MULTINATIONAL COLLABORATIONS ON CHALLENGES TO THE ENVIRONMENT

PROF. GRETCHEN KALONJI
The University of Washington

A Proposal to the NSF IGERT Program

Project Summary

The goal of our project is to create a new collaborative multinational model for interdisciplinary graduate education and research. In our approach, a small, dedicated, and carefully selected set of partner institutions will work in concert to: 1) develop collaborative and sustainable interdisciplinary graduate research opportunities; 2) implement new project-based courses which are offered cooperatively at multiple sites; 3) create international internship opportunities for participating graduate students, 4) implement a multinational mentoring, advising and communications network, 5) develop teaching and curriculum development experiences for graduate students which provide them with a rich international perspective on the challenges facing higher education, and 6) share experience in more effectively targeting university research to address practical problems facing our regions. Our partner universities are: Tohoku University (Japan), the University of Auckland (New Zealand), the Polytechnic of Namibia (Namibia), the University of Natal (South Africa), Eduardo Mondlane University (Mozambique), Can Tho University (Vietnam), Sichuan University and Tsinghua University (both in China). We will also work closely with Pacific Northwest National Laboratory (PNNL), our region's major governmental research lab, in the design of the research and educational programs for our students.

Our focus on 5 interwoven environmentally-related themes, specifically 1) water quality and wastewater treatment; 2) "eco-materials" (or reducing the environmental cost of materials processing and use); 3) biodiversity, with a focus on botanical and aquatic systems; 4) goods and services from forest ecosystems; and 5) environmental social sciences. Together, we will implement a coherent and powerful set of interdisciplinary experiences for our students that will enable them to emerge as imaginative and effective leaders in our communities. Simultaneously, our program will offer new insight to all partners on the strengthening of graduate education across the disciplines. Our educational program incorporates: 1) participation in one or more of the 5 interdisciplinary thematic research clusters, as described above; 2) a year-long, project-based course on *Coupled Human, Natural and Materials Systems*, which brings together faculty and students from all of the 5 thematic clusters; 3) a required research internship at one of the partner institutions (6 – 12 months) under the supervision of a local co-advisor; 4) a "pedagogical" internship working either at the K-12 or undergraduate level on a project related to international educational reform in science and engineering; 5) an on-going weekly IGERT seminar; 6) two "dissertation workshops" (one in the early, problem-definition stage of their research, and another in the writing stage); and 7) activities focused on career awareness, ethics, and professional development, with a particular emphasis on the international dimensions of these issues.

The **Intellectual Merits** of the proposal include: the high quality scientific research it will enable; the plans for linking the research to the solution of common, practical regional problems, and the innovative strategies for integrating international research and graduate education and training.
The **Broader Impacts** of the program include 1) the contribution we will make to the generation of a globally-engaged, diverse and technically astute international workforce, and 2) the insight we will provide to the broader higher education community on such basic questions as:

- How to create international research experiences for our graduate students that are effectively integrated with the rest of their professional development and research;
- How to structure inter-institutional partnerships in graduate education such that the benefits are truly reciprocal and sustainable;
- How to structure interdisciplinary international programs so that they are more effective in attracting and retaining a diverse set of graduate students.

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A. LIST OF PARTICIPANTS

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Benita Beamon, Industrial Engineering
William Beyers, Geography
Raj Bordia, Materials Science and Engineering
Michael Brett, Civil and Environmental Engineering (Co-PI)
Guozhong Cao, Materials Science and Engineering
Nicholas Chrisman, Geography (Co-PI)
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James Fridley, Forest Resources
Ben Hall, Botany and Genetics
Stevan Harrell, Anthropology
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Kevin Hodgson, Forest Resources
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Fumio Ohuchi, Materials Science and Engineering
Devon Peña, Anthropology, American Ethnic Studies
Sarah Reichard, Forest Resources
Jennifer Ruesink, Biology
David Stahl, Civil and Environmental Engineering
David Stensel, Civil and Environmental Engineering

As at UW, an interdisciplinary team of faculty will be involved in the project at each school. In this list we indicate the local lead faculty member/administrators:

- Sichuan University (Chengdu, China): Li Guangxian, Professor of Polymer Science, Director of Research
- Tohoku University (Sendai, Japan): Tetsuo Shoji, Professor and Director of National Center on Physics and Chemistry of Fracture and Failure under Combined Environments
- Tsinghua University (Beijing, China): Pan Wei, Professor and Chair, Materials Science
- The University of Auckland (Auckland, New Zealand): Linda Smith, Co-Director, National Institute Research Excellence in Maori Development and Advancement; Professor of Education
- The Polytechnic of Namibia (Windhoek, Namibia): Dr. Tjama Tjivikua, Rector
- The University of Natal (Durban, South Africa), Prof. Janusz Zwolinski, Director, Forestry Programme.
- Eduardo Mondlane University (Maputo, Mozambique); Prof. Luisa Santos, Director, Faculty of Agronomy and Forestry Engineering.
- Can Tho University (Can Tho,Vietnam); Tran Phuoc Duong, Professor of Microbiology, Director, Center for Biotechnology, Rector-Emeritus, Can Tho University

B. VISION, GOALS AND THEMATIC BASIS

Vision

Our vision is to create a new collaborative multinational model for interdisciplinary graduate education and research. In our approach, a small, dedicated, and carefully selected set of partner institutions from around the world will work in concert to: 1) develop collaborative and sustainable interdisciplinary graduate research opportunities; 2) design and implement new project-based graduate courses, which are offered cooperatively at multiple sites; 3) create international internship opportunities for participating graduate students, 4) implement a multinational mentoring, advising and communications network, 5) develop teaching and curriculum development experiences for graduate students which provide them with a rich international perspective on the challenges facing higher education, and 6) share experience in more effectively targeting university research to address practical problems facing our regions.

The research domain in which our multinational student-faculty teams will work is the broad theme of challenges to the environment facing our regions.

Thematic basis

As the world looks forward to the next 50 years, a number of certainties emerge. These include a 50% increase in the world's population to 9 billion; further declines in the availability of clean water and air; greater pressures on the earth's supply of renewable and non-renewable mineral and energy resources, and on agricultural and forest lands; climate change and, as a result, the further loss of relatively undisturbed natural systems and the biodiversity they sustain. The convergence of these certainties means that students trained in the environmental and engineering sciences must hold a global perspective as they seek a fundamental understanding of systems, processes and drivers as they engage in solutions to these rapidly expanding areas of concern. Globalization of problems and solutions can readily be seen in such issues as SARS, invasive species, and global climate change. However, global assessments and solutions must come with an increased sensitivity to and respect for local knowledge and culture.

In light of the global challenges highlighted above, our assessment of the most pressing needs in our regions, and the research strengths of our institutions, the partners in this IGERT proposal have chosen five areas as particularly appropriate foci for our collaboration on graduate education reform: 1) water quality and wastewater treatment; 2) "eco-materials" (or reducing the environmental cost of materials processing and use); 3) biodiversity, with a focus on botanical and aquatic systems; 4) goods and services from forest ecosystems; and 5) environmental social sciences. Together, we will implement a coherent and powerful set of interdisciplinary experiences for our students that will enable them to emerge as imaginative and effective leaders in our communities. Simultaneously, our program will offer new insight to each of the partners as to how graduate education can be strengthened across the disciplines

What is currently missing from graduate education?

Graduate education in the US is one of our most sought-after commodities. In recent years, at any given time we have approximately 100,000 foreign graduate students studying on our campuses [1]. US higher education is widely regarded as the best the world has to offer.

However, current US graduate education also suffers from some serious weaknesses, weaknesses which have been identified in a number of national studies [2-4] and which serve as the motivation for a number of national initiatives [5-7], in addition to the formation of the IGERT program. These weaknesses include the following:

- The character of the education and training we offer does not match well to the full spectrum of career pathways of our students. While it is quite well-suited to the preparation of future professors for research intensive universities, it is less effective in preparing students for jobs in industry, government, the non-profit sector, community colleges and other educational venues, etc.

- We do a relatively poor job of developing interdisciplinary knowledge and in helping our students acquire skills to work in complex teams.
- While the US undergraduate system has a strong "general education" orientation, in graduate school students have insufficient time and opportunity to continue to fully develop themselves as well–educated citizens.
- Our graduate education programs have been relatively unsuccessful in attracting and retaining a diverse student body, particularly in technical fields.

Other weaknesses are not as commonly cited but deemed critical by our IGERT team.

- Many students in science and engineering are motivated by a laudable desire to contribute to the solution of practical problems facing our communities. However, the character of graduate education, with its strong emphasis on specialization and its focus on problems for which professors are able to get funding, makes it difficult for graduate students to find opportunities through which they can simultaneously develop themselves professionally while "giving back" to the communities from which they emerge.
- US graduate education is generally not well-suited to preparing our students for the challenges of participating in an increasingly interdependent global scientific community. While there is a huge flow of students into our institutions from countries around the world, our own students have a woefully low level of participation in research and educational opportunities outside the US [8]. And, though our academic communities and our nation are greatly enriched by the infusion of talent and energy of the graduate students that come to us from around the world, US graduate education has done relatively little to creatively tap into the experience and aspirations those students bring with them in order to enrich the graduate education of all students.

Structure of our program: what our IGERT has to offer

The multinational collaborative IGERT program we propose is designed to address the issues highlighted above through a variety of novel and ambitious approaches. The following is a brief description of our program elements. Students will receive degrees from traditional departments and maintain disciplinary depth in their chosen fields. In addition to their disciplinary requirements, all students in our IGERT will benefit from the following activities: 1) participation in at least one of the 5 interdisciplinary thematic research clusters, as described above; 2) a year-long, project-based course on *Coupled Human, Natural and Materials Systems*, which brings together faculty and students from all of the 5 thematic clusters; 3) a required research internship at one of the partner institutions (6 – 12 months) under the supervision of a local co-advisor; 4) a "pedagogical" internship working either at the K-12 or undergraduate level on a project related to international educational reform in science and engineering; 5) an on-going weekly IGERT seminar; 6) two "dissertation workshops" (one in the early, problem-definition stage of their research and another in the writing stage); and 7) a set of activities focused on career awareness, ethics, and professional development, with a particular emphasis on the international dimensions of these issues.

Our program addresses the weaknesses in contemporary graduate education identified above in the following manner. It is intensely interdisciplinary in design; in addition to learning about overcoming the challenges of interdisciplinary work through participating in their own thematic research clusters, students benefit from being part of the broader IGERT team by gaining a deep and critical understanding of the interactions among these complex sets of environmental issues. With respect to their professional development, students gain a sophisticated and nuanced view of the challenges of teamwork across national, disciplinary, and cultural boundaries through working together with colleagues from different regions and backgrounds towards a set of commonly identified goals. They also gain invaluable experience in communicating complex ideas and results through the required reports and presentations associated with each of the program elements above. Students gain a sophisticated understanding of international variations in research and education, not only through their research and pedagogical

internships, but through their participation in a targeted and deeply internationalized community throughout their graduate experience. In addition, due to the practical nature of the set of environmental challenges we have selected as our research foci, we are able to offer students opportunities to do work that they really believe in, that can offer significant benefits to local communities, and that can serve as a launching point for a wide variety of career paths in science and engineering.

Our IGERT builds on significant experience with multi-national project-based education at the undergraduate level, including ongoing projects with several of the partner institutions. These include a partnership with Tohoku University on engineering design [9] and a collaborative four-year undergraduate curriculum with Sichuan University, on challenges to the environment in the US Pacific Northwest and southwest China [10]. These projects are pilot efforts of a new initiative at UW for the more effective internationalization of research, education and service called *UW Worldwide*. Through the IGERT, we will launch the graduate component of the *UW Worldwide* program. Our graduate program will benefit from our experience at the undergraduate level in building mutually beneficial partnerships in education reform. The experience of the graduate students in our IGERT will, furthermore, be significantly enriched by the opportunities for mentoring and professional development that this deep connection to an existing undergraduate education reform initiative provides.

Unifying aspects of the interdisciplinary research and educational activities

The intellectual community our IGERT brings together is extraordinarily diverse. A key strategic challenge is to have enough commonality in research to promote real collaboration among partner institutions and amongst the 5 thematic clusters, while keeping open multiple and diverse opportunities at a variety of international sites to promote participation by graduate students with diverse interests and goals. Because of our strong commitment to international internships for our students, our thematic umbrella is broader than would be typical for an IGERT focused on one local site.

Several common activities and goals hold our community together. All participants will share:

- An explicit focus on unraveling the details of interaction among the 5 research themes, and on understanding how those interactions vary at different sites, based on history, economy, geography and culture. This collective, community-building effort will be launched from the beginning of the students' program with us, through the project-based course sequence on *Coupled Human, Natural and Materials Systems*, and will continue to be a core, unifying theme throughout their graduate education. We will, furthermore, prioritize for IGERT support those students whose projects span 2 or more of the 5 research themes, such as materials for low-cost wastewater treatment methodologies.
- A focus on the pragmatics of multi-national scientific and engineering collaborations. Participants in all 5 thematic clusters will share experience on how to overcome challenges to multi-disciplinary multinational projects, and they stand to benefit a great deal from discussing how those challenges vary among the projects in our collaboration.
- A focus on educational reform: what works in terms of student learning, what works in terms of institutionalizing change, and how successful practice varies internationally. Students in all the disciplines will have a deep experience in the process of educational change. In addition, we expect to support at least one graduate student per cohort whose primary professional focus will be on the internationalization of science and engineering education.

To further promote intellectual cohesion, common understanding and effective collaboration, we will also work together on the creation of a set of common tools. These tools include GIS-based modeling of environmental change; web-based tools for collaborative decision-making; and a multi–lingual, multi–disciplinary concept map and glossary. The creation and continuous refinement of these tools, by students at the various sites, is envisioned as one of our most innovative and exciting mechanisms for building sustainable, collaborative international graduate research communities.

Goals for students, faculty and institutional change

The goals for our program fall into three categories: goals for students, goals for faculty, and goals for institutional change. Each set of goals is more fully elaborated in Section F: Performance Assessment, in which we also outline the methods we will use to assess whether our goals are indeed being met. Briefly, our goal for students is that they emerge from the program with a truly impressive set of research accomplishments and with the knowledge, skills and attitudes that will enable them to contribute significantly to the solution of important global problems in a variety of career pathways. Our goal for faculty is that our program proves useful to them in further developing interdisciplinary, international directions in their research and teaching that are both rewarding and sustainable. Our goals for our institutions are that they each become more effective in supporting interdisciplinary, internationalized graduate education, and that a lasting network of mutually beneficial collaborations is forged.

Broader impacts of our IGERT project

The primary benefit our IGERT will offer the higher education community is insight into new models for the internationalization of interdisciplinary graduate research, education and training. Through a process of rigorous evaluation and energetic dissemination of the lessons learned, we will contribute to basic understanding of the following questions:

- How do we create international research experiences for our graduate students that are effectively integrated with the rest of their professional development and research?
- How can we structure inter-institutional partnerships in graduate education such that the benefits are truly reciprocal and sustainable?
- How can we take better advantage of the multinational character of the communities that already exist on our campuses to improve the quality of graduate education?
- How do we create deeper collaborations between the social science communities and the physical science and engineering communities in working in the international domain?
- How can we best educate and train doctoral students to be effective in applying interdisciplinary knowledge and skills to solve complex real-world problems, while retaining significant professional immersion in their respective disciplinary fields?
- How can we structure international programs so that they are more effective in attracting and retaining a diverse set of graduate students?

In addition, our program will provide high quality research on an important set of environmental problems and will contribute significantly to the generation of a globally-engaged, diverse and technically astute international workforce.

C. MAJOR RESEARCH EFFORTS

The over-riding focus of our collaboration is on building multinational collaborations that are effective in addressing common practical regional challenges. All of the students in this IGERT will gain experience in the pragmatics of working across national boundaries through working with colleagues at selected partner universities on one of five interwoven environmental research themes. Each of the themes is, in itself, richly interdisciplinary. Not all institutions will participate in each theme; rather, clusters of institutions will participate in teams that include multi-facetted opportunities for graduate students in their research design, and that are tailored to mesh with local strengths and priorities. In addition to the university partners, our region's major national research facility, the Pacific Northwest National Laboratory (PNNL), is enthusiastic about working with us, especially on the materials, water, and environmental policy issues, and on building international educational and research connections.

The remainder of this section is organized in the following manner. Section C1 offers theme–by–theme summaries of the research we envision. Section C2 offers a description of the community-wide research

on the coupling between human, natural and materials systems, including some examples of the exciting directions made possible through the formation of our highly interdisciplinary and international network.

C1. Research in our 5 Thematic Clusters: This section provides a general overview of research opportunities that will be available to students through our IGERT. Each subsection includes: a list of key UW participants and of partner institutions that have prioritized each theme; a summary of the major research issues; and a description of possibilities for graduate projects. We also include a description of questions that our multi-institutional, multinational community will address at each site. The comparative understanding of how the underlying phenomena vary from region to region is one of the principal intellectual advantages we gain through the formation of the IGERT.

Theme I: Eco-materials: Reducing the Environmental Impact of Materials Processing and Use
UW Participants: Kalonji, Bordia, Ohuchi, Cao (Materials Science); Beyers, Chrisman (Geography); Beamon (Industrial Engineering); Anderson (Computer Science)
Key Partners: Tsinghua University, Sichuan University, Tohoku University, Can Tho University and the Polytechnic of Namibia, Pacific Northwest National Laboratory (PNNL)

The goals of the "eco-materials" group are 1) to understand of the interaction of materials, environment and economic development in our regions and 2) to develop a new generation of materials and processes that are more environmentally friendly. The project builds on ongoing research at UW and on very strong existing partnerships between UW and several Chinese institutions, including our partner schools Tsinghua and Sichuan. A planning grant from the NSF's new program MUSES (Materials Uses, Science, Engineering and Society) supported the development of an integrated research and educational plan with our Chinese partners, and a full proposal is now under review. The IGERT program expands the set of activities, while adding participants from Japan, Vietnam and Namibia.

Materials emerge from natural resources, are processed, assembled in products, transported through inter-regional and international trade, and then, ultimately, re-cycled, re-used or discarded. Underlying our research is the realization that materials-related activity is inherently systemic in nature, involving interaction, both geographically and temporally, between society, the economy and the environment. Our materials research plan spans three levels, from regional level analyses of materials industries, to plant level research on specific factories in Washington State and the partner regions, to the microscopic level of the design of new materials. The specific industries and materials we will prioritize are those associated with the transportation and electronics sectors. Initial focus will be on aluminum and its alloys, on steel and on materials for fuel cells and sensors.

Regional level research: Our projects at the regional level address the connections between materials phenomena and the broader setting of environmental processes and economic flows. Within our group, there is extensive expertise in economic modeling using input-output models; in geographic information systems and their application to environmental processes; and in modeling of materials processing [11–13]. The multi-national platform of our IGERT community provides opportunities to link together models from regions in several spatial domains, specifying their internal structural relationships, and then the interregional dimensions, in order to address materials flows in and between regions in novel and powerful ways. There are interesting experimental opportunities to 1) develop input-output models for non-spatially contiguous domains; 2) further explore the significance of feedback relations among these systems; and 3) articulate the relationships between materials processing variables (from the plant level analysis) to measures of broad economic impact within the affected regional economies, as well as to measures of environmental impacts. Another set of projects combines environmental process models with geographic information systems to provide detailed understanding of how specific materials processing decisions at the plant level propagate effects across the region. In this work, we build on the advanced set of environmental models developed by UW PRISM project [14]. However, both the input-output and the environmental process models will miss some of the complexity of the environmental

system. Students in our IGERT can also work on developing an intermediary layer of modeling that connects the environmental process models (that are spatially and temporally rich) to the input-output models (that capture the interconnectivity of the economy at the expense of spatial resolution). These two distinct types of models will be linked to multi agent simulations to connect materials choice and plant-level decisions to their larger context.

Plant Level Research: The research at the plant addresses the aggregate environmental effects of full scale manufacturing of the specific chosen. Our goals for the plant level research are: 1) to construct life cycle inventory models of several materials and products, and 2) to examine quantitatively the environmental improvements of pollution prevention in the various regions. Students at the IGERT sites will construct sets of mass and energy balances to create profiles of emissions and energy use for each manufacturing process and each related life cycle, using the design-based methodology developed at North Carolina State University [15]. As validation of these manufacturing mass and energy balances, several metallurgical plants in the partner regions, and fuel cell and sensor manufacturing where it is underway (China, Japan and the US) will be examined. By looking at similar facilities in Washington and the partner regions, it will be possible to gain an environmental contrast in manufacturing technology and implementation. Our international multiple–region study system can provide a new level of industrial ecology modeling that is focused more directly on supply chain and products as these most closely reflect the industrial decision-making for environmental improvement [16].

Materials Level Research: We envision two initial foci at this level. The first focus is materials and processing techniques for light weight, energy efficient fuel cells. Solid oxide fuel cells (SOFCs) are the most energy efficient fuel cells and are candidates for auxiliary power units for both aircraft and automobiles and for distributed and central power production. However, in order to realize this potential, the current designs of fuel cells need to be improved. We will investigate new approaches that use a single step co-sintering protocol for multilayered solid oxide fuel cells [17] and build on our understanding of the processing of multilayered systems [18]. The second area is environmentally friendly electronic ceramics, including lead free piezoelectric ceramics for use in actuators, sensors and memory storage devices [19], and thermoelectric ceramics. Thermoelectrics are an exciting new class of materials that generate electricity when subjected to a temperature gradient [20]. It is well known that in an internal combustion engine as much as 60% of the energy is wasted as heat. Even if a small fraction of this heat can be recovered, it will have a major impact on reducing energy consumption and pollution. Our IGERT student-faculty teams will investigate the optimization of the composition and processing of these materials into useful energy conversion devices [21].

Theme II: Water Quality and Wastewater Treatment

UW Participants: Brett, Stensel, Stahl, Korshin (Civil and Environmental Engineering); Meshcke (Environmental Health)

Key Partners: Tsinghua University, Sichuan University, Can Tho University, Tohoku University, the Polytechnic of Namibia, Eduardo Mondlane University, Pacific Northwest National Labs (PNNL)

Natural or deliberate contamination of water sources and supply systems with microbial agents of disease is of international concern [22]. Global population growth coupled with the widespread occurrence of improper practices (e.g., over-dosing of pesticides and fertilizers, inadequate treatment of industrial and municipal wastewaters) has caused a rapid degradation of drinking water quantity and quality [23, 24]. The emergence of new types of contaminants (e.g., residuals of pharmaceuticals and other endocrine disruptors) [25, 26] in combination with well-known ones (chlorinated solvents, disinfection by-products) [27, 28] poses a growing threat to exposed populations. Achieving sustainable water resources for growing populations in developing economies requires that water be treated in a manner that protects human health and the environment. The water group will direct multi-disciplinary research projects looking at the incidence of chemical, microbial and viral contaminants in drinking water supplies,

innovative municipal wastewater treatment processes, and the incidence of eutrophication induced cyanobacteria blooms in surface waters and drinking water supplies.

Microbial contaminants in drinking water: We will conduct a longitudinal study on the occurrence of microbial contaminants in drinking waters in the vicinity of each partner institution. The occurrence of microbial contaminants (including pathogenic viruses, bacteria, protozoans, and helminths) in drinking water due to the lack of sanitary water supplies and inadequate waste treatment facilities poses a significant threat to global human health. According to the WHO and UNICEF Global Water Supply and Sanitation Assessment of 2000, one sixth of the global population lacks access to an adequate/safe water supply [29]. The majority of treatment inadequacies occur in economically developing nations, especially rural areas. To assess the level of microbial contamination, graduate students will collect and analyze paired drinking water and source water samples monthly from ~ 50 locations for a suite of bacterial and viral indicators. These will include traditional indicators of fecal contamination (such as total coliforms, fecal coliforms and *E. coli*), as well coliphages and spores of both aerobic and anaerobic bacteria (*Clostridium perfringens* and *Bacillus subtilis*). Additionally, graduate students will determine the type of treatment (if any) for each water source and use this information to compare theoretical levels of treatment with the observed levels of treatment for each water source. This data will enable a quantitative microbial risk assessment to be generated for each of the examined drinking water sources.

DNA Microarrays for Viral Monitoring: Since most outbreaks of acute gastrointestinal illness are of unresolved microbial or viral etiology, there is a well-recognized need for improved diagnostic technology. As part of the proposed training program we will expand upon our current research in DNA microarray diagnostic technology to incorporate probes specific for Noroviruses [30]. These viruses have been associated with frequent food- and water-borne outbreaks, and have been implicated in outbreaks on cruise ships, in hospitals, nursing homes, and military barracks. In addition to providing improved molecular epidemiological methods, the use of this diagnostic tool to measure spatial and temporal variation during outbreaks would be invaluable for developing outbreak prevention strategies [31]. Noroviruses are small (27nm) RNA viruses, have a low infectious dose, may be shed from symptomatic individuals and cause acute gastrointestinal illness characterized by vomiting and/or diarrhea. Currently, the best available method for detection of Noroviruses is reverse transcription polymerase chain reaction (RT-PCR) followed by probe hybridization or genetic sequencing. PFGE ribotyping and RT-PCR are powerful techniques, however they require technically sophisticated equipment and personnel. These techniques are also time-consuming and costly, thus limiting their application as diagnostic tools. Our development of a microarray technology for the rapid detection and characterization of Noroviruses would provide an excellent tool for training students in microbial genetics, virulence mechanisms, and the development of advanced diagnostic methods. Initial studies would adapt a set of previously described, genotype-specific probes to our current microarray format [31]. We would use the Norovirus microarray as a prototype for future development of more comprehensive diagnostic arrays, designed to target other priority viral and microbial agents.

Chemical contaminants in drinking water: Due to the complexity, ubiquity and increasing concentrations of chemical pollutants in drinking water supplies, it is necessary to determine the mechanisms of their generation and breakdown and to explore new technologies to assure the availability of safe drinking water in developing nations. Drinking water treatment practices and perceptions of dangers associated with it vary dramatically from one society to another. The students working on this sub-project will examine the performance of conventional and novel water treatment methods (coagulation, ozonation, advanced oxidation processes) in the removal of unwanted chemicals or their precursors. They will use both methods to quantify the most important chemical entities (e.g., aromaticity, metal-binding capacity), and when necessary will isolate organic precursors from drinking water (e.g., by reverse osmosis or adsorption) to carry out advanced analysis using instrumentation available at UW.

Wastewater Treatment and Water Reuse: Wastewater treatment technologies that are more appropriate for developing nations and that also offer water reuse at reduced costs and with lower risks are evolving. We will direct graduate research projects in two such developing areas; processes using membrane separation technologies and processes providing a high level of biological nutrient removal. Membrane technologies involve the use of synthetic membrane materials with 0.1 to 0.40 μm pore sizes that can be used in place of gravity sedimentation and filtration to separate suspended solids and bacteria from activated sludge process liquors. Membrane separation provides excellent solids removal and may also capture bacteria. We have evaluated membrane separation technology for aerobic processes [32] and will also evaluate their application for anaerobic wastewater treatment processes. We focus on the following critical membrane technology issues: 1) the effect of biological nutrient process configurations on membrane flux and fouling control, 2) the preferred anaerobic process configuration for use with membrane separation to produce a recyclable effluent with minimal energy demand, and 3) evaluation of key microbial populations responsible for biological phosphorus and nitrogen removal in membrane biological reactors. A laboratory membrane biological reactor system will be in operation in our laboratories for the evaluation of biological nutrient removal process configurations for evaluating novel process improvements. Students will work with mechanistic models to evaluate biological and membrane processes, and develop experiments to evaluate process kinetics and membrane flux and fouling control.

Surface water eutrophication: We will conduct a study of surface water eutrophication at lakes and rivers in the vicinity of each partner institution. The cyanobacteria blooms typically associated with severe eutrophication are often times toxic [33], result in taste and odor problems in drinking water supplies, degrade fisheries production and greatly diminish the aesthetic qualities of lakes and streams [34]. Eutrophication induced algal blooms also lead to increased dissolved organic carbon concentrations in surface water, which when combined with the common drinking water disinfectant chlorine lead to the production of carcinogenic disinfection byproducts [35]. Thus eutrophication of surface waters used for drinking water supplies can have serious consequences for human health and the environmental quality of natural systems [33, 34]. Because most developing nations only have limited wastewater treatment, the potential for severe nutrient loading and hence eutrophication induced nuisance algal blooms is pronounced. To assess the extent of eutrophication in surface waters in general and drinking water supplies specifically the graduate students involved in this project will periodically sample 50 lakes and rivers in the general vicinity of each partner institution according to the US EPA developed EMAP random sampling design [36]. In addition to this randomized sample of surface water, the graduate students will also sample all surface water bodies used as drinking water sources. Each site will be sampled at 3-4 four times per year, and on each sampling date water samples for the quantification of total phosphorus, chlorophyll, clarity (as secchi depth), phytoplankton species composition, total suspended solids, and ash free dry weight will be collected, in order to conduct a comparative assessment of eutrophication severity in the study areas encompassed by this project.

Theme III: Goods and Services from Forest Ecosystems

UW Participants: Fridley, Hinckley, Henry, Hodgson, Reichard (Forest Resources)
Key Partner: Tsinghua University, Sichuan University, Can Tho University; Eduardo Mondlane; University of Natal, University of Auckland

Humans depend upon terrestrial ecosystems to derive a tremendous range of goods and services, from fresh water to land on which to build infrastructure, from farm and grazing lands to industrial forests to wild lands for recreation, to carbon sequestration and preservation of biodiversity. Many uses create tradeoffs, many uses lead to degradation, and most uses result in conflicts. The convergence of certainties mentioned in the introduction to this proposal insures that these problems will dramatically increase in the future without concerted, integrated, and cultural and locally appropriate solutions. Two words or phrases often are used to capture possible future solutions and these are sustainability and ecosystem health.

Sustainability and sustainable practices imply a temporal and multi-functional balancing act where, for example, a forest ecosystem provides goods and services that sustain human well-being while the ability of that system to provide those amenities does not degrade over time (nor potentially degrade other, unforeseen amenities which might be derived). Sustainability is relatively easy to define and to provide examples of, but, given the convergences mentioned, it is not easily incorporated at local, regional or global levels. All of the partners in this IGERT initiative are interested in some aspect of sustainability.

A major issue or focus in ecosystem goods and services is ecosystem health – this is manifested in a number of ways. For example, the President of the United States has proposed a change in public forest policy where the forests of western US should be returned to a "healthy" status via a combination of traditional forest management and prescribed fire. The Millennium Ecosystem Assessment Program focuses on how ecosystems provide goods and services that sustain and fulfill human life, how and why ecosystem health is in a state of decline, and, why, without assessment and locally appropriate emerging policies, ecosystems will continue to decline both locally and globally [37]. In a broader, more philosophical assessment, Victor and Ausubel argue that if society continues to rely on conventional forestry and agricultural to supply its fiber and food needs, there will be fewer and fewer wild forests in the future [38]. As noted by others, the biodiversity harbored in these wild lands or forests is the foundation for all ecosystem goods and services. In contrast to the historical approach, they offer a novel approach; an approach involving the careful and aggressive blending of diverse elements of conventional land management practices, more sustainable practices such as agroforestry and organic farming, appropriate incorporation of traditional knowledge and opportunities and advances in biotechnology. They term this approach the green restoration as it reduces the land area necessary for food and fiber production and increases wild lands, mostly forested.

Irrespective of the approach one takes to sustainability or ecosystem health, embodied in the wise application of any of the approaches is the need for a fundamental understanding of natural and human systems, the tradeoffs between them and the cultural and technical sensitivity and ability to bring appropriate, integrated technologies to local people. Three elements of the proposal insure this – the integration of disciplines, the orientation to problem solving and the international approach. Unifying our collective vision is a focus on fiber production and use; this weaves together the diversity of interests and backgrounds associated with our group. Cutting edge opportunities for student research include:

- The application of the fundamentals of interfacial (i.e., surface and colloid) science to an understanding the properties and processing of recycled cellulose fiber. Current graduate student projects are focused on challenges presented by the recovery and reuse of fibers from municipal solid waste; a critical step necessary to make this source commercially feasible. However, the payoff for utilizing this fiber source is potentially huge: reduction by 2/3 of the volume of material that must be landfilled, and a cheaper source of fiber for certain commodity products, such as boxboard.
- The integrated application of engineering design, computer graphics and graphical simulation to study a range of traditional and non-traditional natural resource management problems [39].
- A nationally and international recognized program in invasive and native rare and endangered plants – an ever increasing threat to native biodiversity [40] – has graduate students working in highly human impacted to wildland environments..
- A two decade long research program in canopy processes [41-44] in species ranging from old-growth Douglas-fir to fast-growing, hybrid cottonwood continues to address fundamental issues of productivity and forest tree domestication.
- Research programs in applied soil biogeochemistry (e.g., mining pollution [45] or the application of biosolids [46]) have a strong emphasis on practical problem solving. Students are currently working on EPA superfund sites and on forested sites with a long history of biosolid applications.

This core of set of projects will provide will a wonderful mixture of basic and problem-solving research and study opportunities for students.

Theme IV: Biodiversity

UW Participants: Hall, Olmstead, Ruesink (Boiology); Naish, Friedman (Aquatic and Fisheries Sciences)
Key Partners: Sichuan University, Can Tho University; Eduardo Mondlane University; University of Natal, University of Auckland

Biodiversity is the study of biological systematics and its inventory, the phylogeny of life, ecosystem complexity, and the processes involved in maintaining that complexity. The loss of biodiversity is reaching crisis proportions worldwide. Students involved with Biodiversity research through the IGERT program at UW will have the opportunity to participate in international research projects in collaboration with scientists and students in host countries. These collaborations will enable UW graduate students to learn how to carry out field work in developing countries, while contributing to the pressing needs to document biodiversity. At the same time, the research collaborations will enable host country scientists and students to address questions pertaining to the patterns and causes of biodiversity at a more sophisticated level. The University can play a key role in informing our society about Biodiversity issues through the education of tomorrow's scientists, teachers, policymakers, and citizens.

The crisis in Biodiversity stems in large part from the impact of human development on the natural world. In developed countries, the inventory of most prominent groups of plants and animals is well known and efforts are underway to prevent its loss. Most biodiversity research and graduate student training in developed countries now focuses on understanding the patterns of evolution among living things with the goal of understanding the origin and causes of diversification of life. However, in most of the developing world, the basic survey and inventory research needed to document biodiversity is still underway and far from complete. These two areas of research are inextricably linked. For example, as recently as 2002, a new species of conifer was discovered in the forests of Vietnam, which has been shown through phylogenetic research to be the closest living relative to the Yellow Cedar native to the Pacific Northwest. Collaboration between scientists in Vietnam, the US, and the UK made this research possible [47].

The reduction in diversity throughout geographic regions and even extinction of many species is taking place at a rate exceeding the ability of science to undertake that documentation. At the same time, scientists in developing countries are eager to begin the phase of biodiversity research that will enable them to address the sorts of questions being asked in developed countries. In order to advance the education and training of graduate students in collaborating institutions, US students will be given the opportunity to participate in research at host institutions to document biodiversity in places where the effort still is needed to make a difference in our understanding of global patterns of biodiversity. This is an important, yet often neglected, component of scientific training in biodiversity in US universities. By having this opportunity, our students will obtain a better integrated background in biodiversity research than would be possible without this International component to their graduate training. At the same time, they will collaborating with faculty and graduate students at those institutions to help integrate the sort of research questions and methods used in US universities into the academic programs at the host institutions, thereby implementing the IGERT theme of a shared focus on education reform.

Our team brings combined plant and animal expertise to these global issues. We have identified the following research areas for our multinational IGERT community. Some are ongoing as part of the *UW Worldwide* program with Sichuan University and the Institutes of Botany in Beijing and Kunming; others have been identified as representing critical needs in both China and in other regions in which we will work. We have identified the following overarching themes:

How can modern molecular phylogenetic methods be integrated into biotic surveys in developing countries to better document their biodiversity? The use of both of these approaches [48-50] can provide a powerful means of identifying "biological hotspots" of a range of plant and aquatic organisms in under-surveyed regions, hence facilitating the formulation of effective conservation actions. Current projects include a phylogenetic study of *Rhododendron*, which involves field work in the region of the world with the greatest diversity of *Rhododendron* species [51] and a molecular systematic study of the Asian tribe Hyoscyameae of the potato/tomato family, Solanaceae [52]. Future projects include integrating such work with phylogeographic studies of aquatic organisms in Asia [53].

What are local uses of native plant and animal species in indigenous cultures and how does that use impact the biodiversity in the region where it occurs? The effective maintenance of ecosystem function should include sustainable human agriculture practices, based on a genetically diverse array of organisms. Currently, we are conducting a survey of the plant biodiversity in the communally-used landscape of an ethnic minority community in SW Sichuan, with a special emphasis to document the ethnobotanically important plants in the region. We are researching the environmental consequences of the uses of native species in aquaculture, and the effects of escapements on related wild populations. The impacts of aquaculture are not well understood in countries that have a significant fraction of the world's biodiversity, yet aquaculture comprises an overwhelming portion of world production in these countries.

How can the spatial distribution of genetic variation within and among species be used to interpret the biological and physical factors (including climate change) that have resulted in patterns of biodiversity on the landscape at regional and global scales? The efficient management of threatened species requires that we identify reproductively isolated "evolutionarily significant units" to avoid inadvertent extinction loss. We are conducting research identifying such units in plants [54] and animals, by using traditional life history studies and modern molecular approaches [55].

What are the ecosystem consequences of changes in biodiversity? A number of factors play an important role in maintaining "healthy ecosystems". We are attempting to characterize thresholds in species interactions following such changes, thereby providing critical information on the ecological consequences of anthropogenic activities such as fishing, aquaculture and coral reef damage. We are also conducting research into the impacts of exotic species introductions on changes in biodiversity [56] and the role of biodiversity in ecosystem functioning [57] - part of the burgeoning debate casts biodiversity as an emergent property against the importance of particular species.

This integrated set of projects will provide our students the opportunity to study biodiversity in a holistic way that makes the international crisis more than just a theoretical construct, while at the same time providing researchers at the some of our partner institutions with access to the technology necessary to address the global-scale questions being asked at institutions such as the UW.

Theme V: Environmental Social Science

UW Participants: Chrisman, Beyers, Nyerges (Geography); Harrell, Peña (Anthropology); Abramson (Urban Design and Planning)

Key Partners: Sichuan University, University of Natal, University of Auckland, Tohoku University, Tsinghua University, Pacific Northwest National Laboratory (PNNL).

The social science component of this project spans a number of disciplines, with senior staff at UW drawn from anthropology and geography. Participants at partner institutions are also drawn from economics, political science, public policy, and sociology, depending on the research scholars active on each campus. The social science component seeks to problematize the whole division between a "human" component and the "environment". We see not a simple duality, but a series of complex interactions in which people create complex systems that influence every facet of the "natural" systems. Rather than seeing the human component as exogenous "drivers", we will emphasize recursive interactions, and particularly the role of

information in mediating different views of the environment. Environmental justice, the equitable distribution of resources and negative impacts, is a unifying theme.

The regional economics framework mentioned above as part of the eco-materials research provides one framework to add a human component to all the other four clusters. Economic geography provides methodology to integrate the secondary and tertiary impacts of changes in inputs and outputs of industries distributed across a region, as well as between regions.

A major concern of social sciences deals with participation in environmental decision making. Nyerges has led a string of projects to study participation through the use of information technologies. Chrisman has experience with international comparative work on environmental information systems. Harrell has extensive experience with minority groups in southwest China. We will connect these backgrounds with the resources available at our partner institutions to deal with the negotiations that occur between scientific knowledge and other interpretations. Over-arching questions that will inform the environmental social science research include:

- How do the social structures of local communities change as government policies, including various development and environmental policies, are applied to those communities from the outside? To what extent are alternative views of the environment negotiated?
- How do community members perceive questions of environmental change, pollution, and environmental protection, and how do these perceptions affect their economic and social activities over time? How are these perceptions related to organized scientific information, and how are competing viewpoints negotiated in coming to decisions?
- What are local community needs for environmental education: how can both an appreciation of the environment and the practical knowledge to preserve it be included in local school curricula?

Two projects illustrate the type of local field studies we envision students undertaking with IGERT support. The first is a detailed ecological study of a rural community over time from the work of Devon G. Peña and his associates in the San Luis Valley in the Upper Rio Grande region of northern Colorado. This 10-year long study combined methods from environmental natural sciences such as soil science, hydrology, and botany with results from ethnographic and ethnohistorical studies of the community [58].

The second example is major project currently underway in Sichuan Province, through the *UW Worldwide* program and involving faculty from 3 of our 5 themes. The primary research objectives are to develop a comprehensive and detailed assessment of the human and natural ecology of village ecosystems; the effort so far has concentrated in the area around four villages in Liangshan Yi Autonomous Prefecture, Sichuan. The program contains four primary components:

1) *A survey of the physical characteristics of the various ecological zones included in the local environment.* In cooperation with the forestry and biodiversity components, we are examining the plant community both quantitatively and qualitatively, as well as testing soils and making GIS-based inventories of the region. In addition, native knowledge of the plants used in the local environment is being recorded and analyzed through ethnobotanical work with village elders and other residents.
2) *A survey of human productive activities and their adaptation to and influence on the environment.* This includes extending our study of the plant community to agricultural areas; interviewing farmers about historical and current agricultural and livestock raising practices, measuring forest product use and comparing it to the available forest resources.
3) *Research on the social structure of the community and its changes* from the period of traditional society before 1956, through the Great Leap Forward, the Cultural Revolution, and China's recent Reform and Opening.
4) *Assessment of the educational needs and prospects of the community*: This component includes monitoring of the progress of students in a local elementary school, taught with a combination of

traditional and more innovative pedagogical methods. In particular, the results of ethnobotanical work with the collections made by the biodiversity students are incorporated experimentally into upper-grade natural science classes, and local students given responsibility to take over continuing climatological monitoring of rainfall and temperatures.

Projects of this type, in which social scientists work closely with natural sciences and engineering, and which involve balanced participation and benefits for all partners, are the type we envision for graduate students from the social sciences in our IGERT.

C2: Coupled Human, Natural and Materials Systems: It is clear that the questions posed above under the five disciplinary rubrics are difficult to answer if scientists remain wholly within their own disciplines, and much easier to solve through interdisciplinary cooperation. For example, knowledge of human productive activities and their influence on the environment, an anthropological question, depends on physical assessment of the environment through forest ecology, water resources, biodiversity, and other natural science disciplines. By the same token, the structural impediments to environmentally friendly manufacturing, a materials question, are best answered in concert with research by social scientists about the ways policies are formulated and implemented through local bureaucracies and local social structures. The focus on international collaboration with a number of partner institutions and on a number of distinct but richly interconnected research themes, gives us opportunity to engage students in research training that is distinctive and highly valuable. The most distinctive elements will come from the coupling between the five clusters as well as from the comparisons between regions around the world. This section describes some of the advantages we see stemming from the formation of this complex community.

To some extent, a call for "integrated science" is hardly surprising or new these days. There have been many thoughtful recommendations from many blue ribbon panels, but results from collaborative projects spanning a large number of disciplines are harder to find. Why? Interdisciplinary work is complex, and the environment itself makes larger projects more unwieldy. One path to avoid some of the difficulties takes the research agenda from some lofty plane of integrated science in the abstract down to specific interactions in specific places. This kind of "place-based" science is one of the key recommendations from the Advisory Committee for Environmental Research and Education in their report "Complex Environmental Systems: Synthesis for Earth, Life and Society in the 21st Century" produced this year as a "10-Year Outlook for the National Science Foundation" [59]. We hope to train a new generation of environmental experts through this project who will have first-hand experience in the messy details of complex systems. We can point to some examples of the kinds of couplings from some current projects that can serve as pilots for the research on coupling among our five clusters.

When the Boeing plant at Paine Field in Washington State attaches a tail assembly to a new 757-200, they do more than connect pieces of the airplane. This tail assembly has been constructed in Chengdu in the Sichuan province of China. This connection means that the economic interactions between these regions have become more complex, and the environmental consequences more intricate. The aluminum used by Boeing can be supplied from US smelters, but the competing demands for electrical power run right into concerns about the flow of water in the Columbia River and the linkage to endangered species. A switch to Chinese sources for some of the components of a Boeing airplane substitutes the Sichuan smelters, also dependent on hydropower but from a very different set of rivers. Our IGERT team engages in research that combines comprehensive analysis of materials processing at the plant level in both Sichuan and Washington State to the economic flows that link these two economies in the far-flung world economic system. We combine life cycle inventory methods from engineering with regional economic input-output techniques from the social sciences. These techniques have much in common, but the connections remained theoretical until assembled for the larger purpose of region-based research.

A second example of the way the themes in our project are interwoven comes from the Mekong Delta, the region around Can Tho University in Vietnam. Each successive administration of the region has

constructed canals, diversions, and dams to reroute the flow of water and to drain land for agricultural purposes. While the intentions were often laudable, the results have had manifold negative consequences on the native mangrove forests, the fisheries in the waters and the potential for agriculture. Each group that confronts the Mekong Delta—colonial engineer, wartime planner, rice farmer, contemporary scientist—has a distinct set of values for the landscape. Canals encapsulate interactions between various human interest groups and the delta environment. Canals move volumes of water in the overall delta hydrological network. They are critical to agricultural production, especially during the dry season when salt intrusion is most severe in coastal areas. With future predictions of sea-level rise, canals and the hydraulic infrastructure will be central to maintain current levels of agricultural production. Likewise, survival of estuaries is important to water quality, flood control, and fisheries. In most cases, canal construction occurs at the expense of these estuaries.

The coupling of human and natural systems in this example engages many relationships beyond concerns with water quantity. For example, rice agriculture (particularly as it has expanded on the acid sulphate soils of the reclaimed delta) creates a load of acid into the canals [60]. The major ion involved is Al^{3+}. The acid outflow is at its peak at the onset of the rainy season (June to July) with dramatic consequences for aquatic invertebrates and fish. Some tree crops (particularly *Melaleuca cajuputi*) can absorb and neutralize acid from the rice paddies [60]. Thus, the issue of water quality is strongly linked to the crops that are economically viable and ecologically sustainable. Our partners at Can Tho have a strong interest in these coupled systems. These interactions require civil engineers, agronomists, and botanists to participate in a common effort with historians, geographers, economists and anthropologists. The interactions in the Mekong have comparisons to mangrove swamps in Mozambique as well as to other kinds of hydrological manipulations and aquatic health in Washington State.

As these examples indicate, our research team will be able to engage the couplings between human, natural and materials systems in a more efficient manner because of our connections to our partner institutions. By engaging with scholars at our partner institutions and their graduate students, we hope to build a long-term set of connections that our IGERT trainees can develop over their research careers. If our program works well it will assist in the launching of life-long collaborations, created at the time when research scholars are most able to forge new alliances. The "invisible colleges" that mold interactions between colleagues are formed in the years of graduate training [61].

D. EDUCATION AND TRAINING

Participation in a multinational research team that addresses a concrete interdisciplinary challenge is the core of the innovative experience we will offer our IGERT students. Essentially all of the elements of our educational program are built around the central goal of building in our students the capacity to engage creatively, sensitively and effectively in multinational research teams that work on practical interdisciplinary environmental problems. Thus the integration of education and research is central to our program design. Another key principle is the recognition that our programs must be designed such that the benefits to participating institutions are reciprocal, if the programs are to be sustainable. A third principle is that the research projects around which the educational program is woven need to be of real practical benefit to the communities that the participating universities are intended to serve, and to involve local stakeholders in their design and implementation.

The cluster of universities we have brought together in this IGERT team all have very strong track records in targeting education and research towards the solution of regional and national problems. Students and faculty at each of the institutions stand to gain a great deal from learning about each others' experience. This cluster of institutions is large and diverse enough such that we can really benefit from the comparative assessment of a common set of challenges, yet small enough such that the relations among us can be meaningful and intensive. The institutions, furthermore, have made the commitment to

bite the bullet and try out some dramatically new models for graduate education and research, models that could inform the future of their graduate programs if they prove successful.

Basic Features of our Educational Program: Students in our IGERT will be drawn from a variety of disciplines and will have a wide variety of career aspirations. All students will receive their degrees in their home departments. Graduate training for the doctorate traditionally focuses on building conceptual, experimental and applicable expertise in some cutting edge area of specialization – our approach does not abandon this time-honored approach, but incorporates a set of parallel activities which build students multi-disciplinary and multinational teamwork skills, and which immerse them deeply in another part of the world, working together with local partners on a complex research project. Students will be exposed through real world problems in an international setting to the value of including local knowledge, being sensitive to cultural values and embracing the needs of local communities. The primary departments from which students will be drawn include: Civil and Environmental Engineering; Materials Science and Engineering; Biology; Forest Resources; Aquatic and Fisheries Sciences; Geography and Anthropology.

Three-Quarter Course in "Coupled Human, Natural and Materials Systems": This three-quarter project-based course sequence serves as the introductory, community-building activity for each cohort of students admitted to our IGERT. Faculty from each of the five thematic research clusters will participate. As mentioned in the previous sections, students in our IGERT have two qualitatively distinct but overlapping research communities in which they participate. The first is their primary "thematic research cluster", e.g. water quality or eco-materials. Each student is also a member of the broader IGERT community that spans the five thematic clusters. In the design of the three-course introductory sequence, we have taken the following strategy:

1) Introduction to Coupled Human, Natural and Materials Systems: We will begin with the big picture in the first course in the sequence. All students will get a basic exposure to the key environmental challenges addressed in our program. All students will also get an overview of the environmental monitoring and assessment tools that can be used across projects, an introduction to the partner universities, and an overview of the regional issues they are facing. Students and faculty at partner schools will participate electronically in many aspects of this course, which will be offered jointly for credit at partner institutions. In the first quarter students work in "pairs of pairs" with students at one of the partner schools, to generate the first web-based illustrative example of the coupling of two of the five themes at two of the partner sites. They will also launch the first version of the web-based concept map and multi-lingual, multidisciplinary glossary, as described below.

2) Introduction to Coupled Human, Natural and Materials Systems (Part 2): In this second part of the sequence, student teams zoom in on a specific phenomena within a thematic cluster, again, building a multinational comparison of that issue. Examples include a quantitative comparison of the state of wastewater treatment in all of the regions represented by our project, or a comparative assessment of the health of forest ecosystems across regions. Again, the product of this course is a web-based document that summarizes the status of knowledge of these phenomena among our student working groups. This quarter will also include a special module on the conduct of responsible research in their particular discipline. Students will share these findings to gain a sense of different approaches to the ethics of scientific research and professional practice.

3) Introduction to Coupled Human, Natural and Materials Systems (Part 3): In the third part of the sequence, student zoom out again to synthesize the knowledge they have gained working in their thematic research clusters. They re-address the cross-national comparison of couplings they undertook in the first quarter. They begin to develop project ideas (each of which must be created with a student collaborator in one of the partner schools) that can serve as the basis of their international internships. They will also re-address the web-based concept map and multi-lingual, multidisciplinary glossary, from the first quarter, updating it, and critically reflecting on the growth of

their understanding. This quarter will also provide some preparation for fieldwork and the practical issues of international exchange.

By the end of this three-quarter sequence students will have: 1) identified which of the one or more thematic research clusters they wish to call home; 2) made significant intellectual connections with students and faculty at one or more of the partner schools; 3) gained a relatively nuanced level of understanding of how human, natural and materials systems interact; 4) have a big picture of the challenges facing the partner regions and the opportunities available to them at partner schools; and 5) begun to define ideas for what they will work on for their international research internships. At the end of the sequence, we will conduct the first of our early stage "dissertation workshops", as described below.

Dissertation Workshops: In our approach to building ongoing and effective multi-disciplinary graduate communities, we rely heavily on the experience with the "dissertation workshop model", pioneered by Dr. David Szanton. These workshops were first developed at the Social Science Research Council, then implemented widely at UC-Berkeley, and then applied more broadly at other universities in the US and abroad, including at two of our partner sites, the University of Auckland and the University of Natal. This dissertation workshop model, which to date has been applied primarily in the social sciences and the humanities, brings together clusters of graduate students, drawn from a variety of fields but sharing a common interdisciplinary research theme. Together with a small set of faculty, students are guided through a multi-year process of defining, critiquing, evaluating and strengthening each others' work. This model has proven successful in helping students understand how to communicate complex ideas to a diverse audience, in assisting them in refining research objectives, and in forming long-term communities of collaboration [62]. The model has proven to work well in different national settings, and with diverse student bodies. Our project will, however, provide the first implementation of the basic approach for students in natural sciences and engineering. Modifications will also be required because of the geographic dispersion of our student participants. Nevertheless we are confident that many of the benefits that stem from the formation of lasting communities of peer support will also hold true for our students.

We will offer two dissertation workshops for each cohort of IGERT Fellows in our program. The first workshop will be offered at the end of the required 3-quarter project-based sequence on *Coupled Human, Natural and Materials Systems*. Thus we can build on the activity launched in that course, and also help student to prepare for their international research internships, which will take place shortly thereafter. We call this the "early-stage – problem-definition" dissertation workshop. Typically the 12 – 13 IGERT Fellows admitted to the program each year will participate in this 3-day workshop together, with 4 –5 faculty members, at a remote off-campus site (one of the UW research facilities maintained by our Colleges of Forestry and Fisheries will be our first choice). Later in their program, after students have undertaken their international research internships and are well underway in laying out their dissertations, we will offer a second, "dissertation writing workshop" to each cohort. Between these two bookends, we will use asynchronous web-based collaboration tools to continue to discussion of shared topics.

International Research Internship: Each student in our program will be required to undertake a research internship at one of the partner sites for a minimum of 6 months duration. We will encourage most students to spend a full year. This internship will be under the supervision of one of the participating faculty members at the partner schools. Each of the partner universities has a deep commitment to participating in the project, and the quality of the research supervision will be very high. Most of our partners already have experience in hosting UW doctoral students for their research. All students will have a well-defined research project, vetted by advisors at UW as well as approved by their host professor, before leaving for their internships. Group projects will be encouraged, but individual projects will be accepted. In all cases, there will be a clear connection with the research and educational priorities of the partner institution. The UW faculty will bear the responsibility for working with the partner co-advisors to assure that the project is realistic, and that the student will have the resources needed to succeed. On return, each student will be required to complete a written report on her

experience, and to make a presentation to the on-going IGERT weekly seminar. Thus the steady-state IGERT community of new students will be continuously enriched by the insight the returning students have to offer.

Ongoing IGERT Seminar: The weekly IGERT seminar is the venue where all of the branches of our community come together. In the steady state, this community is enriched by: UW IGERT students (both entry-level participants, and those who have returned from their international internships); exchange students from the other campuses, visiting scholars; faculty from all of the various departments, interested undergraduates and local community members involved in our programs.

Pedagogical Internship: One of truly innovative aspects of our program is our required pedagogical internship. Here, we are strongly influenced by the benefits science and engineering students gain when they engage in educational activities with local communities. In terms of their intellectual and professional development, personal satisfaction, and retention in science and engineering, engagement in these types of educational reform activities has proven to be extremely valuable for our students, while also yielding considerable benefits to the communities they serve. As examples, we cite our experience with the multiple activities of the NSF-sponsored ECSEL Coalition and our more recent PRIME program (funded by the G-K12 initiative of the NSF). PRIME sends graduate students in science, math and engineering to local middle schools, to work with teachers and students in hands-on inquiry-based activities related to the graduate students' research areas. In an international extension to the PRIME program, we have also sent graduate student- middle school teacher pairs to two of our partner sites for this IGERT, Tohoku and Sichuan Universities, to work with local Japanese and Chinese middle schools. Both for the US teachers and students, and for the partner schools, this proved to be an extraordinarily valuable experience. In recognition of the value of these activities for the professional development of our graduate students, we have included a required "pedagogical internship" in our IGERT program.

The pedagogical internship can be completed in a variety of ways. It will focus on international issues in science education, but the experience can either take place in Seattle or at one of the partner institutions, for example when the student is there for research. The internship can be done either at the K-12 or the undergraduate level. For example, a student could choose to help a local elementary teacher introduce some activities comparing catfish aquaculture in Vietnam to salmon farming in the Pacific Northwest. Another student might choose to help a university professor at his partner site introduce topics related to Native American claims to forestry rights in a class on forest ecology; while a third student might satisfy this requirement by supervising a group of *UW Worldwide* undergraduate students undertaking a group project on alternative materials for wastewater treatment. A multi-disciplinary team of faculty will be responsible for overseeing and approving the projects undertaken to satisfy this requirement and each student will prepare a written report and oral presentation based on her experience. This documentation will be part of a teaching portfolio for those seeking employment in academic institutions.

Tools for Collaboration: All graduate programs require thoughtfully designed means to create communities of participation. Because of the geographic distribution of our sites, and the multilingual, multi-cultural nature of our IGERT, the challenges of building sustainable graduate research communities are more demanding; analogously, though, the opportunities to do something truly exciting and innovative are enormous. We have four specific plans that involve developing tools to foster ongoing collaboration; the process of creating, using and refining these tools is a core part of our educational plan.

Development of a multidisciplinary, multilingual concept map and glossary: As a route to building an intellectual community which can work together more effectively, we will implement a web-based multi-lingual concept map and glossary, in the broad area of coupled human, natural and materials systems. Contributions will be generated by students and each campus will have a rotating "glossary coordinator", who will help stimulate and organize participation. The IGERT office will maintain the site. Students usually find each other the best guides on understanding new and complex ideas, and informal networks

of information-sharing play powerful roles in graduate education. This website will be a way to organize that sharing mechanism more transparently, and to make it accessible to a wider community. Students will offer information, for example, on the best introductory articles in a field, where the best info is on the web, and what practitioners in a given field really "mean" when they use a given term. While this may seem straightforward, miscommunication between different disciplines and between communities of practice is well documented in the literature of science studies [63, 64]. The concept of a "boundary object" [65, 66] has become a robust analytical tool to describe how different groups can learn to "agree to disagree" – to understand how each scientific discipline redefines objects and interactions according to specific world views. Our concept map and glossary will be a dynamic entity, one that allows each contributing discipline and institution to have a voice. By negotiating the overall structure of the concept map, students will come to a deeper understanding of the complex systems we are studying, while also becoming aware of the roles cultures, values and experience can play in the interpretation of ideas.

GIS-based tools for collaboration: The second strategy to foster cooperation involves the construction of geographic information. The principals in this project already use geographic information systems (GIS) in their individual research. We intend to make the GIS database a shared space in which couplings between each theme become more apparent since they are operating in the same places, linked by various environmental and human processes. "Spatially explicit information" is seen by the NSF Advisory Panel [59] as a key element in fostering integration of human and natural systems. Nyerges and Chrisman have 15 years experience in teaching a GIS Workshop, which has maintained a strong emphasis on connection to community issues using teamwork and collaborative tools. This will be a model for our program.

Web-mediated tools for group-decision making: The last set of tools involves management of group participation, a meta-level coupling of all our efforts. Nyerges has studied group participation in various environmental modeling and decision processes involving hydrology, pollution cleanup and nuclear waste disposal [67]. In this process, a number of web-mediated tools have been developed to critique documents, manage collaboration asynchronously, and integrate databases. We will combine these resources with other public domain tools to ensure robust interactions among our distributed teams.

Electronic Portfolios: Each student will create an electronic portfolio of the work she completes in our program. These e-portfolios will serve a variety of purposes: they are a mechanism for students to share their work with each other as it evolves; they can ultimately be used as part of the application materials students use when they go on the job market; they can serve as a window to the outside world on the research of our IGERT and will be shared with outside experts as part of the evaluation of our program, as described in the Section F: Performance Assessment. Most importantly, developing the e-portfolio is a professional development activity for the student herself.

Professional Development, Ethics and Career Awareness: We are fortunate that UW is home to the newly created Center for Innovation and Research in Graduate Education (CIRGE), and to the Re-envisioning the Ph.D. project, funded by the Pew Charitable Trusts. We will work with CIRGE and the Graduate School to design seminars for our students that help them better understand the variety of potential career pathways that are possible for them, especially in the international arena. The seminar will also focus on the ethical conduct of research, again, with a particular focus on international and cross-cultural challenges. CIRGE will also work with our IGERT on team dynamics issues, and on designing processes for more effective communication.

Studies in Language, History, Culture of Partner Regions: We are fortunate in the great depth of language instruction available to us at UW – almost all of the languages needed for our program are taught, and we can obtain the assistance of local tutors in others. While the level of linguistic competence required for research varies from discipline-to-discipline and from region to region, we are committed to helping all of our students gain at least conversational competency. Some of the students may benefit from various foreign language training grants (such as FLAS) in addition to their IGERT

funding. In addition to the language training, students (particularly in the more technical fields) will require additional exposure to the history and culture of their selected region. There are numerous existing courses at UW we can draw from. In addition, each of the students from engineering, the natural sciences and forestry will have a social science advisor who will help the student create a program of self-study on the region in which she will be conducting research.

Role of Diversity in Our Program: Diversity issues are interwoven into the design fabric of our program in multiple ways. These include the choice of partner institutions, the academic character of the research projects, the choice of required program elements (described in Section I), the management structure (in Section E), and the recruitment and retention strategies (in Section G).

Student Pathways, Sequence and Staging: Our program brings together faculty and students from a wide variety of departments and from four colleges and schools (Engineering, Arts and Sciences, Forest Resources and Ocean and Fisheries Sciences). There are very significant differences in the culture and practice of graduate education across these units, which will demand creativity and flexibility on our part. To make the program work well for a diverse set of students, it is essential that we allow multiple entry points, multiple pathways to its completion, and multiple options for the timing of the international travel.

Except for the first year, we expect most students to join our program at the beginning of their doctoral training. Each cohort will take the introductory three-quarter course sequence together; it is extremely important to catch them early, so as to be able provide them with a vision of all of the possibilities for interdisciplinary research in our IGERT, as well as to start bringing them together as a team. In their first year, they will also participate in the first of the "dissertation workshops", again, as a cohort. After the first year, their pathways through our program will diverge somewhat, based on the differing qualifying procedures and timelines in the various departments and on the variation in language and technical skills they need to have under their belt prior to leaving for their international internships. Some will be ready to go abroad as early as their second year; for others, it will be more appropriate to wait until the third year. Regardless of the variation in departmental practice with respect to qualifying procedures for the Ph.D., our IGERT program will require them to have completed a coherent plan (which is approved by the UW advisor(s) and the co-advisor at the partner site) before they leave for their internship. On average, each student will be supported with an IGERT Fellowship for two years. Typically, these years will be the first year and the year of the international internship, whenever it takes place. Upon return, the student will complete the requirements of the department and the program, including the pedagogical internship (if it has not been completed at the partner site) and writing up the results of the research. The second "dissertation workshop", which focuses on assisting the students in the writing stage, will bring each cohort back together again. These workshops, and the tight networks formed among the students in our program, are a key strategy for reducing the time to degree. The average time to degree in our departments varies considerably. It is significantly lower in engineering than in the other departments (about 5.5 years). Our goal is to accelerate the progress of the students in the other programs (bringing them closer to the engineering average) while bringing the engineering average down below 5 years.

In the first year of IGERT funding, we will recruit a special "pioneer cohort" of students who are already quite advanced in their studies in one of our departments, and who already have international experience (preferably in one of our partner regions). This "pioneer cohort" will work with us in the first year to further refine the details of the steady-state program we will offer in the beginning of Year 2.

E. ORGANIZATION, MANAGEMENT AND INSTITUTIONAL COMMITMENT

Program Organization and Management: Our IGERT is a complex entity and will require a strong and stable administrative structure to accomplish our goals. The Program Director, Prof. Gretchen Kalonji, will be responsible for overseeing the operation of the program. Prof. Kalonji has extensive experience both in the management of large-scale multi-institutional educational reform initiatives [68], as well as in

the shepherding of international research and educational collaborations [69]. A Local Management Team will be established to guide the operations of the program at UW. This team will be chaired by the IGERT Director, and will include the IGERT Co-PI's, a representative of the UW Office of Minority Affairs, a student representative, and a representative of our Local Evaluation Team. The Local Management Team will be responsible for developing and implementing policies for all aspects of the program, and for assuring equitable allocation of group resources. The Local Management Team will meet at least monthly to review program progress and address issues of policy, procedure and resource allocation as needed. The Local Management Team will also be responsible for evaluating and selecting students for admission to the program.

An IGERT office will be established in the UW Department of Materials Science and Engineering. Existing administrative staff has extensive experience with the administration of grants and fellowships, travel, and payroll. A half-time secretary will be appointed to handle communications associated with IGERT recruiting, update IGERT databases, process student files, create materials for workshops and meetings, and manage the logistics of local events. A half-time international coordinator (whose responsibilities are described in Section I: International Coordination) will also be appointed. For the first two years of the program a post-doctoral associate will be hired (to be paid 50% on NSF funds and 50% on UW funds) to work with IGERT faculty in the areas of research design, initial curricular development, and development of web-based communication and collaboration tools.

Many faculty members will participate in program management. A Core Curriculum Committee, led by Prof. Richard Olmstead, will have as its primary responsibility the design of the required 3 quarter course sequence and the curricular pathways of the students from the various departments. An Evaluation Committee, led by Dr. Laurie Collins, has primary responsibility for the local program evaluation. A Student Advisory Committee will be established; the Chair (chosen by the students) will participate in the Local Management Team. A Recruiting and Communications Committee, led by Prof. Nicholas Chrisman, will have responsibility for creating and disseminating recruiting materials, and for developing reports, publications and websites for our about our various activities.

Student Selection and Support: There are two routes through which students will be admitted to the IGERT Program, an external route and an internal route. We expect that after the first year of our IGERT program most students after the will be admitted through the external route. They will apply to our program at the same time as they apply for admission to graduate school in one of the departments from which we have faculty participation. Supplementary application materials for our program will assess whether the student has the personal background and perspective to thrive in our highly challenging and interdisciplinary community. The second, internal, route is a pathway for students who are already in graduate school at UW. The application process and materials are similar to those for the external candidates. We will be more flexible about participating departments, though, as we hope to grow the pool of faculty who work with us through attracting their best students to our programs; there will be no restriction on department for the students who enter through the internal path. The average time participating students will be supported on IGERT funds is two years. For students entering via the external route, recruiting packages will be assembled by participating departments that in general include support from other sources and guarantee the best applicants full support for the duration of their Ph.D. programs. In general, we expect the IGERT support periods to include the first year (in which the initial cohort building and required 3 quarter introductory course sequence occur) and the year in which the international internship takes place (which will be either the second or third year, depending on language training needs, scheduling of departmental qualifying procedures, and other research logistics). We will admit 12 – 13 students per cohort, and will offer a total of 63 IGERT Fellowships during the 5 years of our program.

An International Management Team will be established to guide the multi-institutional collaborations. Its responsibilities are outlined in Section I: International Coordination.

Institutional Commitment: UW has shown strong institutional commitment to this project. The basic strategy of our program stems from the work of the International Faculty Council, a body which was appointed by recently ex-President Richard McCormick and which was chaired by Prof. Kalonji from 1998 – 2002. The central strategy adopted by that group was the integration of research and education through the creation of multi-disciplinary student-faculty projects. A new campus-wide initiative was launched to undertake this basic approach called *UW Worldwide*. UW higher administration dedicated internal funds of $750,000 from the so-called Tools for Transformation Fund to launch the *UW Worldwide* program. Though no matching funds are required for the IGERT, we are dedicating $150,000 of this funding as a cash match to this grant. The UW institutional support extends down from the President and Provost level to very strong support from participating deans and chairs. All of us are committed to making the program sustainable, assuming it lives up to our expectations in terms of the quality of the experience it provides our students.

F. PERFORMANCE ASSESSMENT

Our expectation is that this project will serve as a national model for the more effective internationalization of graduate education and research. As such, the evaluation component is of vital importance. For innovative programs, the primary goal of evaluation is to characterize and assess the effectiveness of a program in terms of its goals and to provide feedback to program administrators for the purpose of continual improvement [70]. Our assessment program must also provide insight into the IGERT's effectiveness in terms of current best practices in international research collaborations and in interdisciplinary graduate education. Our strategy incorporates both a local team and an external contractor. In addition, both our strategy and our assessment instruments are informed by the results of our extensive evaluation studies of our undergraduate *UW Worldwide* projects [10], and by experience with the NSF-sponsored Engineering Education Coalitions [68].

Locally, our evaluation team includes professors from UW's College of Education (Min Li and Maresi Nerad); education graduate students (we expect one student per cohort to be supported as an IGERT Fellow, focusing specifically on international environmental education and research); and participating science and engineering faculty. Dr. Laurie Collins, of UW's Office of Educational Assessment, will chair the group. The team will implement an infrastructure that promotes opportunities for incorporating assessment strategies into program administration and that provides prompt and effective feedback. This includes (1) working with the faculty to refine program goals, (2) actively contributing to the development and enhancement of program activities and strategies (including courses, dissertation workshops, mentoring programs; pedagogical and international internships, etc.), (3) informing administrative planning and resource allocation, and (4) utilizing a common language for identifying program goals, outcomes, and measures to promote efficient incorporation of feedback.

The local evaluation team will select, develop, and administer assessment instruments and procedures; collect and analyze the data; monitor program accomplishments; synthesize the data into written summaries; and provide formative feedback to program managers on a regular basis, as well as summative evaluation at the conclusion of the program. Multiple methods will be used for triangulation purposes, and will draw from both qualitative and quantitative assessment methods [71] as shown in the following table. Our evaluation efforts will be coordinated with similar activities at the partner sites.

Our external evaluator is Dr. Susan Millar, from the University of Wisconsin, Madison. Dr. Millar has extensive experience in the dynamics of educational reform and institutional change. Dr. Millar will provide an external perspective on the quality of the experience we provide our graduate students and on the prospects for institutionalization of our new model. This will be accomplished by interviewing a select set of critical team members and students during a yearly visit to campus, and by consulting with us from a distance during the academic year. Dr. Millar will also provide a critical meta-level view of our

evaluation process itself, helping us to understand if there are issues we have missed or additional methodologies that we might employ.

The evaluation will assess the effectiveness of the program in three areas: benefits to students, benefits to faculty, and institutional change. We will also request assistance from technical experts to review electronic portfolios of student work, in order to assess the quality of research accomplishments. We plan to draw these reviewers from other IGERTs with environmentally-focused themes.

Table 1. Details of Performance Assessment Plan:

IGERT Goals and Outcomes	Assessment Methods
Goals for Students (e.g., learning, research, professional development): • Interdisciplinary knowledge and skills • Disciplinary depth; igh quality research accomplishment • International, multi-disciplinary teamwork skills • Understanding international variation in scientific research and education • Highly effective communication skills • Understanding of how social, cultural and economic factors constrain the realm of possible solutions to technical problems • Preparation for and awareness of a variety of career pathways	Surveys, interviews, reflective essays, concept maps, performance-based tasks, analysis by experts in research field of contents of students' e–portfolios
Goals for Faculty • Increased international dimensions in research, educational and service • A greater focus in their research on interdisciplinary practical problems • A more sophisticated ability to work with diverse, multinational faculty and student bodies	Interviews, surveys, monitoring of collaborations
Goals for IGERT Program and for Institutional Change • Greater research and educational collaboration between participating departments • IGERT funds should leverage new projects (e.g., catalyze single and multi-institutional grants, launch new sub-projects in promising areas) • Greater success in attracting and retaining a diverse student body to our degree programs, and to international exchanges • Reciprocal benefits to partner institutions in research and curriculum development; Increased student and faculty flow between partner • Sustainable infrastructure to support integrated graduate educational programs with international partners in the long term	Peer review of research accomplishments; interviews; database of participants and accomplishments ; tracking research funding levels; document level of institutional support

In summary, our evaluation plan incorporates: multiple evaluation perspectives, multiple assessment methods, integration of evaluation strategies into program implementation, formative and summative evaluation, a management and documentation system, and a synthesis of our existing expertise. We are committed to disseminating our results widely to the higher education community, through publications, presentations at conferences and workshops, and through the IGERT website.

G. RECRUITING, MENTORING AND RETENTION

Our IGERT will provide an opportunity to attract a very special cadre of graduate students to UW. Many students leave science and engineering at the undergraduate level because they do not perceive our fields as offering career pathways which 1) give them opportunities to work with people; and 2) give them opportunity to use their technical skills on some of the "big" problems facing our communities. It is students' perceptions of our fields as being narrow and divorced from social meaning that drives many students away, and disproportionately discourages female and minority students [73]. From our experience with *UW Worldwide*, the students are willing to engage in such interdisciplinary endeavors as well as to dedicate significant portions of their lives to intensive research in an international setting, are very special indeed. We expect them to be courageous, imaginative, compassionate and energetic.

Once we have brought these marvelous students to our campus, we will dedicate ourselves to helping them complete their degree programs and to assisting them in launching their independent professional careers. We are fortunate that UW is home to many very successful and pioneering efforts in mentoring and retention, particularly for students from underrepresented groups. Our IGERT will build on these efforts, while simultaneously contributing to these programs by giving them insight into how the international character of our community affects student satisfaction and success.

Recruiting: We will recruit nationally for this IGERT, and expect in the steady-state to use most of our IGERT Fellowships to attract outstanding external candidates. We will pay special attention to targeting the following institutions: historically black colleges and universities; tribal colleges; and campuses with high Hispanic and Pacific Islander enrollment. In addition, we will focus special attention on schools that have innovative undergraduate environmental programs, and that have particularly strong track records in sending their undergraduate students abroad. Interestingly, the heavily international focus of our program will almost certainly help us in attracting greater numbers of females to our graduate science and engineering programs; women are significantly overrepresented in study abroad programs at the undergraduate level throughout the disciplines [8]. We will also recruit among returning Peace Corps volunteers and through environmentally focused non-governmental organizations. We will work directly with the student professional societies, such as the National Society of Black Engineers, American Indian Science and Engineering Society, the Society of Women Engineers, and the Society of Hispanic Engineering Professionals. We will coordinate our efforts closely with those of UW's Office of Minority Affairs, including coordinating with the McNair Scholars Program and the Early Identification Program, which offer opportunities to mentor prospective graduate students on our campus.

Students will apply to our program in parallel to their application to graduate school in of the departments of our program. While in general, we will prefer students to have a masters thesis or relevant work experience prior to joining us, this will not be a hard and fast rule. In addition to a strong background in the relevant natural sciences, social sciences or engineering fields, we will look for students who show evidence of initiative in working across disciplinary and cultural boundaries. The recruiting package each student is offered will be competitive with the best of peer institutions, and will include up to two years of IGERT Fellowship support. Each participating department has its own policies for allocating support to the students they admit; in general, they will contribute additional RA and or TA support to extend the period of guaranteed support to a full 4 – 5 years.

Mentoring and Retention: Once we have been successful in attracting outstanding students to our IGERT, we have a major responsibility of assuring that the program meets their needs and that they complete its requirements in a timely manner. Here, our evaluation effort is extremely important – it needs to provide the participating faculty and IGERT leadership feedback quickly as to what is working well and what is not so as to optimize experiences for students. One of the key strategies we employ for student satisfaction and success is active involvement of the students themselves in program management and in the evaluation process. We have also structured our educational program so as to form very lasting connections of mutual support among the students themselves. Each cohort participates in the 3-

credit project-based sequence together, working on a variety of joint projects. They participate together in the "early-stage, problem-definition" dissertation workshop, which, again, helps them to form tight communities of mutual support. They students also will have unusually close interactions with IGERT faculty, which will help retain them in the program.

We are also very fortunate at UW to be the home to several nationally recognized programs which provide mentoring and retention support to students, and particularly to students from groups underrepresented in science and engineering. These programs include: Women in Science in Science and Engineering (WISE); the Minority Science and Engineering Program; the Washington State MESA (Mathematics, Engineering and Science Achievement) Program; and DO-IT (Disabilities, Opportunities, Internetworking and Technology), a program which focuses on students with disabilities. Remarkably, three of these programs (WISE, MESA and DO-IT) have won the prestigious US President's Award of Excellence in Science, Engineering and Mathematics Mentoring, based on their track records of accomplishments for students and their national leadership in the field. The Graduate School at UW also has shown innovation and dedication in supporting the needs of students from underrepresented groups, through the formation of its Graduate Opportunities and Minority Achievement (GOMAP) program. GOMAP, which incorporates in its program design a very active leadership role for students, has created a very dynamic set of initiatives on student recruitment, retention, networking and professional development. All in all, the suite of programs with which we will collaborate in the implementation of our IGERT provides a truly outstanding institutional basis to build a program that does a stellar job in serving the needs of diverse and dynamic student body.

Faculty Diversity: Faculty participants in the IGERT form a diverse team in a variety of senses. Approximately one third are female, a very high percentage for the disciplines involved. The numbers of Asian-American, Hispanic and African-American faculty members in our group are 5, 2 and 1, respectively. A large fraction of our faculty members were born and educated outside of the US – many of them in the partner regions of this project (approximately 25%). The linguistic competency in our team, the experience in international research and education, and the understanding of cultural variation in higher education practice will all be of great value to our IGERT project as it evolves.

H. RECENT TRAINEESHIP EXPERIENCE AND RESULTS FROM PRIOR NSF SUPPORT

The PI has a related graduate traineeship project in the last five years; she was the Co-PI on an International Extension to the PRIME project. PRIME is UW's project under the NSF's Graduate Teaching Fellows in K-12 Education Initiative. PRIME started on 1/1/00 and will continue to 12/31/03, with a total budget of $1,521,250. The International Extension ($48,250) enabled us to send pairs of PRIME graduate students local middle school teachers to Sendai, Japan and Chengdu, China, in the summers of 2000 and 2001. Those locations were chosen because of our relationships with Tohoku and Sichuan Universities, respectively, and our university partners facilitated the arrangements with the local schools and accommodation for the PRIME visitors. Those same universities are also partners on this IGERT proposal (together with 6 others). We also plan to incorporate PRIME-like pedagogical experiences in the educational program for our IGERT students. The value-added aspects of the IGERT are tremendous, however. The International Extension to PRIME was a relatively minor add-on to an existing G-K12 program. The IGERT, on the other hand, is a major re-formulation of graduate education stressing multinational project-based education as its core strategy.

I. INTERNATIONAL COORDINATION

The creation of an international alliance of this character to move forward together on a re-formulation of graduate education and research is a novel strategy. All of our universities have scores of bilateral university exchange agreements in place, most of which are shallow and some of which are quite deep. In general, though these relationships may be of great benefit to and in fact change the lives of individual faculty and students who participate, they do not challenge in anyway the overall culture of research and education at our institutions. On the other end of the spectrum, we have seen recently a trend towards the creation of large multi-university organizations, such as the Association of Pacific Rim Universities (APRU), Universitas 21, and the World University Network (WUN). These organizations have created some interesting arrangements for junior faculty development, for sharing of course-ware (including co–marketing agreements), and for catalyzing faculty research collaborations. Because the numbers of institutions are so large, however, the relationships that have evolved to date are relatively superficial. It is also the case that membership has tended to exclude everyone except the most prestigious of research institutions, leaving out many other institutions with valuable lessons to offer. In the design of the alliance of institutions in our IGERT we have learned from the lessons of existing models of international collaboration, and propose something that is intermediate in scale: large enough to permit a great deal of regional and institutional variation, but small enough so that all participating institutions can develop substantive relationships of engagement.

The institutions that are brought together in this proposal were chosen for a variety of reasons. In general, they are institutions with which UW faculty members have had sustained and multi-facetted relationships over a significant period of time. They are also institutions that have exhibited dynamism and creativity in the way they have addressed the changing needs of their students. They tend to be institutions with quite a practical, "let's do it and not just talk about it" character, and many play very key leadership roles in their regions in the development of science, technology and education policy. All in all, they will be excellent homes for our students to think about the role of universities in society and to get some alternate viewpoints about what kind of academic lives are possible. We are also very fortunate in the individuals who have agreed to take on the key leadership role for the IGERT on the various campuses; they are an extraordinarily talented and energetic group, from which our students can learn a great deal.

At each partner region there are multiple opportunities for students for interdisciplinary research; conversely, a student with a particular research focus will have multiple sites to choose from. Part of our program design was to choose sites that we have reason to expect will be attractive to students from a variety of backgrounds and with a variety of interests. In particular, research on minority participation in international programs indicates that moving away from a Eurocentric focus, and incorporating partners in "heritage regions" is an effective strategy for encouraging students from underrepresented groups to join [73]. While one does not have to be Vietnamese-American to be interested in Vietnam, nor African-American in background to be interested in exchange programs in Africa, we are confident that participation of African-American, Asian-American, Native American and Pacific Islander communities will be enhanced by the opportunities available to them at the partner institutions we have chosen. A high priority will be to add a Latin American partner institution within the first 2 years of our IGERT program.

In addition to sending our students to the partner schools for their research internships, we look forward to receiving students and visiting faculty from our partners for extended visits in Seattle. We believe it is vitally important to create a sustained physical presence on each others' campuses. While NSF funds will only be used to support US citizens and permanent residents, the home tuition agreements we have in place will make it possible to offer tuition waivers to graduate students who come to UW to participate in this program, in return for their home institutions hosting our students. The additional support that will have to come from non-NSF sources is thus limited to travel and cost-of-living allowances. These

reciprocal flows offer tremendous advantages. All of the graduate students can benefit from the presence in their midst of doctoral students from a variety of regions working on common problems.

As we have stressed earlier in the proposal, we have tried to design our collaborative network such that the benefits are reciprocal. All institutions that are participating in this alliance expect to accrue benefits from the relationships. Their expectations include strengthening research, faculty development, institutional capacity building, and, of course, providing opportunities to improve the education of their own students, in addition to hosting ours. Please see the Letters of Support section to learn more about 1) what they expect to contribute; 2) what they expect to gain from participating in the IGERT, and; 3) more information on developments underway on their campuses related to the proposed collaboration.

Organization and Management of the International Activities

Coordination and management of our educational and research programs will be challenging. Fortunately, the lead individuals on each campus have a lot of experience in running complex research and educational programs and in working across national and cultural boundaries. Our IGERT will establish an International Management Team which will include each of the local lead faculty members/administrators at each of the institutions, and which will be chaired by the IGERT Director, Prof. Kalonji. The International Management Team, because of the geographical distribution of sites, will meet primarily through telecommunications. However, we plan one physical meeting per year, rotated among sites in a cost-effective manner. From our experience it is vitally important for people to have face-to-face meetings, and it is very useful to visit each others' campuses to discuss research, visit labs, and meet with graduate students. We will combine the annual meeting of the International Management Team with an IGERT Research Workshop, focusing on two or more of our research themes.

The IGERT will appoint a half-time international coordinator, Dr. Cindy Hao, to manage many of the details of the international activities. Dr. Hao has extensive experience in promoting international scientific and educational exchanges, especially between the US and China. She will be responsible for helping students arrange international internships, organizing meetings of the International Management Team, maintaining program websites and other international communication matters.

Learning about and from our international community

Our highly international IGERT community gives us the opportunity to strike out in some new directions in graduate education, but it won't be easy. Fortunately, we have thoughtful involvement of higher education colleagues who will work with us to help us identify potential stumbling blocks, and who will provide a critical perspective with time on what aspects of our program are working well and what need to be re-thought. Our IGERT is very fortunate that UW houses the newly-established Center for Innovation and Research in Graduate Edcuation (CIRGE), led by Prof. Maresi Nerad. A major focus of Prof. Nerad's work is on helping Ph.D students cross boundaries between countries and employment sectors, to work collaboratively in complex global communities. She will work with us at regular intervals to reflect about our multileveled experience, and to help us understand and untangle common organizational hurdles in international collaborations. She has a great deal of experience in helping teams of graduate students and faculty creatively cope with the dynamics of uncertainty in unchartered learning domains, and with confusion caused by cultural misunderstandings. Prof. Nerad will also assist the IGERT faculty and the Director in extracting generalizable best practices of doctoral education that are international and organizationally novel by nature.

Summary

At UW, our goal for the IGERT is the creation of a new model for interdisciplinary internationalized graduate education. We have adopted a very ambitious strategy, but one that has the potential for high pay-back; if successful, our work could have a significant impact on higher education not only at UW and in the US, but through our network of partners, in a variety a regions. We look forward to sharing the lessons we learn with the broader higher education community as the work evolves.

J1. RECRUITMENT AND RETENTION EXPERIENCES

Aquatic and Fishery Sciences

ALL STUDENTS

Years Evaluated	Total No. of Applicants	Total No. of Applicants Accepted	Total No. of Accepted Applicants Enrolled	Total Currently Enrolled Students		Total Ph.D.s Awarded	Average Time-to-Degree (years)
				Full-time	Part-time		
1999-2000	119	14	19	74	30	7	7
2000-01	102	19	20	83	22	9	8.25
2001-02	99	23	22	99	21	10	6.25

WOMEN STUDENTS

Years Evaluated	Total No. of Women Applicants	Total No. of Women Applicants Accepted	Total No. of Accepted Women Applicants Enrolled	Total Currently Enrolled Women Students		Total Women Student Ph.D.s Awarded	Average Time-to-Degree for Women Students (years)
				Full-time	Part-time		
1999-2000	61	5	8	34	10	2	4.75
2000-01	54	12	14	41	7	2	6.75
2001-02	63	13	13	54	9	1	7.25

MINORITY STUDENTS

Years Evaluated	Total No. of Minority Applicants	Total No. of Minority Applicants Accepted	Total No. of Accepted Minority Applicants Enrolled	Total Currently Enrolled Minority Students		Total Minority Student Ph.D.s Awarded	Average Time-to-Degree for Minority Students (years)
				Full-time	Part-time		
1999-2000	6	1	1	7	3	0	N/A
2000-01	1	0	0	6	2	1	6
2001-02	7	5	4	8	4	0	N/A

(We were not able to get access to data concerning students with disabilities for the participating colleges and departments.)

J2. RECRUITMENT AND RETENTION EXPERIENCES

Biology

ALL STUDENTS

Years Evaluated	Total No. of Applicants	Total No. of Applicants Accepted	Total No. of Accepted Applicants Enrolled	Total Currently Enrolled Students		Total Ph.D.s Awarded	Average Time-to-Degree (years)
				Full-time	Part-time		
1999-2000	219	19	15	100	6	14	6.4
2000-01	195	23	19	94	7	15	6.1
2001-02	225	26	11	85	3	15	6.75

WOMEN STUDENTS

Years Evaluated	Total No. of Women Applicants	Total No. of Women Applicants Accepted	Total No. of Accepted Women Applicants Enrolled	Total Currently Enrolled Women Students		Total Women Student Ph.D.s Awarded	Average Time-to-Degree for Women Students (years)
				Full-time	Part-time		
1999-2000	119	13	11	48	3	4	7.5
2000-01	121	12	12	53	2	3	5.75
2001-02	141	9	3	45	2	8	6.2

MINORITY STUDENTS

Years Evaluated	Total No. of Minority Applicants	Total No. of Minority Applicants Accepted	Total No. of Accepted Minority Applicants Enrolled	Total Currently Enrolled Minority Students		Total Minority Student Ph.D.s Awarded	Average Time-to-Degree for Minority Students (years)
				Full-time	Part-time		
1999-2000	17	3	1	6	1	3	5.25
2000-01	8	0	0	4	0	3	6
2001-02	26	4	2	4	0	2	7

J3. RECRUITMENT AND RETENTION EXPERIENCES

Anthropology

ALL STUDENTS

Years Evaluated	Total No. of Applicants	Total No. of Applicants Accepted	Total No. of Accepted Applicants Enrolled	Total Currently Enrolled Students		Total Ph.D.s Awarded	Average Time-to-Degree (years)
				Full-time	Part-time		
1999-2000	131	30	15	65	29	9	10.75
2000-01	110	38	19	70	19	14	10
2001-02	133	40	14	78	14	11	10

WOMEN STUDENTS

Years Evaluated	Total No. of Women Applicants	Total No. of Women Applicants Accepted	Total No. of Accepted Women Applicants Enrolled	Total Currently Enrolled Women Students		Total Women Student Ph.D.s Awarded	Average Time-to-Degree for Women Students (years)
				Full-time	Part-time		
1999-2000	83	15	8	41	17	5	10.75
2000-01	67	25	13	47	9	9	10
2001-02	92	28	11	52	10	7	10.5

MINORITY STUDENTS

Years Evaluated	Total No. of Minority Applicants	Total No. of Minority Applicants Accepted	Total No. of Accepted Minority Applicants Enrolled	Total Currently Enrolled Minority Students		Total Minority Student Ph.D.s Awarded	Average Time-to-Degree for Minority Students (years)
				Full-time	Part-time		
1999-2000	11	2	0	4	3	2	10
2000-01	14	8	6	10	2	2	17.75
2001-02	14	6	2	10	0	0	N/A

J4. RECRUITMENT AND RETENTION EXPERIENCES

Geography

ALL STUDENTS

Years Evaluated	Total No. of Applicants	Total No. of Applicants Accepted	Total No. of Accepted Applicants Enrolled	Total Currently Enrolled Students		Total Ph.D.s Awarded	Average Time-to-Degree (years)
				Full-time	Part-time		
1999-2000	120	38	20	60	8	3	5.25
2000-01	112	19	5	52	10	4	7.5
2001-02	95	31	17	51	11	8	6.5

WOMEN STUDENTS

Years Evaluated	Total No. of Women Applicants	Total No. of Women Applicants Accepted	Total No. of Accepted Women Applicants Enrolled	Total Currently Enrolled Women Students		Total Women Student Ph.D.s Awarded	Average Time-to-Degree for Women Students (years)
				Full-time	Part-time		
1999-2000	65	25	14	35	4	0	N/A
2000-01	59	10	3	33	4	1	7.25
2001-02	40	10	7	28	6	5	6.25

MINORITY STUDENTS

Years Evaluated	Total No. of Minority Applicants	Total No. of Minority Applicants Accepted	Total No. of Accepted Minority Applicants Enrolled	Total Currently Enrolled Minority Students		Total Minority Student Ph.D.s Awarded	Average Time-to-Degree for Minority Students (years)
				Full-time	Part-time		
1999-2000	8	5	3	8	2	0	N/A
2000-01	6	1	0	6	1	1	11
2001-02	3	1	0	5	1	0	N/A

J5. RECRUITMENT AND RETENTION EXPERIENCES

Civil and Environmental Engineering

ALL STUDENTS

Years Evaluated	Total No. of Applicants	Total No. of Applicants Accepted	Total No. of Accepted Applicants Enrolled	Total Currently Enrolled Students		Total Ph.D.s Awarded	Average Time-to-Degree (years)
				Full-time	Part-time		
1999-2000	262	132	48	108	31	6	6
2000-01	329	106	40	101	28	6	6.25
2001-02	279	104	47	96	30	7	5.75

WOMEN STUDENTS

Years Evaluated	Total No. of Women Applicants	Total No. of Women Applicants Accepted	Total No. of Accepted Women Applicants Enrolled	Total Currently Enrolled Women Students		Total Women Student Ph.D.s Awarded	Average Time-to-Degree for Women Students (years)
				Full-time	Part-time		
1999-2000	77	48	23	39	1	2	5.75
2000-01	102	44	15	38	3	1	5.5
2001-02	63	23	17	32	12	1	4.75

MINORITY STUDENTS

Years Evaluated	Total No. of Minority Applicants	Total No. of Minority Applicants Accepted	Total No. of Accepted Minority Applicants Enrolled	Total Currently Enrolled Minority Students		Total Minority Student Ph.D.s Awarded	Average Time-to-Degree for Minority Students (years)
				Full-time	Part-time		
1999-2000	26	20	6	6	6	0	N/A
2000-01	15	10	4	6	4	1	9.25
2001-02	16	11	4	6	0	0	N/A

J6. RECRUITMENT AND RETENTION EXPERIENCES

Materials Science and Engineering

ALL STUDENTS

Years Evaluated	Total No. of Applicants	Total No. of Applicants Accepted	Total No. of Accepted Applicants Enrolled	Total Currently Enrolled Students		Total Ph.D.s Awarded	Average Time-to-Degree (years)
				Full-time	Part-time		
1999-2000	78	28	10	35	15	6	5.5
2000-01	64	34	15	36	15	3	6.25
2001-02	59	15	7	40	19	1	3.25

WOMEN STUDENTS

Years Evaluated	Total No. of Women Applicants	Total No. of Women Applicants Accepted	Total No. of Accepted Women Applicants Enrolled	Total Currently Enrolled Women Students		Total Women Student Ph.D.s Awarded	Average Time-to-Degree for Women Students (years)
				Full-time	Part-time		
1999-2000	19	8	2	9	2	0	N/A
2000-01	19	11	8	12	4	0	N/A
2001-02	13	2	1	14	6	1	3.5

MINORITY STUDENTS

Years Evaluated	Total No. of Minority Applicants	Total No. of Minority Applicants Accepted	Total No. of Accepted Minority Applicants Enrolled	Total Currently Enrolled Minority Students		Total Minority Student Ph.D.s Awarded	Average Time-to-Degree for Minority Students (years)
				Full-time	Part-time		
1999-2000	9	4	1	6	2	1	6.75
2000-01	9	9	5	8	2	1	8.5
2001-02	4	1	1	8	2	0	N/A

J-7. RECRUITMENT AND RETENTION EXPERIENCES

College of Forest Resources

ALL STUDENTS

Years Evaluated	Total No. of Applicants	Total No. of Applicants Accepted	Total No. of Accepted Applicants Enrolled	Total Currently Enrolled Students		Total Ph.D.s Awarded	Average Time-to-Degree (years)
				Full-time	Part-time		
1999-2000	182	72	40	161	23	11	7
2000-01	174	65	45	165	23	8	6.75
2001-02	182	78	46	155	42	15	6.75

WOMEN STUDENTS

Years Evaluated	Total No. of Women Applicants	Total No. of Women Applicants Accepted	Total No. of Accepted Women Applicants Enrolled	Total Currently Enrolled Women Students		Total Women Student Ph.D.s Awarded	Average Time-to-Degree for Women Students (years)
				Full-time	Part-time		
1999-2000	90	28	17	65	10	3	8.25
2000-01	85	36	23	73	10	2	6.75
2001-02	90	38	23	77	14	6	5.75

MINORITY STUDENTS

Years Evaluated	Total No. of Minority Applicants	Total No. of Minority Applicants Accepted	Total No. of Accepted Minority Applicants Enrolled	Total Currently Enrolled Minority Students		Total Minority Student Ph.D.s Awarded	Average Time-to-Degree for Minority Students (years)
				Full-time	Part-time		
1999-2000	13	8	6	11	3	0	N/A
2000-01	10	6	2	12	2	0	N/A
2001-02	15	8	3	13	1	1	4.5

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