Creating and Sustaining a Culture of Interdisciplinarity:

Novel approaches to graduate education in the environmental sciences

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January 2003

Understanding ecological and natural resource issues increasingly demands integrated approaches that bridge the natural and social sciences. Developing integrated approaches requires effective interdisciplinary teams. Key values to building and maintaining socially-relevant interdisciplinary teams include an ability to: see the big picture, define problems early, develop mutual respect and understanding for diverse approaches, carefully recruit team members, engage in open and honest communication through frequent interaction among team members, and explain complex ideas in simple, jargon-free speech, (Brosnan et al. 1996, Nicolson et al. 2001). Adhering to, and building on, these values will do much to improve scientists' abilities to address and perhaps even solve some of society's most pressing problems. However, to actually change the dominant culture of environmental science from a narrow pursuit of specialized questions with little societal relevance to a truly integrative pursuit of complex, socially-relevant questions, we need to train ourselves and especially our graduate students differently.

The US National Science Foundation's Integrative Graduate Education and Research Training (IGERT) grant program, established in 1997, aims to incubate new approaches to interdisciplinary education. IGERT has been developed to meet the challenges of educating doctoral-level scientists, engineers, and educators with the interdisciplinary backgrounds, deep knowledge in chosen disciplines, and technical, professional, and inter-personal skills to lead their fields and become creative agents for change (http://www.nsf.gov/home/crssprgm/igert/start.htm). At the University of Washington, we have developed an IGERT program in Urban Ecology that has provided us with insights into how to create and sustain a culture of interdisciplinarity that we believe is highly effective. Here we describe our approaches to interdisciplinary team-learning, team-working, and team-teaching, discuss our progress, and report on our problems, challenges, and progress.

The Need for Integrated, Collaborative Problem Solving

Urban ecology is an emerging discipline that studies the social, economic, geophysical and political drivers of human settlement; quantifies the pattern of landcover change resulting from settlement; determines how changes in landcover and human activity affect human society and ecological processes; and investigates the policy process response to and modification of these changes (, McDonald et al. 1997, Collins et al. 2000, Grimm et al. 2000, Pickett et al. 2001, Alberti et al. In review).

Urban ecological problems cannot be studied or resolved by disciplinary experts working independently. Strategic decisions on how best to tackle issues like the planning of urban

growth and investment in public infrastructure depend on the synthesis of extraordinarily complex and rapidly evolving knowledge in a broad range of disciplines such as forestry, fisheries, urban planning, zoology, civil engineering, geography, political science, environmental psychology, public health, law, and economics. Effective synthesis requires high performance teamwork. Consider for example the problem of contamination of salmon spawning streams due to surface water runoff. For the wastewater engineer, the problem is simply one of providing adequate capacity for the storm sewers and appropriate treatment at the outfalls to meet required standards. For the ecologist, the problem may be cast in terms of restoring the stream habitat to its natural state. A fish hatchery manager may look at the survival and return rates of the salmon and seek to adjust output accordingly. While the various experts know how to optimize each aspect taken separately, they do not know how to design solutions that address many problems simultaneously. Our motivation for the last seven years has been to develop new education and research approaches to facilitate the "simultaneous thinking" among the various experts that the emerging field of urban ecology requires. We want our students to be able to effectively synthesize diverse information, work in teams, and identify and address pressing urban ecological issues. These skills could serve them well within and outside of academia.

Issues in Interdisciplinary Education

Are the interdisciplinary abilities we encourage in Urban Ecology students unique to our field? Apparently, they are not. Higher education scholars argue (Nyquist 2000, Nerad 2002) that science doctoral students are being trained too narrowly, lack key inter-personal professional skills, such as collaborating effectively and working in teams, and are poorly informed about employment outside academia. Moreover, many students take too long to complete their doctoral studies and in some fields, many do not complete their degrees at all. After graduation, many doctoral students face excessively long transitions to stable employment. In response, leaders of US graduate education called for change in content, structure, and process of doctoral studies so that PhD recipients are prepared to work as scholars and researchers in the 21st Century inside and outside of academia (CGS 1990, AGS 1991, Bowen and Rubenstein 1992, COSEPUP 1995, Nerad and Cerny 1999, LaPidus and Hamblin 2000). The National Academies of Sciences, the National Science Foundation, major private foundations, the Council of Graduate Schools (CGS, professional association of graduate school deans), individual universities, and graduate students have asked academicians to rethink doctoral education (www.grad.washington.edu/envision/, www.woodrow.org/responsivephd/, www.carnegiefoundation.org/CID/).

Rethinking doctoral education means matching the knowledge and skills students will need for the workplace in academia and beyond with the education and training they will acquire during their studies. To address socially relevant questions, such as those emerging in Urban Ecology, students need to study not only discipline-specific methodology and theory, but they must be versed in methodological and theoretical approaches of several, complementary disciplines, as well as the fundamental idea of integrative theory and practice. Therefore, programs must be restructured to emphasize interdisciplinarity, if not in fact, "transdisciplinarity," and partnerships with communities, business, industry, NGOs, and/or government. Through explicit interdisciplinary teaching experiences, interdisciplinary writing and publishing, interdisciplinary public presentations, and rich interdisciplinary experiences in grant writing, doctoral programs must offer the opportunity for students to be trained in professional development so they are able to communicate complex ideas and issues to diverse populations. Moreover, students need to acquire skills, such as teamwork, leadership and time-management, that will allow them to work successfully in a variety of organizations.

While many agree that changes are needed in doctoral education, enacting these challenges is challenging because they must occur within the present university structure that is solidly based on disciplinary departments and a value system that rewards individual rather than collective achievements. Accordingly, powerful sets of tensions, that must be mediated, are put in motion by attempts to implement the proposed changes. The most pressing tensions are: 1) disciplinary versus interdisciplinary teaching, research, and writing; 2) additional demand on faculty's time; 3) competing sets of needs and loyalties, e.g., needs demanded by the IGERT program versus departmental program needs; 4) working in nonhierarchical teams rather than more traditional hierarchically structured individual scholarship; 5) addressing non-academic community needs versus academic agenda and priorities; and, 6) paying attention to and effectively communicating interpersonal matters versus strict adherence of the separation of the personal and the scientific.

Changing the Culture of Graduate Education

Through a seven-year process the UW Urban Ecology faculty-team realized that our task was greater than simply combining our individual expertise in a new integrated program. We realized that beyond organizational obstacles, there are multiple linguistic and conceptual barriers and complex group dynamics in building effective teams. Linguistic and conceptual barriers are rooted in the fundamental way in which researchers in various disciplines define

questions, gather information, and validate hypotheses. Conceptual barriers interact with group dynamics to hinder the effectiveness of these teams. For faculty to be able to effectively bridge the gaps between disciplines we need to be aware of our own mental models, disciplinary bias, and group dynamics. We therefore needed to change the culture of graduate education, and we needed to re-train ourselves if we wanted to succeed.

Our experience suggests three fundamental changes in graduate education are needed to provide effective interdisciplinary teams, socially-relevant research, and re-invigorated doctoral education. First, interdisciplinarity must permeate all aspects of the teaching, learning, and research environments. This permeation should begin at the outset of the graduate experience, not be added late in the process. Second, group dynamics must be recognized as an important element in team performance. Group dynamics need to be explicitly discussed, studied, and assessed by students and faculty on an ongoing basis. Group process and team-building skills become central to the set of skills that both students and faculty working in an interdisciplinary setting need to acquire. Third, a problem-based learning environment centered on a research project developed in partnership with planners, managers, or policy-makers is needed to focus students and faculty from diverse backgrounds on productive, socially-relevant collaboration. We propose that these changes are crucial to transform graduate education from an enterprise focused on individual achievement to one clearly empowering and emphasizing the team.

Interdisciplinary Emersion

We intentionally invert the usual approach to interdisciplinary education by emphasizing interdisciplinarity first and disciplinarity second (Fig. 1). Interdisciplinarity is threaded throughout the graduate experience, but begins fully fledged in year one as a series of courses (1 per quarter) that we have designed to: 1) formulate an interdisciplinary research problem, 2) design a methodology to research the problem, and 3) work on the problem as an interdisciplinary team. A number of teams of 4-6 students from different degree programs and disciplinary fields work collaboratively on the problem for a total of two years. During this time, doctoral students work closely with an interdisciplinary team of faculty, mentor undergraduate and MSc students, and produce a co-authored paper suitable for publication. This paper also serves as an interdisciplinary, multi-authored centerpiece of each student's dissertation. Our structured first two years in the program thus have tangible outcomes relevant to students (progress on the dissertation, publication, networking, and development of team skills) and faculty (publications, development of facilitation skills, increased connection to regional community).

Our classes are unusual in two pedagogical ways: simultaneous faculty participation and student-driven course content. Rather than being a traditional lecture by one or several faculty, all of our faculty attend each class and discuss topics, often in a panel setting, with the students. This full simultaneous participation by the faculty allows students and faculty to learn about the many different ways that scientific problems can be framed and investigated. Faculty grow together as a team and continually reassess their joint teaching and research programs. Faculty introduce basic concepts during the first quarter of class, but students then set most of the class direction by identifying knowledge needs. Faculty and students work together to develop "just in time" knowledge needs, locate relevant papers on the topic for group discussion, identify important resources, or recruit guest speakers to address the need. Just in time team-teaching driven by student needs forces faculty to think on their feet and engage in intense interactions with peers to answer emerging questions. Students learn about uncertainty in the research process and have to continually decide when a given path of inquiry needs to be abandoned in favor of a more promising one. This stimulating and relevant environment keeps faculty and students invigorated and engaged.

We take active participation by students in the learning process a step beyond the norm by requiring all doctoral students to develop and team-teach an introductory urban ecology class. In their third year of the program, after the interdisciplinary research project is done, research teams become teaching teams. Because doctoral students are often ill prepared to teach (Nyquist 2000, Nerad 2002), a special class and workshop in the first quarter of year three (Fig. 1) allows students to focus on pedagogical issues, practical teaching skills, and syllabus preparation.

Advanced students increase disciplinary coursework and research in the second and third years. Thesis committees are in place in year one and disciplinary knowledge exams are completed in year two or three. Interdisciplinarity is maintained in formal course, seminar, and workshop settings. Seminars from a variety of academic and non-academic speakers foster scientific cross-fertilization, where new, exciting ideas are spawned, and where urban ecologists get to know each other well. Students engage speakers by discussing their publications in class and hosting receptions and dinners where science, education, and real-world issues are discussed. Workshops are focused events involving all students and faculty. We use this venue to develop experiential team process techniques (facilitation, active listening, meeting efficiency), explore diverse quantitative methods (spatial analysis), and build community.

A unique physical setting is needed for interdisciplinary teamwork. We maximize communication and partnering among our students by housing them in a common space

designed and equipped to facilitate interdisciplinary work. This lab has state-of-the-art wireless computer technology to facilitate flexible teamwork and group problem solving. Students do not maintain formal offices in the team lab. Instead, offices are maintained in disciplinary labs to maintain connection to core disciplines.

Coming to Grips with Group Dynamics

Intense class discussions among motivated students and passionate faculty require careful attention to group dynamics. Group dynamics interact with teamwork and the learning process. We have become acutely aware of dynamics among faculty, among students, and between students and faculty. Early recognition and discussion of these dynamics is important. We have found that these discussions can address another important dimension of graduate education: the explicit development of a code of professional and group ethics. We are forced to address issues of authorship, data sharing, divergent interpretations of results, and differences in societal values because urban ecology explicitly studies tradeoffs among a variety of human and ecological services.

At the onset of a project such as ours, faculty are still learning how to be effective team players and mentors. We have found it necessary to enlist others to provide a productive forum for group process discussion and learning, as well as to assess and provide feedback on our performance as a group. However, even after faculty become comfortable with the challenges of group management, involving an outside, neutral party as a team coach or facilitator is recommended. The faculty collectively decided to hire a facilitator to help the team improve their group dynamics and requested the assistance of the University of Washington, Center for Innovation and Research in Graduate Education (CIRGE) to help devise a strategy. Recognizing the importance of group dynamic systems of all sorts, CIRGE undertook interviews with each faculty and student participant to learn about our ambitions, goals, approaches, and biases. A CIRGE innovation consultant then designed workshops that helped us accomplish administrative tasks (e.g., collective brainstorming about outreach activities, development of our mission statement) as we learned and practiced new skills in teamwork (e.g., group discussion facilitation, appreciative inquiry, teaching warm-ups and fairly routine individual and team "check-ins") and personal effectiveness (time management, stress reduction). Rather than being an additional time drain, these workshops provided us with important tools and involved the entire group in getting necessary chores completed. But more fundamentally, the innovation consultant helped us to recognize the ongoing and crucial challenge of blending who we are as people with whom we are as scientists.

Building a Problem-based Learning Environment

We function entirely in a problem-based learning environment by building graduate research teams around interdisciplinary research projects. These projects allow us to increase the societal relevance of our work and provide the integrative focal point our students and faculty need for successful collaboration. We identify important research projects by inviting several local and regional planners, managers, and policy makers into the classroom to discuss pressing issues in their field that would benefit from our attention. These seeds are fertilized by student and faculty discussion and grow into detailed research proposals completed with pilot data analyses and methodology testing during the first year course sequence. Our readings, discussions, and writings are unified by their relevance to these research projects.

Complex research problems allow us to expose students to a variety of disciplinary research tools. Simultaneous participation in class by faculty allows students to learn about several approaches to each problem. This often produces novel approaches to traditional problems and unique combinations of approaches to new problems. For example, our students combined remote sensing, landscape ecology, and urban planning to explore the unintended consequences of urban growth on native forest connectivity. Another student group is applying methodologies from the social sciences (interviews and cognitive mapping) to understand what qualities of natural science are most useful to urban planners challenged with revising their critical area ordinances. We expect, and encourage, our students to blend methodologies from the social and natural sciences to study the intersections among political, social, and ecological processes at work in our region. This would rarely (if ever) occur in traditional disciplinary programs.

National and International Exposure

While our interdisciplinary team projects center on the Puget Sound region, thereby building a larger community of scholars and weaving an effective professional network for our students, we explicitly encourage a broader world view of our subject. Urban systems characterize humans worldwide and pose especially pressing environmental challenges in developing countries. To allow our students to put their research into a global perspective we have developed connections with urban ecologists in Phoenix, Los Angeles, Berlin, Oslo, Warsaw, Melbourne, and Khabarovsk. All our students are encouraged to participate in *Comparative Urban Ecology* during their second or third year (Fig. 1). This class is a multi-week trek to several European cities where our students work, travel, and socialize with other students and faculty, learn about urban ecological research being conducted there, and study the drivers, patterns, processes, and consequences of settlement in each city. Students may

also elect to conduct research in these locales or continue to build their network virtually by collaborating with distant scientists and students using Internet chats and video conferencing to review each others' work, discuss new papers, or write together.

Tensions

In our experience an inability to effectively communicate is the mother of most tensions felt by interdisciplinary groups. We have explicitly addressed (and thereby reduced) this tension by immersing ourselves in interdisciplinary group life complete with professionally-facilitated workshops to study and discuss our group processes. We grow together in our abilities to solve day-to-day breakdowns in communication that stifle many groups. We have learned that effective communication is not a singular occurrence, once built, always in place. Instead, it requires continual attention and assessment. As faculty, we began to understand each other's biases and strengths and use them to build a strong and mutually acceptable vision of where we want our program to go. This vision reduces tension because it explicitly says what we feel is most important; it reduces digression from our central theme and focuses our creative energies. Students also gain focus from our vision, but their connection to a shared research project is most effective at defining a relevant mission and immediate set of goals. Despite these innovations, three primary tensions remain: (1) disciplinary – interdisciplinary balance; (2) fitting within a traditional university structure; and (3) sustaining costly programs.

Maintaining Disciplinary Rigor

The tension between disciplinarity and interdisciplinarity, while obvious, is the most nuanced. For faculty, interdisciplinary research and teaching is complicated because they have been educated and trained within disciplines. Working effectively in an interdisciplinary unit entails a willingness to work across differences in basic assumptions, methodological approaches, terminology, and disciplinary traditions toward a common shared research and pedagogy (Klein, 1990; Davis, 1995; Salter and Hearn, 1996). For the students, who come from different disciplines and are therefore entrenched in particular disciplinary approaches, the challenges of interdisciplinarity are considerable. Moreover because our students still receive their doctoral degree in a department, they are obligated to fulfill both disciplinary and interdisciplinary requirements. Navigating between their department and their Urban Ecology requirements adds an extra level of anxiety to their doctoral studies. Therefore, faculty need to design an interdisciplinary curriculum that is fluid enough to integrate the various disciplinary foundations into the new field of urban ecology. Differences should be celebrated and

studied, which is possible in the class setting we employ. Structuring the curriculum also needs an awareness of the unexpected that emerges in every teaching and learning situation. Our use of student-driven course content and "just-in-time" presentations enables adjustments as they are needed.

Dissertations can function as melting pots where interdisciplinary and disciplinary scholarship is brought together. We require Urban Ecology dissertations to include a common, co-authored section (usually a single manuscript that results from the team's initial two years of work) AND an individually-written section (usually several journal papers or a monograph) based on a separate, more traditional disciplinary analysis or further work on the interdisciplinary team problem. Disciplinary roots are maintained as students present their research results at standard, disciplinary meetings and publish in disciplinary outlets. Organizing papers from diverse perspectives into common sessions at a meeting can focus and highlight the benefits of collaborative interdisciplinarity in traditional, disciplinary settings.

Living in a Traditional Setting

One additional tension that interdisciplinary programs have to negotiate stems from their being situated within an established university bureaucracy. Universities are traditionally organized by disciplines and all administrative concerns, both of students and faculty, are handled through disciplinary channels. These channels pose hurdles for interdisciplinary programs. Joint listing of classes, involvement of Deans from participating colleges in program reviews, and a graduate college receptive to change have minimized this issue for our program. However, our program's unique administrative needs are too often overlooked and the administrative work involved in accomplishing otherwise routine tasks is under estimated. The innovative character of interdisciplinary programs requires innovative administrative support. Specifically, administrators must be familiar with the traditional discipline-based administration of graduate programs and be able to make their innovative program fit in a creative way within the university structure.

Sustainability

Innovative, interdisciplinary programs demand faculty time, often require small classes, and need substantial funding for students. NSF's annual support of each IGERT program is 500K. This provides solid base funding, but it is not permanent. How are universities and faculty going to keep their innovations growing?

Program sustainability is a function of its success, flexibility, and relevance. Success motivates sustainability in our experience. When faculty (1) perceive their students thriving,

growing, and getting jobs; (2) gain new insights into old problems through novel collaborations; (3) enjoy and trust working with each other; and (4) obtain more grants, publications, and interest in their research, they remain motivated to address the challenges of interdisciplinary collaboration. When administrators interact with motivated faculty who give them examples of successful students, cutting edge projects, and publications, grants, and exposure, they in turn become motivated to sustain innovative, productive programs. Flexibility enables change. Faculty and students in an interdisciplinary program need change, and programs that adapt remain successful and sustainable. Relevance to societal needs builds program support at local, regional, national, and global levels thereby increasing funding opportunities and sustainability.

How do we remain successful, flexible, and relevant? Persistence is one key to obtaining and maintaining success. We continually recycle, retune, revise, and resubmit our ideas to funding agencies. Success begets success so we highlight past success in current proposals. Flexibility is somewhat inherent in all interdisciplinary programs because of their diversity. Diverse ideas and approaches should spawn novel disciplinary and interdisciplinary proposals to a diverse array of potential funders. Funding opportunities expand from the usual research grant to suddenly include opportunities for technology, education, and team-process research. Increasing the diversity of funding bases increases flexibility, especially if some funds are unrestricted thereby facilitating needed workshops, incentives, and pilot investigations not normally funded by state and federal sources. Flexibility goes beyond funding to include faculty participation. As career and life demands change, faculty must be able to increase or decrease their participation in the group without disrupting group function. Discussion and acceptance by group members of such changes are important and a non-hierarchical leadership model within the group is well suited to this reality of collaborative work. Relevance is maintained by involving local planners, policy makers, and managers in our program. We continually ask them to tell our students what questions need to be answered and what science is most useful in the policy context, and we conduct research to address their needs. Involving them and key university administrators on program evaluation panels also helps make sure the program is receptive to greater university and regional needs. These participants become strong advocates for the program, which translates into increased funding and a broader network of program supporters.

Conclusion

Training scholars and practitioners capable of synthesizing diverse knowledge to solve complex problems requires interdisciplinary graduate education. Our experiences suggest that effective interdisciplinary education requires an early start to team-based research, constant attention to group dynamics, experiential learning and cognitive group process techniques, and a problem-based learning environment. This challenges typical disciplinary faculty and students. The assumption that disciplinary faculty can successfully create interdisciplinary teams and teach in interdisciplinary settings underestimates the difficulty of team teaching within disciplines, much less across disciplines and is the principal cause of failures in interdisciplinary efforts. Despite growing interdisciplinary efforts, faculty trained within specialized disciplinary settings who seek to cross disciplinary boundaries are hindered by multiple barriers (physical, organizational, and conceptual) and complex group dynamics. These difficulties are generic to all interdisciplinary efforts worldwide. Physical barriers arise simply because research in different fields takes place in different locations; spatially segregated teams do not have the same opportunities to share information and explore ideas as those in the same physical location. Organizational barriers are due to the structures of institutions, incentives, and organization of academic knowledge. Linguistic and conceptual barriers are rooted in the fundamental way in which different disciplines define research questions and select appropriate methodologies. Conceptual barriers interact with group dynamics to hinder the effectiveness of interdisciplinary teams. To help faculty and students become aware of their own mental models, disciplinary bias, and group dynamics and acquire effective teamwork skills, it is critical to involve colleagues with expertise in group process and team-building.

Perhaps the greatest challenge is to recognize and balance the conflicting tensions associated with interdisciplinary programs. These various tensions experienced by students, faculty, and administrators must be acknowledged and accepted as inherent to an innovative program. It should be further acknowledged that there can be no one-time and single solution to these tensions. Rather negotiating these tensions must be viewed as an ongoing learning process fundamental to the interdisciplinary concept itself.

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Figure 1. Balancing interdisciplinary (dark gray) and disciplinary (light gray) educational components in a 4-year doctoral program. Our initial emphasis on interdisciplinary assumes that entering students already posses a disciplinary Master's Degree. Details indicate the elements that define our Urban Ecology program each of the first four years (each block is a year divided into four quarters). Comparative Urban Ecology is represented in years 2 and 3 in dashed box because it is not required and can be taken either year. Additional years (if needed) would replicate year four.