

AC 2007-2274: COMBINING EDUCATIONAL STUDIES, RESEARCH AND INTERNATIONAL EXPERIENCES IN SUSTAINABLE ENGINEERING

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Abstract

A new challenge facing engineering educators is how to train both undergraduate and graduate students to routinely include sustainability topics 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 students from the BS through PhD levels as part of a comprehensive educational and research program in sustainability. This program has numerous sources of funding, including the National Science Foundation's Integrative Graduate Education and Research Traineeship Program (IGERT) and International Research Experiences for Students Program (IRES), the US Department of Education's Graduate Assistance in Areas of National Need (GAANN), and the National Collegiate Inventors and Innovators Alliances (NCIIA) as well as private foundations. We present our plan to create an innovative sustainable engineering program, with primary research foci in green construction and sustainable water use. This interdisciplinary initiative involves faculty and students from across the University of Pittsburgh. To best address global concerns, we have partnered with the University of Campinas (UNICAMP) in São Paulo, Brazil to provide substantial international and research experiences. In addition, to increase the number of Hispanic American engineering students, we have created partnerships with the University of Texas-El Paso and University of Puerto Rico-Mayaguez. Also, to best prepare students for study and research in sustainability, a special sequence of courses is being implemented at both the undergraduate and graduate levels. Finally, the University of Pittsburgh's Center for Latin American Studies is developing a sequence of courses in Brazilian Portuguese to better prepare students for their international experience. This paper presents an overview of our initiative and describes progress at the end of the first year with respect to research and pedagogy with a special emphasis on describing the new course development.

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 al² 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 both undergraduate and graduate engineering education systems, in contrast to the current tendency to narrow one’s focus when matriculating from an undergraduate to MS to PhD program. We propose that serious changes are needed in the way we educate engineers 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 students at both the undergraduate and graduate levels in sustainability. Our goals are to:

- Train engineers to routinely incorporate sustainability into new engineering designs.
- Educate 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 are 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 and they are ideally suited for teams of undergraduate and graduate students. The technology advances that our students create will directly benefit the quality of life of people in both the developed and developing worlds.⁴

In short, we are creating 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). At the graduate level 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 study and research experience in Brazil that will enable students to learn to live and work cross-culturally. To accomplish this 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 São Paulo, Brazil, who will host the international experience for all participating students. 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).

Figure 1 provides an overview of this integrated program where we have combined funding from the National Science Foundation, the US Department of Education, the National Collegiate Inventors and Innovators Alliance (NCIIA), the University of Pittsburgh and the generous support of The Heinz Endowments, The Dominion Foundation, the estate of George M. Bevier, and alumnus John C. Mascaro, whose vision and foresight have created the Mascaro Sustainability Initiative (MSI) within the University of Pittsburgh's School of Engineering. As shown in the figure, we have combined undergraduate and graduate education with a strong research focus to create what we believe is a unique, innovative program.

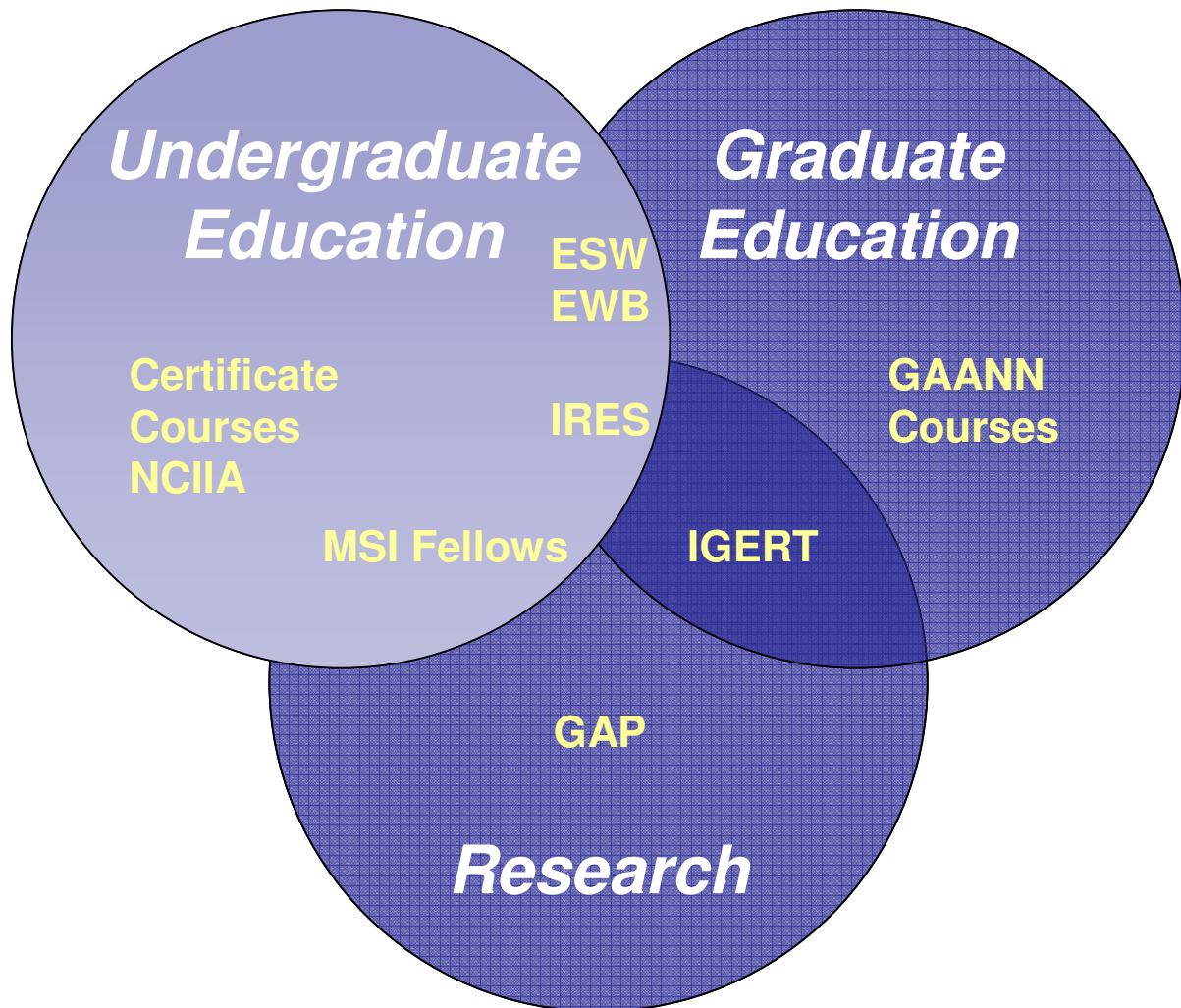


Figure 1: An Integrative Approach to Create Holistic Engineers

At the undergraduate level we are expanding a certificate in product realization to include an international component and a virtual team design experience, funded in part by the NCIIA. At the graduate level, a series of courses are being created to enhance the education experience. Undergraduate students are provided with a research experience as MSI Fellows; a recently awarded NSF IRES (International Research Experience for Students) will enable undergraduates to team with graduate students for research experiences first in Pittsburgh and then in Brazil. An NSF IGERT provides graduate education and research opportunities; a US Department of Education GAANN project provides additional graduate fellowships. A University of Pittsburgh GAP (Global Academic Partnership) will provide funding to bring US and Brazilian researchers together to develop additional research initiatives. Finally, the School of Engineering is establishing student chapters of both Engineers without Borders (EWB) and Engineers for a Sustainable World (ESW) that will enable students and faculty to address problems of the developing world through global service learning.

The following sections will present more details of our current and planned activities focusing on the progress at the end of the first year with respect to research and pedagogy with a special emphasis on describing the new course development.

2. Major Research Efforts

The research interests of the associated University of Pittsburgh and UNICAMP faculty are broad, providing students with numerous possibilities. 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 São Paulo (where the IGERT Fellows will spend a full eight months conducting research). Students will enter the IGERT program from a variety of backgrounds, with only a few having had formal exposure to sustainable design. Hence, the graduate education 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. Examples of research that may be explored include creation of more sustainable building materials, development of systems that allow for a healthy indoor

environment while using less energy, and life cycle analysis and planning systems to benchmark new technologies against existing situations.

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 microchip⁶ - 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. Examples of research areas that may be explored within the sustainable water use area includes examination of sustainable water treatment and use, nitrate contamination of water, and water supplies compromised by bacterial contamination related to sanitation challenges and chemical contaminants.

3. Education

The education component is a crucial element towards creating the holistic sustainable engineer. Efforts in this area have been made both at the graduate and undergraduate levels.

3.1 Graduate Student Education

A major driver towards developing the graduate student education component has been the IGERT and GAANN Sustainable Engineering Fellowship Programs. These programs include development of a series of new courses including *Introduction to Sustainable Engineering*, a two-semester *Capstone Design Course*, and an *IGERT Seminar* (specifically developed to prepare the IGERT Fellows for a rotation in Brazil). The *Introduction to Sustainable Engineering* course is common to both the IGERT and GAANN programs.

3.1.1 Introduction to Sustainable Engineering

Introduction to Sustainable Engineering was first offered in the fall term of 2006. Enrollment was initially capped at 12 students and restricted to IGERT and GAANN Fellows. Remaining seats were made available to PhD students nominated by their faculty advisor. Seven students registered for the course and two students audited the course for a total of nine students. This first course provided a common frame of reference with respect to sustainable engineering within green construction and sustainable water usage.

The course met once per week for a 2-1/2 hour session. It was held in a conference room which provided a more comfortable and informal environment. The course was overseen by two core IGERT/GAANN faculty members, Dr. Kim LaScola Needy and Dr. Laura Schaefer. In addition to the instruction provided by Needy and Schaefer, the course included numerous guest lectures by other School of Engineering faculty as well as other guest speakers locally and abroad. Case

studies were used to illustrate and compare the impact of both sustainable and non-sustainable designs.

The class consisted of two team-based research projects, one on green construction and one on sustainable water usage. (There were no exams.) Students were required to complete a project in each area, although the order did not matter. Although these projects were done in teams of 2-3 students, portions of each project were completed by individual team members. For example, the group would select a project topic. Upon approval, the group would develop a paper outline along with each team member individually preparing a literature review on the topic. Next, each individual team member would write a short paper based on a portion of the topic. Finally, the team would submit a final paper and present the work to the class. Each of these major project deliverables was graded to formulate a total project grade. Specifically, the grading policy was as follows:

- 20% – Class Contribution (including participation and preparedness)
- 40% – Project 1 – Green Construction or Sustainable Water Use
- 40% – Project 2 – Green Construction or Sustainable Water Use

In total, three projects were completed on green construction and three on sustainable water usage as follows:

Green Construction

- Feasibility of Building Green: New Residence Hall on the Carnegie Mellon University Campus
- Green Roofs: Alleviating Urban Stress
- Green HVAC in Residential Homes

Sustainable Water Usage

- Sustainable Water Usage in Campinas-Brazil
- Water Resource Conservation
- An Industrial Ecology Approach to Waste Water Management

Multiple textbooks were used for the course. The primary textbook that students were asked to purchase was *Green Engineering – Environmentally Conscious Design of Chemical Processes* by: D. T. Allen and D. R. Shonnard, Prentice Hall, 2002. Secondary readings were assigned from *Technological Choices for Sustainability* by: S. K. Sikdar, P. Glavic and R. Jain, Springer, 2004; *Industrial Ecology* by: T. E. Graedel and B. R. Allenby, AT&T, 1995; and *Sustainable Energy – Choosing Among Options* by: J. W. Tester, E. M. Drake, M. J. Driscoll, M. W. Golay and W. A. Peters, MIT, 2005. These secondary textbooks were held on reserve in the library. Additional readings in the form of journal articles, conference papers, and case studies were assigned by the guest lecturers.

Table 1 depicts a week-by-week description of the course including both pre- and post-assessments. Students completed the pre-assessments within one-week after the class. The post-assessment was completed at the end of the course at which time students were asked to reflect upon the entire course experience. Week 1 is not included as it was used as a course

introduction. During Week 6, students attended a special reception with faculty, staff and board members affiliated with the School of Engineering’s Mascaro Sustainability Initiative. Weeks 10 and 16 were used for project presentations. There was no class on Week 13 due to the Thanksgiving holiday. Students were also asked in the post-assessment to comment on the effectiveness of the projects and the textbook readings. The score shown in the last two columns of Table 1 is an average rating of each topic based on a 5-point Likert scale where a score of 1 indicated that the topic was not very helpful and a score of 5 indicated that the topic was very helpful at learning the course material. Ratings are tabulated from the seven registered students. We were unable to perform any statistical analyses on the data due to the small sample size (N = 7).

Interestingly, there is not much deviation in the pre- and post-assessment ratings. We were pleased that with the exception of Responsible Conduct of Research (in the post-assessment) and Regulatory Frameworks (in the post-assessment), that all topics scored above a 3.0 rating. In addition, the projects were rated as being very helpful in learning the course material. It was not a surprise that the students rated the textbook so low. It has been our experience that students are usually disappointed with the textbook and in particular in this class since we covered such a broad set of topics, there was no single textbook that could cover all of the material. The textbook readings covered the topics in a broad sense and did not always match well with the guest lecture. In the future, the issue of which textbook to use will be examined.

Table 1. Course topics and Pre- and Post-Assessments

Week	Topic	Pre (out of 5.0)	Post (out of 5.0)
2	Sustainable Water Use Issues	4.3	3.7
3	Green Construction Issues	3.9	4.3
4	Green Construction and Sustainable Water Use	4.7	4.9
5	How can the library help?	3.4	3.1
7	Life Cycle Costing	3.6	3.3
8	Ethics and the Environment	3.6	3.1
9	Responsible Conduct of Research	3.1	2.7
11	Environmental Economics & Policy	3.9	3.9
12	Regulatory Frameworks – U.S. and Abroad	3.4	2.9
14	Building Technology & Energy Monitoring and Control	4.1	3.9
15	Bioclimatic Architecture	4.0	4.0
	Project 1	Not Rated	4.6
	Project 2	Not Rated	4.4
	Textbook Readings	Not Rated	2.6

As part of each week’s pre-assessment, students were also asked to provide feedback on each topic in a series of questions such as:

- Prior to the lecture on ___ what did you know about the topic?
- What is the main point that you learned about ___?
- What topics related to ___ would you like to learn more about?

In the post-assessment, students were also asked to comment on a series of questions. The students' comments are shown below with the frequency indicated in parenthesis. Note, that we only show responses in which two or more students made a similar comment.

- Q1. What do you like best about this class?
Discussion / seminar style (4)
Projects (2)
Guest speakers (2)
Content (2)
Wide spectrum of involved disciplines (2)
- Q2. What do you like least about this class?
Some guest lecturers were not interesting / too much detail in law and ethics (3)
Class duration (2)
- Q3. Is there anything that we should definitely do again when the course is offered?
Keep variety of topics / presenters (3)
- Q4. Is there anything that we should definitely change when the course is offered again?
Focus more on “green” and “sustainable” issues (2)
- Q5. What would have made this class a better learning experience for you?
Mixed responses
- Q6. Did this course stimulate your interest in sustainable engineering? Please explain.
It let me understand how widely sustainability is implemented in real world (3)
I understood what sustainability is and what kind of research I can make on sustainability (2)
- Q7. Did this course help you to narrow in on a specific area of research? Please elaborate.
No, I already had set my research area (5)
- Q8. Would you recommend this course to a friend?
Yes, definitely (6)

This feedback from the pre- and post-assessments will be used to select and develop topics when the course is offered in the future.

3.1.2 Capstone Design Course

A 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 industrial, non-governmental organization (NGO) or governmental partner will provide field laboratory space.

3.1.3 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 five-credit 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.

3.2 Undergraduate Student Education

Our undergraduate education objectives are to teach students to:

1. Routinely incorporate sustainability as a design constraint. Although sustainability is fast becoming a necessary constraint in product and process design, it is yet to be systematically covered in most undergraduate engineering curricula.
2. Work in design teams that progress from initial reliance on faculty and graduate student advisors to reliance on team members over the course of the program. Team-based design is the hallmark of industrial practice; we will teach students the leadership and team building skills necessary to work as a cohesive unit while making individual contributions to the project's success.
3. Work in cross-cultural environments. Today's practicing engineers need to understand how to function effectively on multi-national teams.

An innovative product realization course is being created and will be offered for the spring term of 2007. It will enable undergraduates from Pitt and UNICAMP to collaboratively create new products focused on sustainable human development. This partnership between UNICAMP's

research and Pitt's existing product realization programs forms a natural extension of our IGERT research activities. The NCIIA grant will enable University of Pittsburgh students to visit UNICAMP during their 10-day March spring break, so that students at both locations can begin collaborating on the development of their sustainability project plans. Teams of students from both locations will continue their collaborations through teleconferencing and internet-based communications for the duration of the course.

In actuality, this undergraduate option will consist of a series of two courses spanning two semesters with the potential to continue for a third term as shown in Figure 2. Pitt and UNICAMP faculty will work together prior to the start of the spring term to identify potential project areas in sustainable development that would lead to fruitful engagement of students at both institutions. Such project areas may include products that respond to clean water demands, promote health or promote sustainable sources of energy, among many other possibilities. For example, students can design windmill-powered pumps for pumping water and durable ceramic filters for purifying water.

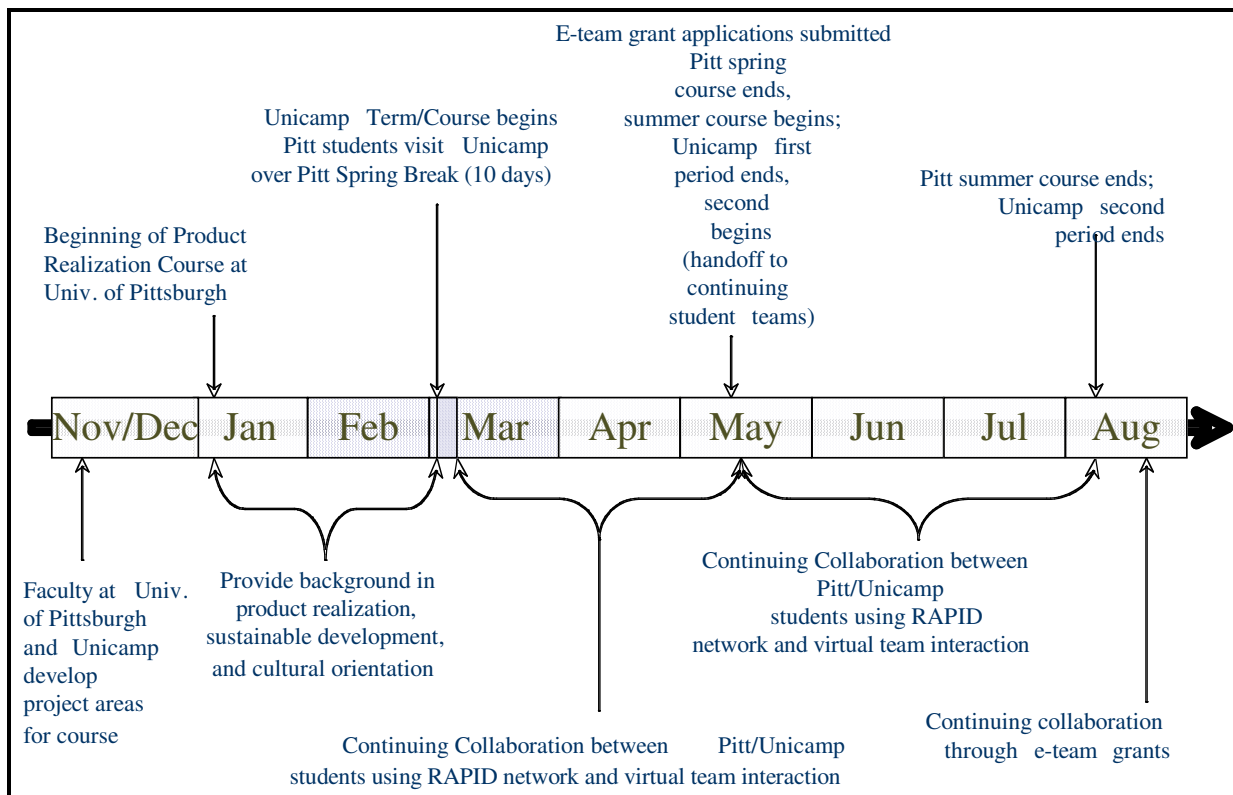


Figure 2: Timeline for Product Realization for Global Opportunities Course

Students at UNICAMP begin the first session of their term in the beginning of March 2007. Students from UNICAMP will meet with students from the University of Pittsburgh, who will travel to São Paulo during their spring break. Students will be able to collaborate together on ideas for product development; they will be able to explore in-person some of the sustainable development needs; and they will be able to participate in cultural experiences during the visit.

From March until May, the Pitt and UNICAMP students will be able to continue to collaborate virtually through the use of videoconferencing capabilities and through other forms of on-line communication. The students' virtual meetings will take place at a minimum of once per week during the March – May period. At the end of this period, students will make a convincing presentation that demonstrates that they have commercial potential before a panel from industry and academia with experience in product realization in a global context. The students will use their functional prototypes for their presentations. They will also present a business plan. The panel will be conducted through a teleconference, so that students, faculty, and panel judges from both Pitt and UNICAMP can participate. Those E-teams who demonstrate that they have substantial commercial potential will be invited to enroll in a follow-on course over the May – August period (Course 2). These students will also apply for advanced E-team grants from NCIIA to continue the product development process. The second period of studies at UNICAMP also begins in May, so the students who are permitted to continue over the May – August period will be able to include all students from both Pitt and UNICAMP teams encouraged to do so.

4. Summary and Conclusions

This paper presents an overview of the University of Pittsburgh's growing programs in Sustainable Design and describes progress to date with respect to research and educational pedagogy. The 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 Friedman, 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." Coincidentally, 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 innovative, integrated undergraduate and graduate education and research programs discussed above are 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 interdisciplinary, team-oriented BS and PhD programs in which students will design the innovative, sustainability related products needed for the future. In conclusion, after the completion of the first year of our program in sustainability, we have made significant progress towards our objectives. Specific challenges that we have faced with implementing our program include recruiting high quality students and implementing the program across multiple departments within the School of Engineering. We will continue to develop the program and make assessments of the program in order to continually improve upon it.

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