week trip through the Colorado River basin, meeting with nearly two dozen stakeholder organizations. This trip was part of a watershed research training exercise that the group completed their first summer on campus; both as a team-building exercise and as preparation for their full-blown research project in the Tisza River basin (see below). Other IGERT programmatic activities include funding for external dissertation advisors, with the goal of broadening the exposure of our students outside SIU's boundaries, and a range of other educational and training opportunities.

Team-Based Watershed Research Studies

As outlined above, the centerpieces of the SIU IGERT program were the collaborative studies that each cadre conducted in its study watershed. These studies were our principal mechanism for encouraging – "forcing," even – the multidisciplinarity and integration that are the primary goals of all IGERT programs. The three IGERT study basins – the Cache, the Atchafalaya, and the Tisza – were selected because they posed the range of multidisciplinary challenges that characterize many watersheds. As a group, these basins formed a logical progression for our program, starting relatively close to home and increasing in distance, basin size, complexity, and scope thereafter. All three basins are currently under intense scrutiny – at the regional, national, and international scale, respectively – and all three IGERT cadres have the opportunity to contribute meaningfully to long-term management strategies in these systems.

Cache River Basin: The Cache watershed covers 1944 km^2 of southernmost Illinois, a portion of which is part of the Ramsar Convention and has been designated a wetland of international significance. Geologically, the lower reaches of the Cache River are massively under-fit for their floodplain, the valley of which formed as the ancestral Ohio River during the Pleistocene, until glacial outburst floods rerouted the Ohio to its present-day position. Ecologically, the Cache watershed contains a unique and diverse wetland ecosystem that includes bald cypress (Taxodium distichum) and water tupelo (Nyssa acquatica) swamps, and harbors over 100 state threatened and endangered species.

The Cache River basin is a focal point for ecotourism and conservation efforts in southern Illinois, but it suffers from numerous anthropogenic modifications. Like many watersheds in agricultural regions, the Cache ecosystems are threatened by sedimentation, habitat fragmentation, stream channelization, and diversion. The Cache system was channelized and the upper portion re-routed to the Ohio River in 1911, resulting in radically altered hydrology that triggered severe stream-channel incision that has propagated upstream from the channelized reach into the richest ecological areas. While the upper reaches suffer from incision, bank sloughing, and habitat loss, the lower Cache River has been cut off from its headwaters and thus does not flow during much of the year. During summer low-flow, or in this case no-flow, periods the lower Cache becomes anoxic and cannot support a healthy aquatic community or productive fisheries. Proposals are now being developed to re-connect the river as the centerpiece of an on-going wetlands restoration program.

Our first IGERT cadre began working in the Cache River basin in January of 2011, and they have now completed a sweeping research, management, and policy study of the watershed. Findings of this report focused upon key recommendations for management and continued research in this threatened ecosystem and in ecosystems like it elsewhere in the U.S. The report's conclusions have been embraced by stakeholders, and a number of research publications are now in preparation. To give one example, IGERT student trainees Kristin Bouska and Tim Stoebner have mapped

and measured stream restoration structures in the Cache – a class of structures utilized nationwide, but rarely evaluated systematically – and created a hierarchy of effectiveness metrics to guide stream restoration projects elsewhere. Stream restoration efforts around the country have been criticized for not being based on sound science and ecological principles; the IGERT students working on the Cache have produced and synthesized information that is informing management and restoration efforts in the basin, and this project can serve as an example for similar restoration efforts.

Atchafalaya River Basin: The second cadre of students is studying the Atchafalaya River Basin, a major distributary of the Mississippi River. During the spring of 2012, fellows worked with government agencies and NGOs within the basin: the U.S. Geological Survey, The Nature Conservancy, and the Audubon Society. They are currently drafting an interdisciplinary watershed management plan that, in addition to describing the governance structure and state of current scientific knowledge about the basin, will focus on an ecosystem services decision-support tool. The tool will illustrate the manner in which discharge, under the nearly complete control of the Army Corps of Engineers at the Old River Control Structure to fulfill the basin's raison d'etre of flood control, is functionally related to other ecosystem services the basin provides. These include provisioning services such as navigation and crawfish production, cultural ecosystem services such as game fishing and other outdoor recreational activities, and regulatory ecosystem services such as sediment retention and transport, denitrification, and carbon storage. Each of these services is represented by stakeholders whose alliances and rivalries may conform to the complementary or competitive relationships among the services themselves.

Tisza River Basin: The Tisza River is the largest tributary of the Danube River, and its basin is home to 14 million people in Slovakia, Ukraine, Hungary, Romania, and Serbia. The Tisza watershed is the focus of extensive national and international research and discussions regarding flood control, water quality, and management issues. Following severe flooding in the 1990's and early 2000's, the Hungarian government began a large-scale flood-control project (the "New Vasarhelyí Plan") focusing on construction, rural development, and environmental management. Water quality also has been a major concern along the Tisza, especially following a cyanide spill in 2000 from a gold mine along a Romanian tributary that killed fish and contaminated water supplies far down the Tisza and Danube. In 2010, a large containment pond at another mining facility failed, releasing a red sludge that killed 10 people, caused chemical burns to many others, and contaminated a large area of the Tisza River and its floodplain. The Tisza basin countries produced a joint basin management plan in 2009, and currently are working on new basin-wide water quality standards under the European Water Framework Directive. It has been suggested that some, perhaps many, of today's challenges in the Tisza basin can be traced to its 19th century history, during which most of the lowland basin – the Great Hungarian Plain – was dewatered and the Tisza River disconnected from its headwaters, its basin, its floodplain, and longitudinally as well.

The SIU IGERT program selected the Tisza system as the capstone of its basin studies and of its international activities as well. PI Pinter had worked in the past in Central Europe and initiated a series of national partnerships with the help and under a unifying partnership with the United Nations-based International Commission for the Protection of the Danube River (ICPDR). The Tisza basin was selected because of the breadth of its scientific significance and because of the particular challenges of management of a transboundary river system (in this case, under the umbrella of the ICPDR). The third IGERT cadre is departing for the Tisza in January of 2013, beginning 6 months in residence with partners in four countries: Serbia, Romania, Hungary (at universities in Budapest, Szeged, and Kaposvar), and in Austria (at the ICPDR in Vienna). One of the organizational challenges in this project was how to cover the broad territory of a large transboundary river basin while simultaneously structuring a fundamentally collaborative, team-based project. Our solution is an "inhale-exhale" model, in which the IGERT students will disperse to live and work with their national hosts, but then assemble together and with the PI biweekly for 3-4 days at the "home base" in Budapest. The students will also be taking the "Watershed Policy" class,

together with classmates back in Illinois, using an internet-based teleconferencing platform. And the students' "Integrative Watershed Research" class is structured to lead them through the milestones of completing a multidisciplinary analysis with a tentative title, "Tisza River connectivity: Past losses, present-day dynamics, and future opportunities" – a topic recommended by the ICPDR and local partners as particularly timely and significant.

Successes

The SIU IGERT program has had some successes and has worked through some challenges, both of which we offer up as lessons for other groups who may seek to replicate this kind of multidisciplinary program, or parts thereof. Among the successes, we would highlight progress in (1) interdisciplinarity, and (2) team-based collaboration.

The primary goal of NSF's IGERT program is to break down the barriers between traditional "stovepipe" disciplines and foster education, research, and training that crosses these divides. The experience at SIU is that NSF's investment achieved this goal, not only for the students specifically enrolled in the IGERT program here, but for the participating departments and the university as a whole. Annual evaluation of IGERT students includes a survey administered in the spring semester to assess: (a) achievement of project objectives, (b) development of personal and professional skills, (c) perception of internal and external mentoring activities, (d) perception of international activities, and (e) development of diverse career goals. A reoccurring theme expressed by the IGERT students is the educational benefits of team-based collaboration and networking opportunities available because of international travel and internship opportunities. When students were asked to identify their most rewarding experience and skills gained in the IGERT program, the responses were primarily focused on communications skills or learning to work and collaborate as a team.

More broadly, having the IGERT watershed program on campus has (1) led to new cross-disciplinary courses that instantly fed into a pent-up demand for such interdisciplinary training, (2) forged personal connections among the participating faculty have already led to new research activities, (3) encouraged inter-departmental graduate projects that set new standards for outside-the-box collaborations, and (4) broken down institutional barriers to interdisciplinarity. As an example of the latter, the SIU Graduate School originally had a policy against multi-authored manuscripts being accepted as part of a dissertation. We negotiated a new university-wide policy that appropriately large, collaborative, multi-authored works – including our IGERT teams' watershed studies – would be eligible under the university's manuscript option (≥3 published or publishable papers) for dissertations. This new recognition of the value of collaborative, multi-disciplinary research has opened the way for future students beyond the IGERT program.

The SIU IGERT has also been successful in fostering research collaboration, both among our IGERT fellows and more broadly among the participating faculty and departments. Among the watershed IGERT students, their basin research projects successfully trained each group – from the very start of their doctoral work – to conduct research as an interdisciplinary team, with overlapping expertise and duties, rather than as solitary workers. One anecdote that embodies this experience comes from a multi-day field trip that one of the authors here took with Cadre 1 as the students were revising one of the chapters for their watershed study. During two 4+ hour van rides, the author watched as the students passed a laptop computer back and forth as each of them took a turn iteratively writing, editing, and revising the same document. Although single authors or small sets of coauthors may still be the norm for most scientific papers, a growing proportion of academic research, and a much greater proportion of applied research and applied science, comes from broad team-based efforts.

Challenges

An honest assessment of any IGERT program would certainly acknowledge the considerable challenges of implementing such a project. Here at SIU, some of the challenges we encountered were probably unique to our programmatic theme, program structure, and personalities involved, whereas other challenges probably are inherent to the nature and broad ambitions of any IGERT or other sweeping training project. One cross-cutting

challenge that we have heard from other IGERT PIs is the disconnect between the large efforts required to properly manage one of these programs and the limited compensation that can be directed to participating faculty (limited to 1 month/year salary to the Director only). To be 100 percent clear, IGERT awards are a fabulous boon, and NSF's mandate to direct most funds to students is completely understandable, but this structure does demand very high levels of dedication and altruism from PIs and other faculty. The creative IGERT Director will need to find other allowable mechanisms for incentivizing the very large group efforts required.

Another observation ~two-thirds through the SIU IGERT is the considerable variation in group dynamics and personalities, even with our small statistical sample of just 3 cadres. All of our cadres have been successful to date, but some have adapted to the collaborative research paradigm more quickly than others. One interpretation of this variation is simply the range of different student personalities involved. Feedback from the students also points to style variations among the different cadre advisors, ranging from hands-on guidance to more laissez-faire approaches. We draw no sweeping recommendations or insight from this issue, but rather point it out as a topic for further discussion, and probably not a topic unique to team-based or interdisciplinary doctoral projects.

Finally, at the same time our IGERT program was making significant progress in the areas of (1) interdisciplinarity, (2) collaborative research, and (3) focus on application of results, we have been receiving continuous push-back towards (1) single-disciplinarity, (2) individual work, and (3) emphasis on theoretical research. Some of this resistance probably represents academic conservatism, but some resistance points to real trade-offs in the IGERT approach. Our IGERT students begin their doctoral careers working as interdisciplinary teams, but each student has an individual advisor, many of whom press for time and participation in the "home" department and lab. When our IGERT students sometimes complain about limited time and overlapping obligations, we first tell them "Welcome to life in academia!" But time is limited, and commitment to increased breadth in doctoral education, research, and training probably inevitably comes at a cost of reduced depth in any one particular field.

Looking Forward

NSF's IGERT program seeks to create new models of interdisciplinary doctoral education, research, and training. The goals here are to break down the barriers that traditionally separate individual stove-pipe scientific disciplines and, in so doing, to promote future research that is "integrative" and, ideally, even "transformative." The SIU IGERT in "Watershed Science and Policy" is one element of this transformation, but we have documented tangible successes in steeping our Ph.D. fellows in interdisciplinarity and a team-based approach to scientific research and applications. We have also documented challenges to this transformation, including a seemingly inevitable tradeoff between each student's personal depth and technical focus versus the breadth of their interdisciplinary training. The ideal and difficult solution, we have suggested to our students, is that the new generation of interdisciplinary scientists must each have that disciplinary depth, but they must also be rigorously trained in collaborating with other specialists and together integrating their results in order to address problems that cannot be answered one-dimensionally and provide applications to the broad challenges that face today's complex world.

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