Interdisciplinary Research for Graduate Education in Sustainability

Qiong Zhang[1], Dana Johnson[2], James R. Mihelcic[1]
[1]Civil and Environmental Engineering, [2]School of Business and Economics
Sustainable Futures Institute
Michigan Technological University

Abstract

As the world faces increasing threats to the long-term health of the environment, society, and economy, sustainability has emerged and now is gathering the attention of undergraduate and graduate education across many campuses in the U.S. Colleges and universities are beginning to incorporate the concept of sustainability in new curricula. Research experiences in a collaborative environment play an important role for students to learn and apply knowledge. In this paper, one project sponsored by an industrial company through the Sustainable Futures Institute (SFI) at Michigan Technological University serves as an example of how research in sustainability can stimulate interdisciplinary collaboration and can improve graduate student learning in terms of the system approach, discovery of new knowledge across disciplines, critical thinking, and overall educational experience. It was also found that the sustainability projects and interdisciplinary collaboration stimulate high quality scholar articles and continuous collaboration.

Introduction

As the world faces increasing threats to the long-term health of the environment, society, and economy, sustainability has emerged and is gathering the attention of developed and developing world communities. At the 2002 World Summit on Sustainable Development (Johannesburg), world leaders reaffirmed the principles of sustainable development[1] adopted at the Earth Summit ten years earlier. One outcome was the Millennium Development Goals, an ambitious agenda for reducing poverty and improving lives based on what world leaders agreed upon at the Millennium Summit in September 2000. For each goal one or more targets have been set, most for 2015, using 1990 as a benchmark. For example, target 10 of Goal 7 of the Millennium Development Goals aims to reduce by half the proportion of people without access to safe drinking water by 2015. This is important because approximately half of the environmental risk for people living in the developing world is from unsafe water, sanitation, and hygiene (Mihelcic et al. 2006).

[1] One definition of sustainable development is defined as the design of human and industrial systems to ensure that humankind'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 (Mihelcic et al., 2003).

The Millennium Development Goals specifically address poverty, education, health, gender equality, environmental sustainability and global partnerships. Engineers can play a significant role in reaching the Millennium Development Goals and global sustainability. In support of this idea, the World Federation of Engineering Organizations (WFEO) has stated that "engineers play a crucial role in improving living standards throughout the world. As a result, engineers can have a significant impact on progress towards sustainable development" (WFEO, 2002). Sustainability science and engineering is a new metadiscipline which integrates economic/industrial, environmental and social aspects in a holistic approach. With an understanding of each of these aspects and how they interact, engineers can manage projects that reach across borders to significantly improve the natural environment, the quality of life and social conditions, and economic development (Fuchs and Mihelcic, 2006).

This new field requires skills and capabilities across multiple disciplines beyond the traditional engineering education (Mihelcic et al., 2003, Cruickshank and Fenner, 2007). In order to fill this capacity, engineers should be trained not only in technical skills, but also in appropriate technologies, knowledge transfer and education processes, culture and community assessment, policy and governance, economic processes and valuation, environmental science, and ethics and social justice. Several of our own studies demonstrate how framing engineering education around a developing world experience is a positive experience for student learning (e.g., Mihelcic and Hokanson, 2005; Mihelcic et al., 2006; Paterson et al., 2006; Fry and Mihelcic, 2006; Fuchs and Mihelcic, 2006; Hokanson et al., 2007). Global issues can also train engineers to value service and understand they need to not only transform society to one that is more socially just, but also ensure that society learns to live within the carrying capacity of natural systems.

There has been an increasing articulation of the need for future engineers to have the training in terms of sustainability science and engineering. For example, the American Society of Civil Engineers (ASCE) Code of Ethics states that "The Code of Ethics of ASCE requires civil engineers to strive to comply with the principles of **sustainable development** in the performance of their professional duties…[including] global leadership in the promotion of **responsible, economically sound, and environmentally sustainable solutions** that enhance the quality of life, protect and efficiently use natural resources" (ASCE, 2001). Accreditation assessment criteria related to sustainability has also been established by ABET which include "Students must be prepared for engineering practice through the curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating engineering standards and realistic constraints that include most of the following considerations: **economic; environmental; sustainability; manufacturability; ethical; health and safety; social; and political**. …to understand the impact of engineering solutions in a **global, economic, environmental, and societal context**" (ABET, 2002).

Research experiences play an important role for students to learn and apply knowledge. As found in a survey (Lopatto, 2004), undergraduate research experience is an effective educational tool to enhance student learning and increase the interest of students in careers in science and the level of pursuit of graduate education. Research teams in a collaborative environment allow for students from different disciplines to gain a broader understanding and view of project outcomes. Since cross-discipline interactions are one nature of sustainability science and engineering, interdisciplinary research is critical for students to grasp the concept of sustainability and apply its principles to solve real-world problems.

This paper describes a project sponsored by an industrial company through the Sustainable Futures Institute (SFI) at Michigan Technological University (hereafter referred to as "Michigan Tech"). This example project demonstrates how research in sustainability can stimulate interdisciplinary collaboration and how experiences gained from collaboration between engineering and non-engineering students contributed to the discovery of new knowledge and the improvement of graduate student learning in sustainability.

Methods

Interdisciplinary collaboration through the institutional support

Interdisciplinary collaboration is a key component of graduate education in sustainability. A formal mechanism for collaborating established at Michigan Tech is called the Sustainable Futures Institute (SFI). SFI provides focused effort in the education and research on sustainability initiatives related to water, air, and energy; industrial ecology, environmentally conscious manufacturing; green engineering; public policy; built environment; and sustainable development issues of developing nations.

SFI has brought together Michigan Tech researchers from different academic disciplines including engineering, forest resources & environmental science, business, social sciences, sciences, and humanities. In addition to research scientists and faculty, students at the undergraduate, masters, and PhD level are actively engaged in interdisciplinary research projects. A Sustainable Futures Model (Figure 1), developed as a framework for SFI, drives the research activity and funding opportunities available through industrial, federal, and foundation-based organizations.

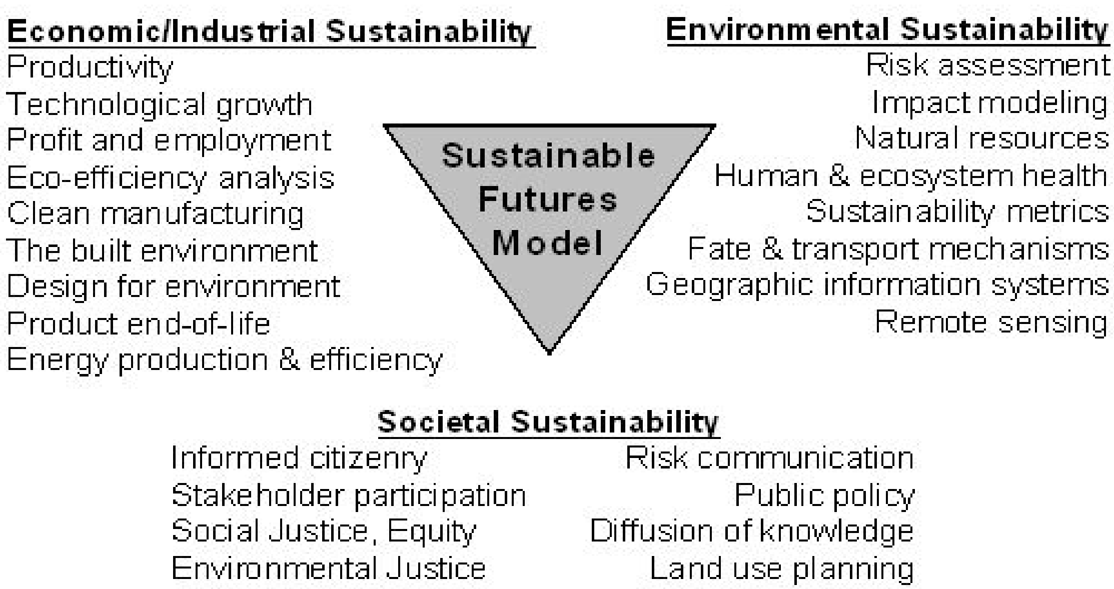

Figure 1. Sustainable Futures Model (Mihelcic and Hokanson, 2005)

Collaboration is not limited to Michigan Tech researchers. However, this discussion focuses on specific projects and educational experiences with industrial partners and Michigan Tech researchers.

As mentioned earlier, the SFI projects are team-based and focus on addressing a specific research issue or problem. The projects are sought out by SFI members and then an appropriate team of researchers, including faculty, scientists, and students is assembled based on a well defined research issue.

Examination of the nature of the project based on Sustainable Futures Model
In this paper, a project sponsored by an industrial company through SFI, serves as an example of how an interdisciplinary collaboration can improve graduate student learning in sustainability. The project was to determine the business attractiveness of supplying water purification that may be combined with power systems to rural areas of less developed countries. The original Sustainable Futures model as shown in Figure 1 focused on sustainability in industrialized nations, not the developing world. Fuchs and Mihelcic (2006) followed this up with an adapted model to discuss sustainability in international development (Figure 2). In this case, the Sustainable Futures Model becomes an "appropriate technology", applicable to developing communities. The terms listed under each of the three sides of the sustainability triangle are impacts or factors related to sustainability in the developing world. As one example, willingness-to-pay also plays a larger role in developing than developed countries, where local development is dependent on community members' desire and ability to contribute to the overall sustainability of the group.

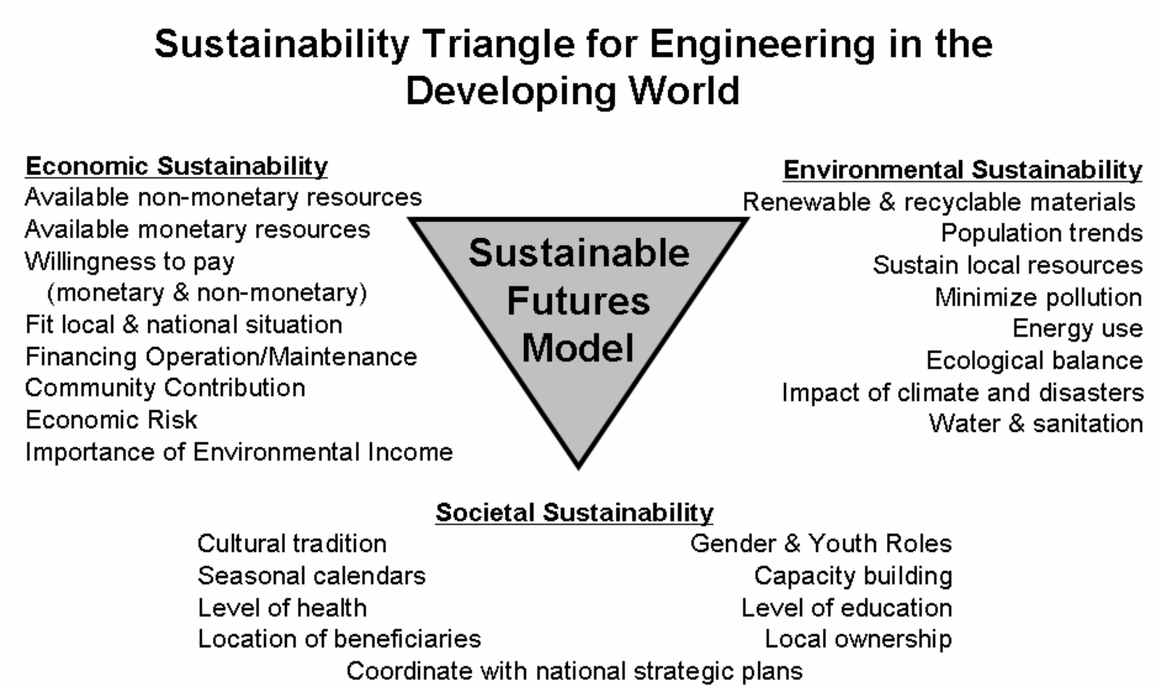

Figure 2. Sustainable Futures Model redefined for international development (Fuchs and Mihelcic, 2006)

The example project consisted of evaluating different water purification technologies for rural areas of less developed countries, their economic/financial feasibility, the role of non-governmental agencies, and markets for the selected technology. Compared with Figure 2, it is clear that the example project addresses the three components of the sustainability triangle as shown in Figure 3.

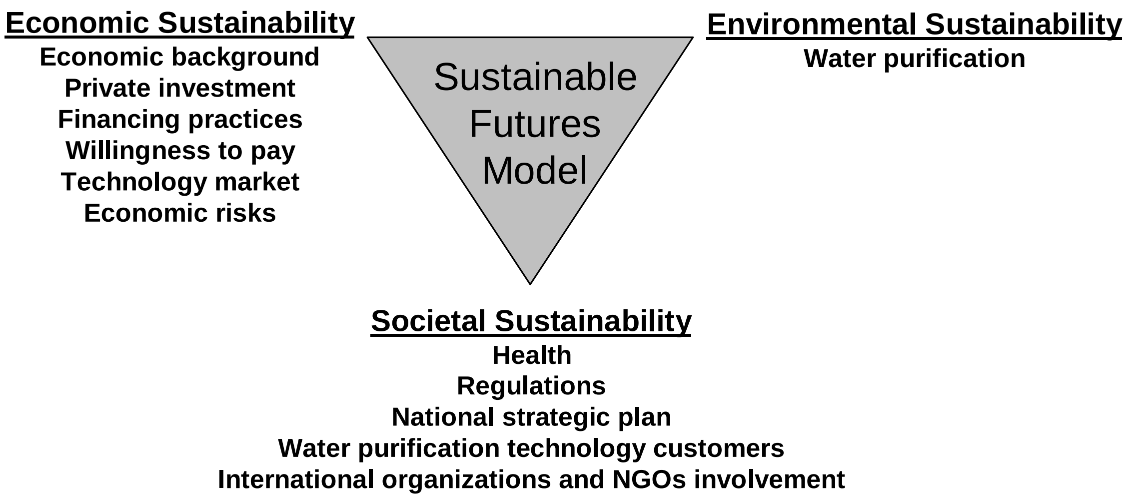

Figure 3. Sustainable Futures Model applied to the example project

Assembling of an appropriate team

To achieve the project objective, three specific tasks were identified: market analysis, technology evaluation and selection, and business case study. The market analysis included evaluating various market segments and identifying requirements for technology, cost, maintenance, etc. for given market segments. The technology analysis was used to evaluate and select various existing water purification technologies to identify the best choice for given market segments in the countries of study. The business analysis focused on evaluating the feasibility of markets in the regions studied (Honduras, Central America; Mozambique, Africa; Madhya Pradesh Province, India; Sichuan Province, China) including capital investment, manufacturing cost, distribution cost, payback time, etc. An appropriate team, including faculty members, a postdoctoral researcher, and graduate students, was assembled to accomplish the tasks. The team members were from an engineering unit – Department of Civil & Environmental Engineering (CEE) and a non-engineering unit – School of Business and Economics (SBE). The researchers in the environmental engineering discipline have expertise in water supply and treatment, wastewater collection and treatment, public health, and water resources. One of CEE faculty members directs the Master's International program in Civil & Environmental Engineering, the only program of its kind in the U.S. This program allows students to combine their graduate studies with 3 months of cultural/language/technical training and 2+ years of water/sanitation engineering service in the U.S. Peace Corps. The Peace Corps graduate students were involved in this project through an informal survey. The School of Business and Economics has faculty researchers with practical international experience who research the global issues associated with business cases.

Identification of different research approaches

The expertise of engineering and business were particularly important in identifying the different research approaches used for the project. The research approach varied depending on the project objective. The example project demonstrates how the methodologies were applied to conduct research, discover new knowledge, and document findings and recommendations.

As mentioned earlier, the objective of the example project was to determine the business attractiveness of supplying water purification technology. Work under this project was limited to markets in rural areas of less developed countries (identified earlier) where neither fuel nor electricity are readily available. Because of limited time and resources to complete the study, it was necessary to identify an appropriate scope for the project. Preliminary research was conducted using a set of thirteen economic and demographic variables from government databases. The variables included:

- gross domestic product (GDP) per capita
- GDP - annual growth rate
- political stability
- government effectiveness
- total population
- percentage rural population
- literacy rate
- average household size
- water use per capita
- percentage of urban population with access to improved water
- percentage of rural population with access to improved water
- electric generation capacity
- electricity use per capita

Another criterion was to make sure that each of the four regions selected were different but generalizable to similar economic, demographic, and geographic regions.

Some of the methodologies employed were performed concurrently. The researchers collaborated weekly to share information and compare findings. The environmental engineering researchers developed a list of criteria to conduct an engineering analysis of identified water purification technology. After the engineering analysis was completed, a final list of water purification technologies meeting the criteria was further evaluated.

For each water purification technology on the final list, the initial investment and operating costs were identified through contacting equipment vendors and through literature reviews. This was primarily completed by the environmental engineering team. While the environmental engineering team was conducting their analysis, the business team gathered business, economic, demographic, and financial information about each of the regions.

While gathering data and facts associated with the technology and economic/financial variables, it became apparent that more information was needed to provide concrete recommendations. A critical component of the research was to gather qualitative data about the regions or similar regions in developing countries who were seeking improved water quality for its citizens. Quantitative data is useful in decision making and is enhanced by the use of qualitative information. The need for additional information was identified and the research team conducted both informal and formal surveys.

The environmental engineering team conducted an informal survey of students in the field through the Peace Corps program that were directly working with some of the water purification technologies being studied. Not only were technical aspects of the technologies considered, but also valuable information regarding the cultural considerations of change and other relevant qualitative information. From the informal surveys, it was learned that nongovernmental organizations (NGOs), such as Water Aid and the World Health Organization (WHO), are promoters and facilitators of improved water quality in developing regions of the world. The team decided to gather more information from NGOs to supplement their informal surveys.

A survey questionnaire was developed. Together the research team collaborated in surveying a number of NGOs that promote clean water for individuals in developing regions of the world. Insight about the technologies and cultures from an agency perspective added to the informal surveys conducted by students in the field.

To build a business case regarding particular technologies, a capital investment analysis was performed using cost of capital rates reflective of risk associated with operating in a particular region, investment and business risk, financial risk, and failure risk. The information from the engineering analysis, business data, informal surveys, formal surveys, and capital investment analysis were then evaluated to obtain overall conclusions regarding the business feasibility of a given water purification technology in the regions studied.

Using qualitative information and quantitative data allowed for a comprehensive recommendation regarding the business feasibility of water purification technologies in rural developing regions. Only one region - Sichuan, China was recommended based on the favorable financial and economic evaluation along with the possible cultural adaptability to using new water purification technology. A major hindrance for all regions was the level of government corruption, with Sichuan, China having the lowest potential impact of government interference and misappropriation of resources. China also has had some experience and success in other regions of the country regarding the implementation of water purification technology and appeared to be more advanced than the other regions studied (Johnson, et. al, 2007). It is important to use quantitative analysis through the engineering evaluation and the capital investment analysis along with qualitative factors regarding the cultural and behavior aspects of implementing new technology. For example, although Ultraviolet (UV) technology and chlorine bleach are financially feasible for Sichuan, China, business risks are present that could impact the financial viability and certainty of planned investment. The qualitative variables, such as government corruption and affordability should weight heavily in the decision making process. Looking solely at quantitative factors could result in a costly business decision and monetary loss to the investor.

Results and Discussion

Student learning

Through this research project, students were challenged to solve the real-world problems with the system approach, which is the fundamental concept of sustainability. As defined by Daly (1996), sustainable development is “development without growth beyond environmental carrying capacity, where development means qualitative improvement and growth means quantitative increase." With this definition, sustainable development has to be considered as nested systems, where the environmental system provides the context for everything else in it. Society in the environmental system invented the economic system. To implement drinking water technologies in developing countries, the students had to consider social and economic systems while selecting the appropriate water purification technologies. For example, the following criteria had been developed by the project team for technology evaluation: (1) disinfection capability to remove or inactivate microbiological contaminants for safe drinking water; (2) primarily applied to domestic use; (3) affordable to the user; and (4) appropriate for cultural and social conditions. The criteria included not only technological consideration (criteria 1 and 2), but also economic factor (criterion 3) and social aspect (criterion 4).

From this interdisciplinary research, the students discovered the knowledge across disciplines. For example, the students from engineering gained the knowledge in societal and economic areas, such as the impact of culture on perception of water purification technologies, the economic risks associated with implementing the technologies, and local water purification project financing practices. For example, UV technology is technologically feasible based on criteria 1 and 2 and preferred according to cost analysis; however, it is not widely practiced in rural areas of developing countries due to its power requirement and skill requirement. The UV technology requires more power than other technologies (e.g., slow sand filtration), which increase operation/maintenance cost and eliminate its potential application in the region without power supply. The technology is also complex and it is difficult for a community to own and operate. In addition, it is difficult for a local community to buy into this technology because they can't visualize the difference between raw water and treated water. The barriers and risks related to economic aspect (e.g., affordability), policy (e.g., water tariff and import regulations), and social condition (e.g., government corruption) have been identified and documented in the project report. Overall, they learned to synthesize the knowledge and find the appropriate technology and effective way to implement the technologies.

Another important aspect in the discovery of new knowledge is the recognition by the graduate students that their project experience was parallel to real world careers and experiences. Oftentimes students tend to focus on their particular discipline or area of expertise without the recognition of other disciplines or the relationship of those disciplines to one another. Branching beyond their disciplines and learning the impact their decisions may have on an entire organization allowed them to understand that discovery of new knowledge also leads to integration of multiple disciplines simultaneously.

The collaborative experiences gained in the project helped students become strong critical thinking. As mentioned above, the team is diversified in terms of disciplines and knowledge, which provided students with learning environment of external knowledge and opportunities to analyze, synthesize, evaluate and make decisions cooperatively. The collaborative learning stimulated their thinking because they had to communicate their opinions by giving justification and the criteria employed in making decisions. This experience benefits students not only in learning, but also their personal and social skill development. They took responsibility not only for themselves but also the team. They learned to compromise and help each other to achieve the goal of the research team as described in the "Research Approach" section.

According to Bloom's taxonomy, higher order learning is expected at the upper levels of education, like graduate programs, and also leads to longer retention of learning. By using the higher order learning skill such as evaluation and synthesis, not only did this collaborative experience enhance the students' overall educational experience, it also lead to a higher level of overall applied learning (Athanassiou, et. al, 2003).

The collaborative research environment enables students to gain a broader understanding of multiple disciplines and their interrelationship. This leads student to making better informed business and engineering decisions on comprehensive and complex information.

Scholar publication from the project

Two peer-reviewed journal articles were produced from the project. One focused on water purification technology titled "Challenges to Implementing Drinking Water Technologies in Developing World Countries," in the journal *Environmental Engineer: Applied Research and Practice*, Vol. 1, Winter 2007, and in Environmental Engineer, the Magazine of the American Academy of Environmental Engineers, Vol. 43, No. 1. This article identified the technical, economic, and social barriers to implementing drinking water technologies in developing countries and provided practical guidance to practitioners regarding the barriers and in developing strategies for successful implementation. Once the article was published, a congratulatory note was received from a regional advisor in environmental health with the World Health Organization.

> "It was good to see the Academy again highlighting the importance of safe drinking water in developing countries through this article. Congratulations to the authors for their well planned and implemented study and their clear and concise article."

The second peer-reviewed article titled "Feasibility of Water Purification Technology in Rural Areas of Developing Countries," has appeared in electronic format of the *Journal of Environmental Management* and will be in print in Fall 2007. This article focused on the technology selection process, economic/financial evaluation, and business risk factors associated with the selection of water purification technologies for developing regions. The editors and reviewers were particularly pleased with the interdisciplinary and comprehensive nature of the paper.

Stimulation of continuous collaboration

The first project has lead to a second interdisciplinary project. The second project involved evaluating alternative energy technologies to lower greenhouse gases. This project involved a broader group of disciplines including business, forestry, chemical engineering, and mechanical engineering graduate students, faculty, and researchers. There are two papers currently under review as a result of this project, with both papers being co-authored by faculty, graduate students, and researchers. Both projects were funded by industrial partners.

This demonstrates that industrial partners value interdisciplinary research and the experience provided to graduate students who are ultimately employed by these companies.

Conclusions

Based on the results listed above it is concluded that:

1. The research projects addressing sustainability in terms of industrial/economic, environmental, and social aspects stimulate the interdisciplinary collaboration and help form the cross discipline research team.
2. The experiences gained from interdisciplinary research help students solve the real-world problems with the system approach and discovery of new knowledge across disciplines. Students recognize that their project experience was parallel to real world careers and understand that discovery of new knowledge also leads to integration of multiple disciplines simultaneously.
3. The collaborative experiences help students in critical thinking, enhance the students' overall educational experience, and lead to a higher level of applied learning.
4. The sustainability projects and the interdisciplinary collaboration stimulate high quality scholar articles and continuous collaboration.

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Acknowledgements

The authors gratefully acknowledge the National Science Foundation for support of our international and engineering sustainability education and research through the Sustainable Futures IGERT project (Grant No. DGE 0333401) and IRES Grant (Grant No. OISE 0623558). More information about the programs discussed in this article can be found at www.cee.mtu.edu/sustainable_engineering and www.sfi.mtu.edu.

Biographic Information

Dr. QIONG ZHANG is the Operations Manager of the Sustainable Futures Institute and an Adjunct Assistant Professor in the Department of Civil and Environmental Engineering at Michigan Technological University. She has expertise in water treatment technologies, risk assessment, and multimedia fate and transport modeling.

Dr. DANA JOHNSON is an Associate Professor, Operations Management, School of Business and Economics. She has extensive industry experience as well as interdisciplinary teaching and research experience. She has expertise in operations management and financial/cost based business case presentation.

Dr. JAMES R MIHELCIC is a Professor and Director of Master's International Program in Civil & Environmental Engineering at Michigan Technological University. He has expertise in biological processes, green engineering and sustainability, and engineering of the developing world