2006-737: COMBINING GRADUATE STUDIES, RESEARCH AND INTERNATIONAL EXPERIENCES IN SUSTAINABILITY

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Combining Graduate Studies, Research and International Experiences in Sustainability

Abstract

A new challenge facing engineering educators is how to train graduate students to routinely include sustainability as important design criteria. Equally important is the need for engineering students to both broaden their perspective and learn to function collaboratively in cross-cultural environments. The University of Pittsburgh's School of Engineering is addressing these issues by educating a cadre of PhD researchers as part of a recently established Integrative Graduate Education and Research Traineeship (IGERT) Program in sustainability. We present our plan to create an innovative sustainable engineering graduate program, with primary research foci in green construction and sustainable water use. This interdisciplinary initiative will involve faculty and students from across the School. To best address global concerns, we have partnered with the University of Campinas (UNICAMP) in Sao Paolo, Brazil to provide an eight-month international research rotation for all IGERT Fellows. In addition, to increase the number of Hispanic American engineering students, we have created partnerships with University of Texas-El Paso and University of Puerto Rico-Mayaguez. Also, to best prepare our IGERT Fellows for study and research in sustainability, a special sequence of courses is being implemented that will include a two-part capstone sustainable design course providing students from the various specialties with a common educational framework. Finally, the University of Pittsburgh's Center for Latin American Studies will develop a sequence of courses in Brazilian Portuguese to better prepare the IGERT Fellows for their research internship. This paper presents an overview of our initiative and describes progress to date with respect to research and pedagogy.

1. Introduction

The hallmark of US engineering has always been innovation, especially in the design of new products and processes that are optimized to reflect performance and price ideals. Although engineering designers have focused on performance and price criteria for over a century, the growing recognition that the world's resources are finite while its population continues to increase have led to a new criterion – sustainability – that now must be incorporated into the design process often as an objective, but always as a constraint.[1] Mihelcic, et al[2] have defined sustainability as "the design of human and industrial systems to ensure that mankind's use of natural resources and cycles do not lead to diminished quality of life due either to losses in future economic opportunities or to adverse impacts on social conditions, human health, and the environment." To them, environmentally conscious design has evolved from simple end-of-pipe treatment through pollution prevention and green design to sustainable development with each succeeding advance incorporating additional constraints. This evolution is an expansion upon the triple bottom line approach to responsible care initiatives (i.e., society, the economy and the environment).[3]

As a result, our focus is directed at fulfilling Mihelcic's definition of sustainability by educating the engineers who will be designing the next generation of technologies to facilitate green construction and sustainable water use. To do this, we must demonstrate how sustainability can become an integral part of a graduate engineering education system that tends to narrow its focus as one matriculates from an undergraduate to MS to PhD program. We propose that serious changes in the way graduate engineers are educated must occur if sustainability is to become a meaningful component of US engineering practice. Further, if these changes do not occur, US engineering education and US engineering may soon fall behind more aggressive and forward thinking countries in Asia and Europe.

We will address these issues by educating a cadre of graduate student researchers as part of a recently established Integrative Graduate Education and Research Traineeship (IGERT) Program in sustainability. Our goals are to:

- Train graduate engineers to routinely incorporate sustainability into new engineering designs.
- Educate graduate engineers to appreciate the diversity in sustainable design across countries and cultures so that they can effectively operate in an international context.
- Create sustainable products and processes, especially for the construction and water collection/purification industries, thus enhancing the design options of architects, designers, and planners.

By focusing on green construction and sustainable water use, we will be finding solutions to problems that require a broad range of disciplines. Further, these areas offer a rich range of projects that are technically challenging, demand broad, fundamental knowledge and have long-term implications. Finally, the technology advances that our students create will directly benefit the quality of life of people in both the developed and developing worlds.[4]

Hence we are creating an engineering curriculum for students interested in sustainability that emphasizes team-based design and truly crosses departmental lines (involving all seven University of Pittsburgh engineering programs). A capstone sustainable design course is included so that students from the various specialties not only learn a common framework for sustainable design, but also acquire the multi-disciplinary team skills needed to address significant problems. Further, because sustainability is a global issue an appropriate technology for the US may be inappropriate for other regions of the world. Consequently, a centerpiece of our program is a two-term study and research experience in Brazil that will enable students to learn to live and work cross-culturally. To accomplish this latter component we have partnered with the University of Pittsburgh's nationally recognized center of excellence in Latin American Studies (CLAS) and the University at Campinas (UNICAMP) in Sao Paulo, Brazil, who will host the eight-month international experience for all IGERT Fellows. UNICAMP has one of the best engineering programs in South America; its faculty has comprehensive research programs in both green construction and sustainable water use. In an effort to increase the number of Hispanic American engineering students, we have also created partnerships with University of Texas-El Paso (UTEP) and University of Puerto Rico-Mayaguez (UPR-M).

2. Major Research Efforts

The research interests of the associated University of Pittsburgh and UNICAMP faculty are broad, providing students with numerous possibilities for dissertation topics. IGERT Fellows will choose at least one co-advisor each from the University of Pittsburgh and UNICAMP. Once students have identified their general area of interest, meetings with their co-advisors will serve to focus on a specific project or research theme; initial UNICAMP participation will be via video link. This use of video conferencing for meetings with students' co-advisors should allow for a seamless research transition between Pittsburgh and Sao Paolo (where the IGERT Fellows will spend a full eight months conducting research). Students will enter the IGERT program from a variety of backgrounds, and few may have had formal exposure to sustainable design. Hence, the educational program is designed to bring everyone to the same, high level of understanding with respect to sustainability, while broadening their perspective on research opportunities in the field. To provide maximum flexibility, students will be encouraged to choose advisors from any engineering department, regardless of their home department.

2.1 Green Construction

While the built environment provides services that sustain our economy and way of life, it does so at heavy costs of resource use and waste generation. Buildings in the US, over the course of their life-cycle, account for 17% of fresh water withdrawals, 25% of wood harvest, 40% of overall materials use, 54% of energy used, and 50% of fossil fuels consumed.[5] The purpose of green construction is to lessen the impact of buildings on the environment over their full lifetime. Although great strides have been made in greening the process and products of construction, scientific and engineering advances in many fields are still needed to create the next generation of sustainable buildings. Based on faculty areas of expertise, examples of research areas that will be explored within the green construction area include: New Materials for Green Construction; Reduced Energy Use Through Smarter Design and Control; and Life Cycle Analysis, Planning, and Economics. For example:

- The creation of more sustainable building materials: *The building materials of the future will require less energy to produce, can be designed with recycling in mind, can signal impending failure and/or heal themselves, and will inhibit/reduce the release into the indoor environment of noxious compounds (either synthetic or natural).*
- Green buildings require systems that allow for a healthy indoor environment while using less energy: *Buildings of the future will contain a "nervous" system that provides real time, highly localized data on energy needs; that buildings of the future will be constructed so as to minimize energy demand while maximizing comfort; and that naturally occurring vegetation can be included in the design of an energy efficient building.*
- Life cycle analysis and planning systems are required to benchmark new technologies against existing situations: *The designers of new buildings will be able to examine the sustainability consequences of design choices on the future productivity of workers and the overall environmental footprint of the building over its lifetime through the use of innovative software tools.*

2.2 Sustainable Water Use

Water, although often perceived to be an infinite resource, is fast becoming a leading source of friction throughout the world. In the developed world, competing needs for water among agriculture, industry and homes can create severe stress upon water supplies. For example, using current photolithographic processes, manufacturers employ approximately 20 liters of water to produce a 2-gram microchip[6] - a typical microelectronics plant can use 3 to 6 million gallons of water per day. Paradoxically, such plants are often sited in arid regions where the water needed to operate is *a priori* known to be unavailable without substantial recycling. In the developing world, the lack of sufficient clean water is fast becoming the most important obstacle to the creation of sustainable economies. Based on faculty areas of expertise, examples of research areas that will be explored within the sustainable water use area includes:

- Sustainable Water Treatment and Use: *Water collection, treatment, and use in the future will be more efficient, lower cost, yet with less accompanying environmental burden than that employed presently.*
- Water for the home is traditionally treated with chlorinated compounds, whose production and use is accompanied by a series of undesirable environmental impacts. Hydrogen peroxide is a benign, effective alternative to chlorination for water disinfection, yet hydrogen peroxide is also substantially more expensive than calcium hypochlorite and is produced via a multi-step process that creates significant waste streams: *The direct generation of hydrogen peroxide from hydrogen and oxygen as a means of producing this material less expensively and with less waste in a way that lends itself to small, on-site generation facilities.*
- Nitrate contamination of water is both deleterious to public health and one important example of a recalcitrant pollutant of rivers and streams: *Examining the nano-structured bimetallic catalysts that promote the reduction of nitrates to nitrogen using hydrogen under mild conditions.*
- Water supplies are most commonly compromised by bacterial contamination related to sanitation challenges and chemical contaminants. High-arsenic groundwater areas have also been found in Argentina, Chile, Mexico, China, Hungary, West Bengal (India) and Vietnam: *By using plants to remediate water, the initial capital, operation and maintenance costs would be relatively low while providing an aesthetically appealing alternative to chemical based methods.*

3. Education and Training

The IGERT Sustainable Engineering Fellowship Program includes a nine-course sequence shown schematically in Figure 1:

- *Introduction to Sustainable Engineering*,
- Two elective courses that allow students to focus on sustainability within a specialty area (such as ChemE, CivE, IE, or ME),
- A two-semester *Capstone Design Course* sequence,
- An *IGERT Seminar*, devoted to preparing students for their Brazil rotations,
- And three courses of intensive *Portuguese* language instruction,

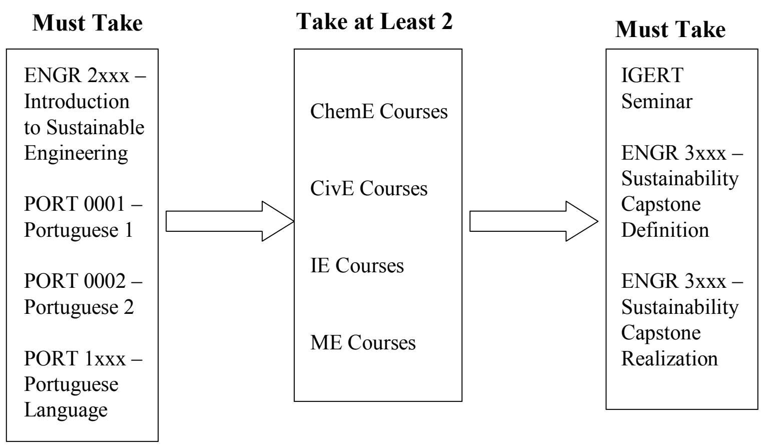

Figure 1. IGERT Course Sequence

3.1 Introduction to Sustainable Engineering

During their first Fall term as a Fellow, all students will take the *Introduction to Sustainable Engineering* course (3 credits). This first course will provide a common frame of reference with respect to sustainable engineering, covering topics that include life cycle analysis; environmental costing; regulatory frameworks throughout the world, with a particular emphasis on the US and Latin America; global and legal issues; risk analysis; social and international implications of non-sustainable design; environmental management in industry; and ethics and the responsible conduct of research. Case studies will be used to illustrate and compare the impact of both sustainable and non-sustainable designs, and will focus on specific projects in Pittsburgh, the US and Brazil. Each semester, one IGERT faculty member will serve as course coordinator with certain individual topics taught by the other faculty as appropriate. Local guest speakers will complement the instruction and both video conferencing and interactive video will be used to have UNICAMP faculty serve as guest lecturers.

3.2 Discipline Specific Elective Courses

Students will take at least two elective courses in their specialty areas (e.g., Chemical, Civil and Environmental, Industrial, or Mechanical Engineering) in order to gain more in-depth knowledge of engineering sustainability applications. A small sample of the sustainability classes offered by each of the departments is outlined in Table 1. Furthermore, as the IGERT Program grows, it is anticipated that the interest and research topics of the students will drive the creation of new courses.

Table 1. Sample of Proposed Sustainability Specialty Courses

Chemical Engineering	Civil and Environmental Engineering
ChE 2610-Atmospheric Pollution Control ChE 2620-Industrial Waste Treatment ChE 2630-Environmental Impact Assessment ChE 2640-Pollution Prevention ChE 3610-Pollution Prevention II	CEE 2209 – Life Cycle Assessment Methods and Tools for the Built Environment CEE 2210-Engineering and Sustainable Development CEE 2501-Environmental Engineering Chemistry CEE 2502-Physical-Chemical Principles in Environmental Engineering CEE 2503-Field Methods in Environmental Engineering
Industrial Engineering	**Mechanical Engineering**
IE 2003-Engineering Management IE 2037-Cost Management for Advanced Mfg IE 2040 – Advanced Engineering Economy IE 2055-Automation in Mfg and Product Design IE 3034-Management of Technological Innovation	ME 2050-Thermodynamics ME 2055-Computational Fluid Dynamics and Heat Transfer ME 2074-Building Thermal/ Mechanical Systems Integration and Analysis ME 3007-Energetics ME XXXX-Energy Optimization: Engineering, Economic, and Environmental Issues

3.3 Capstone Design Course

The two-semester, inter-disciplinary, team-based capstone design course sequence will require the application of rigorous analytical thinking and research investigation techniques in order to address a real-world, complex problem. The first term of the course will be at Pitt with the second term at UNICAMP. Project topics will be developed in combination with recommendations from various stakeholders including the Industrial Advisory Board, colleagues in industry, the IGERT faculty at all four institutions, and the interests and preliminary research of the students themselves. Research will be firmly rooted in industrial needs. The problem will build upon the combined students' acquired engineering knowledge and will require collaboration to resolve. The capstone courses will reinforce the community-building aspect of the IGERT, since students will work in teams both at Pitt and UNICAMP. In the first capstone course, *Sustainability Capstone Definition*, students will work in 3-4 person teams. Students will receive structured instruction utilizing a modular course design focusing on core topics including various aspects of sustainability and project management processes. The subject matter of the various projects will define the specific technology-based content to be presented. By the end of the first semester, students will prepare and present a detailed project proposal for work to be carried out during the second semester in Brazil. The second capstone course, *Sustainability Capstone Realization*, will be offered in Brazil. Students will again work in 3-4 person teams; a substantial portion of the course will focus on student conducted research using both experimentation and analysis methodologies. UNICAMP or in some cases an industry, non-governmental organization (NGO) or governmental partner will provide field laboratory space.

3.4 Preparation for Study in Brazil

Exposure to international sustainability issues is an integral part of the proposed IGERT education program. In order for the IGERT Fellows to more effectively study, research and live in Brazil for an extended period of time, they will take three semesters of Brazilian Portuguese and a one semester IGERT seminar. The first two semesters of Portuguese will be existing fivecredit courses that introduce the students to the practical vocabulary and grammar they will need to function in Brazil. A third semester of Brazilian Portuguese will be specifically designed for this program. This three-credit course will cover technical and educational terminology through examination of Brazilian sustainable engineering case studies while further advancing the students' knowledge and ability in Brazilian Portuguese. The IGERT Seminar will further refine the Fellows' understanding of Brazil and Latin America, introducing important economic, political, social, and cultural aspects.

4. Program Assessment

A detailed and comprehensive program assessment plan has been designed with an overview of this plan being presented in this paper. Three major objectives have been identified for the IGERT Program:

Objective 1 Train graduate engineers to routinely incorporate sustainability into new engineering designs.

Objective 2 Educate graduate engineers to appreciate the diversity in sustainable design across countries and cultures so that they can effectively operate in an international context.

Objective 3 Create sustainable products and processes, especially for the construction and water collection/purification industries, thus enhancing the design operations of architects, designers, and planners.

Objectives are broken down further into sub-objectives with specific strategies/activities and assessment/measures. For example a sub-objective underneath Objective 1 is to: Create a community that becomes the next generation of leaders in sustainability in design. A specific strategy/activity related to Objective 1 includes: Exposing students to cross-disciplinary engineering research projects associated with sustainability. One specific form of assessment/measure for Objective 1 is to: Monitor retention of students entering the program with a B.S. or M.S. and to set benchmarks to meet a 100% retention level.

Data will be collected, analyzed and summarized on how the objectives of the program are being achieved. Both summative and formative approaches will be used. In general, focus groups of students will be used to provide formative feedback on the first two objectives; and faculty interviews from the participating institutions will be used to evaluate progress towards meeting the third objective of the program. In terms of overall achievement of the first two objectives, a comparison study between IGERT Fellows and other representative graduate engineering students will be designed to determine if the IGERT Fellows have developed an appreciation for design in an international context and have obtained the skills and insight needed to incorporate sustainability as a design constraint.

5. Summary and Conclusions

This paper presents an overview of the University of Pittsburgh IGERT Program in Sustainable Design and describes progress to date with respect to research and pedagogy. This proposed program is especially timely given Friedman's description of the twenty-first century "flat world."[7] Friedman has proposed that ten "flatteners" have shrunk the world to a "tiny" size while simultaneously leveling the playing field. Among these ten are six that have created some form of collaboration: outsourcing, offshoring, open-sourcing, insourcing (e.g., UPS and FedEX), supply-chaining and informing (e.g., Google, Yahoo, etc.). To Freidman, when all ten of the flatteners converged around 2000, they "created a global, Web-enabled playing field that allows for multiple forms of collaboration on research and work in real time without regard to geography, distance or, in the near future, even language." Coincidently, three billion additional people from China, India, Russia, Eastern Europe, Latin America and Central Asia suddenly had access to technology and information that until recently had been the sole purview of highly developed countries. Hence, one of our challenges as engineering educators is how best to take advantage of this convergence to improve engineering education, and, as Friedman, and others have proposed, enable the US to retain its lead in innovation and university education and research.

We propose that the IGERT program discussed above is one such mechanism for doing this, enabling our students to learn how to collaborate:

- Across departments, disciplines and fields
- Across schools
- With industry
- Across institutions
- Across cultures, languages and time zones.

It will also provide our students with a renewed focus on innovation where they will:

- Apply science and engineering knowledge to create new products and services with an emphasis on sustainability.
- Work in collaboration with international partners to create products and services that address developing world needs.

Further we propose that this is meeting a need that has been stressed in the NSF's *Best Practices Manual for ERCs*:[8]

- There is a national need for education of interdisciplinary, team-oriented PhDs. There is a collective alarm at the continued production of graduates at all levels who are totally untrained in team research and often openly antagonistic to industrially relevant research.
- The goal of the ERC education programs is to develop a team-based, research-inspired, and industrial practice-oriented culture for the education of graduate and undergraduate students that will produce engineering leaders for the future.

We propose that our program is directed at doing exactly that – creating an interdisciplinary, team-oriented PhD program in which students will design the innovative, sustainability related products needed for the future.

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