AC 2008-2064: AN INTERNATIONAL UNDERGRADUATE RESEARCH EXPERIENCE IN SUSTAINABLE ENGINEERING

Curtis Larimer, University of Pittsburgh

Curtis James Larimer is a senior undergraduate majoring in Engineering Physics in The University of Pittsburgh's Swanson School of Engineering. He expects to graduate in the spring of 2008 and plans to go on to pursue a graduate engineering degree.

Michaelangelo Tabone, University of Pittsburgh

Michaelangelo Tabone is a junior at the University of Pittsburgh majoring in Chemical Engineering. While in school, he works as resident assistant in on-campus housing, volunteers as a teaching assistant of Organic Chemistry, and has served as a paper reviewer for the Pittsburgh Undergraduate Review. Over the past three years he has participated in two sustainable engineering research projects involving sustainable drinking water systems and safe combustion on hydrogen gas. Following receiving his degree, he hopes to eventually go on to either Engineering and Public Policy Graduate School or Law School. Michaelangelo is a member of AIChE.

Matthew Mehalik, University of Pittsburgh

Matthew Mehalik serves as Program Manager at Sustainable Pittsburgh, a nonprofit that researches and promotes polices and practices of sustainability in the 10-county region of Western Pennsylvania. Dr. Mehalik also serves as Adjunct Assistant Professor in the School of Engineering at the University of Pittsburgh. Dr. Mehalik has taught a variety of courses related to sustainable product innovation and design, including taking students to China and Brazil for hands on experience. He has written multiple journal articles in the areas of engineering sustainability and engineering education. Dr. Mehalik obtained a Ph.D. in Systems Engineering, with concentrations in innovation, ethics, and policy, from the University of Virginia (2001).

Kim Needy, University of Pittsburgh

Kim LaScola Needy is an Associate Professor of Industrial Engineering at the University of Pittsburgh. She received her B.S. and M.S. degrees in Industrial Engineering from the University of Pittsburgh, and her Ph.D. in Industrial Engineering from Wichita State University. Prior to her academic appointment, she accumulated nine years of industrial experience while working at PPG Industries and The Boeing Company. Her research interests include engineering economic analysis, engineering management, integrated resource management, and sustainable engineering. Dr. Needy is a member of ASEE, ASEM, APICS, IIE, and SWE. She is a licensed P.E. in Kansas.

An International Undergraduate Research Experience in Sustainable Engineering

Abstract

The University of Pittsburgh's Swanson School of Engineering (Pitt) recently launched a new International Research Experience for Students Program (IRES) sponsored by the National Science Foundation in sustainable engineering research. The Pitt IRES program presents an innovative international research experience in sustainable design for a select group of undergraduate engineering students who have high potential to pursue graduate education. Interns in the IRES program participate in a 12-week summer internship where they join a multidiscipline research team focused on a complex sustainability problem. Each team is co-led by faculty from the Pitt and the University of Campinas (UNICAMP) in Campinas, São Paolo, Brazil. The first year included eight preparatory weeks in Pittsburgh before traveling to Brazil for four weeks in residence at UNICAMP. The program concludes with the team preparing and presenting a final research report at the end of the summer. Interns have an opportunity to continue in the program for a second year. This paper discusses the experience during and after the first year of the IRES program at Pitt. It also discusses the research conducted during this first year – focusing on sustainable drinking water systems. This will be a student-led presentation in which the students discuss their research and experiences with the program.

1.0 Introduction

The purpose of the IRES program at the Pitt is to create an innovative, international research experience in sustainable design for a select group of undergraduate students who have high potential to pursue graduate education. The specific aims of this program are to:

- Teach undergraduate engineering students to incorporate sustainability as a design constraint.
- Teach engineering undergraduates to work as part of an international design team, progressing from initial reliance on faculty and graduate student advisors to reliance on team members over the course of the program.
- Teach undergraduate engineers to function on cross-cultural design teams and in a different cultural environment.

The format of the IRES program is a 12-week summer internship where undergraduate engineering students join a multidiscipline research team focused on a complex sustainability problem. Each team is co-led by faculty from the University of Pittsburgh and the University of Campinas (UNICAMP) in Campinas, São Paolo, Brazil. The first year included eight weeks of directed background research in Pittsburgh before traveling to Brazil for four weeks in residence at UNICAMP. The program concludes with the team preparing and presenting a final research report upon returning from Brazil at the end of the summer. Interns have an opportunity to continue in the program for a second year.

The program has six major outcomes. At the conclusion of the program, students will be able to:

1. Apply knowledge of sustainable design to modern engineering problems
2. Demonstrate leadership skills
3. Function effectively as a team
4. Tackle unstructured problems
5. Effectively communicate and defend ideas
6. Work across cultures

The IRES program in sustainable engineering is housed in the Pitt's Mascaro Sustainability Initiative (MSI). MSI is a center of excellence in sustainable engineering, specifically focusing on the design of sustainable communities. The mission of MSI is to encourage and nurture new collaborative projects based on strong and innovative research that translate the fundamental science of sustainability into real products and processes. Research project teams are cross-disciplinary, international and worked on by teams of faculty, graduate students and undergraduate students.

A detailed project evaluation plan has been developed consisting of both assessment of the various outcomes associated with the project goals as well as an overall evaluation of the students who have participated in the program. A host of assessment tools will be utilized such as rubrics and reflective journals, the specifics are too detailed for discussion in this paper. To address the larger, overall success of the project, the number of students who participate in the program and go on to matriculate into either a graduate program or the workforce will be tracked. The academic performance of each student will also be investigated after they complete the program.

This paper discusses the challenges with implementing the first year of the IRES program at Pitt. It also discusses the research conducted by first year students, which focused on sustainable drinking water systems. Note that this paper is written from the perspective of the IRES students in order to reflect their personal experience with the Pitt IRES program. An emphasis is placed on the organization of the IRES program, the student learning experience, and lasting impact of the IRES program rather than the research results. A summary of the research is included below in section 5.

2.0 IRES Application Process

Applications to the Pitt IRES Sustainable Engineering Research Program are due in February prior to the summer internship. Students are expected to identify a faculty member who can oversee their research, complete the application and write a brief project proposal detailing their research. A committee reviews all proposals based on their merit with a primary objective of selecting high caliber undergraduate engineering students (with a GPA of 3.5 or higher) who have the desire and aptitude to pursue graduate studies (preferably in sustainable engineering). These students must also have an interest in completing an inter-disciplinary and cross-cultural experience. Students are notified in March prior to the summer internship regarding the award decision. Shortly thereafter, students begin preparations for study in Brazil including applying for passports and visas. The Pitt IRES program provided finances for student travel, living accommodations (while in Brazil), and a stipend for the summer.

As this was the inaugural year for the IRES program at Pitt, fewer competitive applications were received than expected. Rather than lowering standards, faculty chose instead to select a smaller group of students to participate in the program and to help shape it. Two students were selected to participate in the IRES program. The first was Curtis Larimer, who had recently completed his third year in Engineering Physics. The second student was a Chemical Engineering student Michaelangelo Tabone, who had just completed his second year.

3.0 Research Begins at the University of Pittsburgh

The 12-week IRES internship began in May of 2007. The primary IRES advisor was Dr. Matthew Mehalik, a faculty member in Pitt's Department of Industrial Engineering and specialist in sustainable product design. Dr. Mehalik had just completed teaching an international product realization course (spring semester of 2007) which included a one week trip to Brazil. Because the IRES program was in its first year, a general outline for the students' research project had not yet been finalized, and as such, the first challenge was to establish research project that would suit the interests of the students selected and faculty from both schools. After faculty advisors at Pitt discussed the direction of student work with faculty at UNICAMP, they agreed to build upon a project that was started in Dr. Mehalik's product realization course, aiming to design an economical consumer product to address the issue of unsafe drinking water in urban Brazil. In the future, student applicants to the IRES program will be able to write proposals for their own research projects and work seamlessly with both Pitt and UNICAMP faculty on these projects.

The students had little experience or background in this area of research so they began by pursuing a knowledge base of water and wastewater treatment. Specifically, they studied water treatment methods, common water problems, background on Brazil's development, and innovative drinking water solutions that have been applied around the world. They reviewed reports from the United Nations Development Programme (UNDP), the U.N. Commission on Sustainable Development (UNCSD), the World Resources Institute (WRI), the Worldwatch Institute, the World Health Organization (WHO), and Brazilian census data to gain a background of the problem. They also began to prepare for the trip to Brazil by studying the Portuguese language using conversation language tapes.

Students met with the primary IRES advisor, Dr. Mehalik, about three times per week to discuss progress. Any new and interesting information was presented, possible effects were discussed, and plans were made for the next steps using product realization models. Dr. Mehalik frequently supplied students with readings about products created for the developing world, the development of Brazil, systems analysis and systems design methodologies, product realization methods, and social dimensions of technology. Also, during these meeting students were updated on the various details of the upcoming trip to Brazil.

The first phase of the research was simply to understand the complex problems related to drinking water in Brazil. To organize research findings, students kept detailed journals of readings, brainstorming ideas, and meeting notes. Also, students assembled an evaluation of the water problem in Brazil into a PowerPoint presentation that could be shared electronically with Brazilian advisors. The functional components of the water system in Brazil were identified in

order to elucidate the shortcomings. Flowcharts were created to explain each step that drinking water must go through in the consumer process, from acquisition to consumption and waste. This also provided a nice graphical way to understand the complex systems involved in water treatment.

While the students grew a working knowledge of the water problem they also continued to explore ideas for potential economically-feasible consumer products using methods of systematic innovation that were adjusted to place an emphasis on sustainability. The students finalized a list of preliminary suggestions as well as background and technical information in support for the use of specific in-home water treatment devices in urban Brazil and sent it to the collaborators at UNICAMP.

Some pitfalls in this early research on Brazil's water systems included the inability to distinguish outdated Brazilian information and the language barrier. Much of the most recent data and information on Brazil's infrastructure is written exclusively in Portuguese. Older information was more often translated, but because students had not yet been to Brazil they could not determine if this information was still relevant to the current problem. For example, research showed that boiling was a widely used method of disinfection but the students later found that, like that piece of information, the practice of boiling water is outdated. Again, because the IRES program was in its first year contact with UNICAMP faculty was infrequent. Long distance research support was slow and the students did not receive significant feedback on their project until they arrived in Campinas and established a working (and personal) relationship with Brazilian team members. In the future, IRES students will have a more active collaborative relationship with UNICAMP faculty and hopefully UNICAMP students. Students developed a website to better facilitate the sharing of information on the IRES program and ongoing research. This was a vital and important tool that was also used while in Brazil to show the project's progress and obtain feedback on new ideas.

4.0 Planning for Travel to Brazil

The final two weeks in Pittsburgh (weeks 7 and 8 of the 12-week IRES program) were spent planning work to be accomplished during the 4-week period in Brazil as well as making final travel preparations. This included finalizing travel plans and attempting to develop a detailed itinerary. Pitt advisors relied heavily on established relationships with contacts abroad to plan a schedule of visits to sites noted for sustainability, water purification, water contamination, as well as sites with facilities in both Brazil as well as the U.S.A. (such as PPG and Alcoa). The schedule required frequent adjustments as in-country opportunities presented themselves. Communication with faculty in Brazil was difficult during this time as it was the last few weeks of UNICAMP's semester and faculty and students were busy with class work. Pitt students and faculty also had to contend with the Brazilian custom of leaving plans more open-ended until the last minute.

Dr. Mehalik accompanied the students to Brazil to help organize research opportunities that would take place during the remainder of the trip. Part of this project involved familiarizing several Pitt faculty already involved with MSI with the IRES program and with travel to Brazil in preparation for future years. Dr. Kim Needy, a faculty member in the Department of

Industrial Engineering, traveled to Brazil for to accompany the students in their second week. Dr. Needy helped to organize plans for the second week that had not yet been finalized and also developed a relationship with UNICAMP faculty. She organized a meeting with PPG, a company that has branches both in Pittsburgh and in southeastern Brazil, opening another opportunity for future collaboration. During the third week, the students "were on their own" in the sense that they were hosted by the faculty and students and UNICAMP without an advisor from Pitt. This seemed to be reasonable because at that point a working relationship was established with faculty and friendships had developed with UNICAMP students. During the fourth and final week in Brazil, two MSIgraduate students from Pitt traveled to Brazil. These students were part of a graduate program called IGERT (Inegrative Graduate Education and Research Traineeship) which includes a six month stay in Brazil.The expectation was that the IGERT students could provide mentoring and guidance to the students on their research while becoming acquainted with living and working in Brazil. A summary of the primary activities (research & professional and cultural) are depicted in Table 1.

Week	Research & Professional Activities	Cultural Activities
1. IRES students and Dr. Mehalik travel from Pittsburgh to Brazil	• Work collaboratively • CDHU São Paulo Housing Area • DIC-III Campinas Housing Area • ALCOA Environmentally Advanced Plant • Poços de Caldas dam, power generation, and waste treatment plants • Poços de Caldas uranium mine monitoring and restoration site • COHAB (NGO)	• Get settled into living environment (buy supplies, etc.) • Meet UNICAMP faculty and students and explore facilities • Tour Campinas • Tour São Paulo • Poços de Caldas resort area
2. IRES students remain in Brazil, Dr. Mehalik returns to Pittsburgh and Dr. Needy travels to Brazil	• Work collaboratively • DIC-III Campinas Housing Area • PPG Latin American Headquarters • SANASA Water Company	• Tour São Paulo, attend a soccer game • Ilhabela resort area
3. IRES students remain in Brazil and are mentored by UNICAMP faculty and students	• Work collaboratively with UNICAMP faculty and remain in contact with Pitt faculty electronically	
4. IRES students remain in Brazil, IGERT students travel to Brazil and at the end of the week IRES and IGERT students return to Pittsburgh	• Work collaboratively with IGERT students and UNICAMP faculty and students, and remain in contact with Pitt faculty electronically	• Caraguatatuba resort area

Table 1. Activity Summary

4.1 In Campinas, São Paulo, Brazil

In Campinas, the presentation that was prepared was reviewed by UNICAMP faculty and product ideas were evaluated and discussed. A wealth of new information was obtained through site visits as well as living experiences. Many of the visits that were made were helpful to give a clear picture of the water problem in Brazil. The students stayed with UNICAMP students in a house about one mile away from the UNICAMP campus, a typical Brazilian living arrangement for students. Over the course of the month, research goals were redirected. Instead of a production realization, the research more aimed to provide a cross-cultural observation of water systems in São Paulo, Brazil. Also, focus shifted to establishing a good relationship with UNICAMP faculty so that future projects could be more pointed and collaborative. Finally, potential areas of research for future IRES students were identified at each site visit and each meeting. A final presentation of the research project, including findings in Brazil was completed during the stay in Brazil and was presented at the MSI Undergraduate Research Symposium upon return.

4.2 Working with UNICAMP Faculty and Site Visits

The first day in Campinas the students met with various UNICAMP professors to discuss the project, the program overall, and the plans for the month long stay in Brazil. UNICAMP faculty provided feedback on the background research that was conducted in Pittsburgh and they were able to identify information that was outdated. In order to better acquaint the students with Brazilian systems, the schedule was modified to add more visits to water-related sites. These visits, detailed in Table 1, were broad in scope, including a decommissioned Uranium mine and a public health clinic in an industrial high poverty area. The schedule was often in flux but the students were still able to expand their knowledge base effectively through site visits.

The large scope of site visits proved important to understanding of Brazil's development, its culture and the impact of these on the drinking water system. One visit to a PPG plant right outside Campinas showed first hand how many Brazilian industries have developed by meeting both ISO 9000 and 14000 standards and applying state of the art technology. Another visit took the students to the public health clinic in the DIC III low income housing district. This was located in former brownfield industrial complexes on the outskirts of Campinas. Half of the housing was legitimate, while the other half consisted of homemade shanty homes that illegally occupied the land. A visit like this exposed the students to the living conditions of the majority of Brazil's poorest population, as well as allowed us to discuss common health concerns related to drinking water.

Fortunately, many UNICAMP faculty members and students aided the students with their research and site visits. These people include Dr. Emília Rutkowski, Leonardo Friere de Mello, and Dr. Doris Kowaltowski. Specifically, Dr. Rutkowski escorted the students to almost every visit and guided them through the creation of their final presentation. Dr. Kowaltowski was the primary source of contact while the team was in Pittsburgh and helped in creating the initial schedule, and she also escorted the group to São Paulo. Mr. de Mello served as a cultural mentor, personally aiding the students in understanding how Brazilians live and work.

4.3 Living and Touring

An important aspect of the IRES program is the international experience. While in Campinas, the students lived with civil engineering students from UNICAMP. All of the students were extremely hospitable. One of them, Murilo Amadeu, spoke English fluently and spent a great deal of time taking the students out to lunch and showing them various restaurants and shops around Campinas. Roommates also served as models of Brazilian culture and were more than willing to talk about customs and lifestyles. They also knew the best places to get good Brazilian food. On two weekends, the students traveled outside Campinas with the Brazilian students. They attended a soccer game in São Paulo and spent the last weekend in Brazil at a beach home in the coastal city of Caraguatatuba.

As tourists in Brazil, the students not only traveled to many research related sites in Poços de Caldas with Dr. Mehalik, but also stayed in the city an extra day to see an outdoor symphony, visit local markets, tour a thermal springs, and ride a cable car up the tallest mountain. Also, with Dr. Needy, the students traveled to an island off the coast of São Paulo named Ilhabela.
The experience was tremendous and to a large extent a defining aspect of the IRES program. Experiencing the sights, sounds and people of Brazil provided a fruitful cross-cultural learning experience. As the research project progressed, students learned the large impact that cultural tendencies play in drinking water. They closely observed the drinking water systems in Brazil and identified strategic areas for future research in sustainability. A summary of the research is found in the following section.

5.0 Research Overview

Research examined the drinking water systems in place in Brazil and identified functional components that contribute to inefficiency and that have the most potential to affect sustainability of water in the future.

5.1 How Brazil's Rapid Urban Growth Has Affected its Water Supply

Beginning in the 1950s Brazil's population has grown rapidly, specifically in urban areas. Today the rural population is declining while cities such as São Paulo and Rio de Janeiro (the world's 4^{th} and 14^{th} largest metropolitan areas) continue to grow. From 1990 to 2007 the population of Brazil grew by almost 27% - an increase of over 40 million persons. Growth by another 29 million is expected by 2025 [1]. By comparison, growth in the United States was 20.7% during the same time period and the world population grew by 25%.

In addition, all population growth has occurred in urban areas while the rural population has moderately declined. The burden of population growth in urban areas has provided a significant infrastructure challenge. Brazil has struggled to provide adequate water, electricity, roads and highways services for its burgeoning population. Today, many areas of Brazil have made promising advances in infrastructure but demand outpaces the rate of advance. For instance, while water treatment facilities grew by 80% in the 1990's, demand for treated water grew by 450%. The regions of greatest growth during this time period were the heavily urbanized Northeast and the Southeast [2].

Water treatment is a process that is as significant to a population, as it is delicate and unstable. If any one of the functional components, shown in Figure 1, is seriously disrupted an entire population can be vulnerable to infection and illness by waterborne disease. Currently, Brazil lacks the infrastructure to safely close the cycle on its water supply. As a result, the water system is rife with inefficiency.

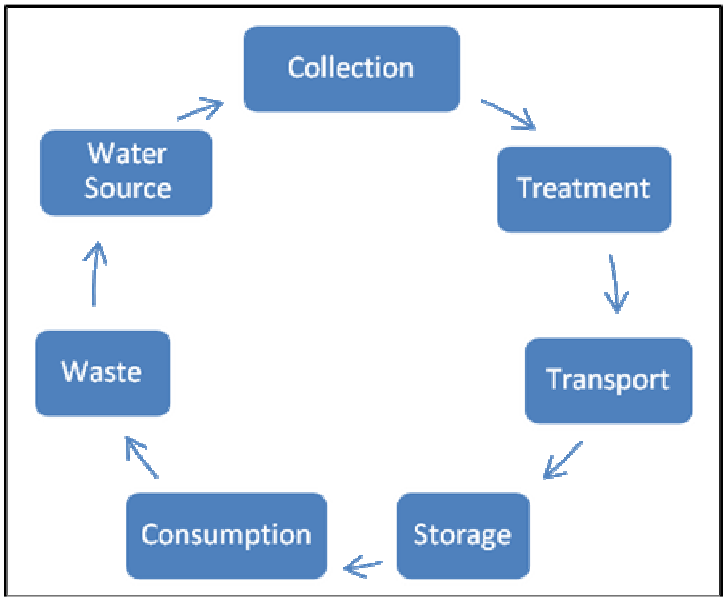

Figure 1. Basic Components of Sustainable Water

5.2 Providing Water has Proven Difficult

A long period of inconsistent water delivery and quality in the first half of the 20th century has bred mistrust of drinking water in Brazil. It is believed that water from a tap is unsafe to drink. And Brazilians are taught at a young age that drinking water should come from either a filter or a bottle.

A technology implemented to combat the problem of inconsistent water pressure was the water storage reservoir, or water-box. A water-box is a tank, usually between 1000 and 2000 liters in size, which is placed on the roof of a home. Figure 2 depicts an illustration of a typical water-box installed on a home. If the pressure of the system drops, the home still has pressure from the height of the box on the roof. Water-boxes are an institution in Brazilian home construction. Modern water-boxes are typically made with polymers; however it is common for older homes to have boxes made from concrete or asbestos cement. Asbestos water-boxes pose a health risk and they were commonly sold and installed as recently as the year 2000.

In addition, a challenge for urban Brazil is the collection and treatment of wastewater. Currently about 75% of Brazil has sanitation coverage (as defined by WHO). But this number is inflated because much of the wastewater that is collected is not treated before being dumped to an

increasingly polluted river system [3]. The full collection and treatment of wastewater – both household and industrial – is a major challenge for Brazilian water authorities.

Figure 2. Water-boxes Installed on Roofs

In the city of Campinas the water authority is SANASA. They cover all services in the city and surrounding metropolitan area with drinking water and wastewater treatment. SANASA is widely considered one of the best water companies in Brazil and even one of the best in all of Latin America. Claiming water from all rivers within Campinas, as well as many outside the city, SANASA provides 98% coverage of drinking water to Campinas' 1.06 million inhabitants in 491 neighborhoods. They also provide 89% coverage of sewage collection and dumping,50% of sewage collected is treated, the rest is dumped directly into natural water basins) [3].

5.3 Technical Issues in the Current Water Supply

Although SANASA sponsors many community-based water education initiatives, including proper water-box maintenance, they do not extend their professional liability for water quality past the water meter outside a home. Water-boxes are cleaned too infrequently and when they are cleaned it is often done improperly. Consequently, the water-box is a looming source of potential contamination in every home. SANASA reports a high number of customer complaints result from water-box contamination and other in-home plumbing deficiencies. In some circumstances, filters were installed before water entered the water-box and the filters removed any residual chlorine from municipal treatment. Unnecessary filtration can increase the ability of bacterial growth in the water-box and redundant filtration adds inefficiency [5].

Additionally, it is fairly common in favelas (a Brazilian term for self-built, unplanned districts) to find a water-box uncovered or covered with a loose fitting makeshift replacement cover. Health officials that work door-to-door in the favelas suggested that as much as 10% of water-boxes are uncovered. Uncovered water-boxes are open to stagnation, infestation by insects, invasion by animals and other equally unsanitary conditions.

Continuous maintenance of the water-box could reduce the risk of contamination. However, the cleaning itself may be a health risk. Water-boxes made from asbestos are potentially dangerous, especially if they are old and dilapidated. The scrubbing of a water-box, as required by proper cleaning procedure could introduce asbestos fibers to the air or drinking water. If precautions are not taken, breathing or drinking asbestos fibers can cause respiratory problems and cancer. Water-boxes are not the only home construction material made from asbestos. Many rooftops are made from corrugated asbestos cement boards. Although asbestos has been banned in Campinas since 2000, much remains in use in favelas and other old structures. A powerful asbestos political lobby has suppressed nationwide bans, health research studies, and education campaigns [10].

Currently the development of sanitation services and wastewater treatment lags the development of treated drinking water in Brazil (as is the case worldwide). Direct contamination of the surface water makes the rivers extremely polluted and unsafe for human contact. It is a significant barrier to a sustainable water cycle. Research has shown that contaminated surface water increases the risk of contamination of the municipal water supply, especially if the pipe system experiences periods of low pressure.

Another challenge for wastewater treatment is the lack of gray water treatment in low income areas. Currently simple plumbing systems are designed to keep separate black and gray wastewater. Black wastewater is piped away from the home to the municipal system and gray wastewater is drained to the street where it eventually flows into rivers. A system capable of treating all wastewater is desirable but would require a large increase in the treatment capacity. The infrastructure of wastewater collection would have to be modernized, also.

6.0 Recommendations for Future Participants in International Research

Based on the international research and travel experience, students prepared two lists of recommendations for future students or advisors.

Research Recommendations

- Participation with advisors in Brazil was greatly increased once a face to face personal relationship was established. I would be beneficial to develop relationships beforehand.
- Driving and transportation in a foreign area is very difficult, when possible have someone familiar with the roads do the driving.
- Maintain communication with advisors in the US in order to keep an outside perspective.
- Study the language, listen well, and try to speak.

Personal Recommendations

- Be prepared to be shocked by something you see. Be prepared to be shocked by something you eat. Shocked may be in a good sense or in a bad sense.
- Indulge yourself on the fine local foods.
- Every nation does something really well. They know it and they are proud of it. It is worth experiencing.

- At some time you will end up doing something that is culturally uncomfortable for you but normal for the locals. Even so, try to embrace it.
- Devote some time to experience the culture.
- Meet and spend time with peers. This was the most rewarding part of the experience in terms of growing acquainted with a new culture.
- Prepare for all kinds of weather, even in a tropical climate.
- Call home over the internet (Skype); it will reassure you and your family (about being apart and about paying the long distance bills).
- Write down your thoughts in a journal or blog and take pictures, so you can cherish the memories.

7.0 Conclusions

This paper presents the results of Pitt's first year of completing its IRES Program in Sustainable Engineering. At the writing of this paper, faculty are recruiting a second class for the summer 2008. Much was learned from the first year and certain modifications to the program have been made for the second year and beyond. For example, one such change will be to move the trip to Brazil earlier in the 12-week period as opposed to holding it in the final four weeks. This allows students to do more research in Brazil and spend time after returning to Pittsburgh working on the final presentation. One suggestion to improve students' preparation for researching abroad is to incorporate some cultural and language training in the form of a once per week seminar that invites Pitt faculty from other areas to lecture on Brazilian history, culture, food, music, politics, travel, etc. A similar graduate seminar has been created for IGERT students planning to live in Brazil.

Although the initial goals of the research project were not completed, significant progress was made. Future IRES teams can anticipate a smoother time with respect to planning the trip as a result of the personal relationships that were made with colleagues at UNICAMP. The experience was rewarding for students and advisors on a personal and professional level. The cultural experience of traveling to a foreign country and working with diverse people was as important as the research work that was done. Establishing a personal connection with UNICAMP faculty and students has laid the framework for successful and fruitful future collaboration. As a result, communication and collaboration will be more frequent while students are in Pittsburgh before the trip. One of the students from the first year of IRES has developed his interest in water treatment in developing nations into an ongoing undergraduate research project. His research aims to increase the efficiency of low cost ceramic water filters that have been impregnated with silver nanoparticles. His investigation of the size, distribution, and morphology of nanoparticles in filter elements may lead to a new method for maintaining clean water-boxes in urban Brazil. He has also enrolled in Portuguese classes, attended the IGERT seminar on Brazilian history and culture, and applied for a second year with the IRES program. His project has already elicited support by UNICAMP and Pitt faculty members and several graduate schools to which he has applied.

The overall aim of the IRES program is to teach undergraduate engineering students how to conduct sustainability research as part of an international design team. Although it is desired, it is not necessarily expected that over a 12-week summer internship that undergraduate students

will make truly ground-breaking discoveries which advance the body of knowledge. A corollary to this desire is that students who participate in the IRES program go on to pursue graduate education and make ground-breaking discoveries later in their academic or professional careers.

8.0 Acknowledgements

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