Int. J. Engng Ed. Vol. 23, No. 2, pp. 254–265, 2007
Printed in Great Britain.
0949-149X/91 $3.00+0.00

Educating Engineers in the Sustainable Futures Model with a Global Perspective: Education, Research and Diversity Initiatives*

DAVID R. HOKANSON,† LINDA D. PHILLIPS AND JAMES R. MIHELCIC††
Civil and Environmental Engineering, Sustainable Futures Institute, Michigan Technological University, 1400 Townsend Dr., Houghton, MI 49931. E-mail: jm41@mtu.edu

Many universities espouse the idea that discipline integration is a prerequisite for successful implementation of sustainability in education. However, few engineering curricula have taken the step to integrate concepts of sustainable development with an international experience. This paper discusses the professional, educational and global drivers for curricular change in this important area and demonstrates how an undergraduate International Senior Design and graduate Master's International program, both of which are based on international sustainable development, can be integrated into an Undergraduate Minor and Graduate Certificate to provide a more interdisciplinary basis for educating engineers on global concepts of sustainability. Importantly, the paper also discusses whether such initiatives may result in improvement of diversity in the engineering student population.

Keywords: diversity; graduate certificate; interdisciplinary education; international senior design; masters degree; sustainable engineering; sustainability; undergraduate minor

INTRODUCTION

THE CONCEPT OF ECONOMIC, environmental, societal sustainability is becoming ingrained in the international engineering community. The next generation of engineers will need to be trained in the context of sustainability with an international perspective if they are to participate in solving problems of sustainability at the local and global scale. For example, engineers must understand that many problems of sustainability in the developing world are not related to manufacturing, but are related to water, soil, agriculture, forestry and fisheries [1,2]. Such complex problems require an integrative approach for solution and engineers must be prepared to meet challenges that extend beyond the boundaries of a single discipline.

Various professional societies and international organizations recognize a need for engineers to come together to meet the sustainability challenge. For example, the American Society of Civil Engineers (ASCE) has recognized the importance of sustainability and built into its Code of Ethics a fundamental canon that engineers shall:

> strive to comply with the principles of sustainable development in the performance of their professional duties.

ASCE sponsors an Environmental and Water Resources Institute (EWRI) that works to solve problems related to sustainable water supply on a global scale through its affiliation with the Global Water Partnership. ASCE is also one of three professional societies, along with the American Society of Electrical Engineers (ASEE) and the American Institute of Chemical Engineers (AIChE), which are co-sponsors of the Engineers Forum on Sustainability (EFS). EFS promotes sustainability principles at local, regional, national and international scales including facilitating interdisciplinary discussion on the topic, disseminating information regarding engineering education programs that incorporate sustainability, encouraging practicing engineers to apply sustainability principles and circulating information on international developments that foster global sustainability. The American Association of Engineering Societies (AAES), which consists of 17 member professional engineering societies including ASCE, is also committed to advancing sustainability on a global scale, as shown by its membership in the EFS and its affiliation with the World Federation of Engineering Organizations (WFEO), which is discussed below.

On the global level, the world community has been collaborating for several decades to develop solutions to the Earth's many environmental, societal and economic problems. Importantly, at the 2002 World Summit on Sustainable Development (Johannesburg), world leaders reaffirmed the

* Accepted 15 December 2006.
† Trussell Technologies Inc., 232 N. Lake Ave., Suite 300, Pasadena, CA 91101, USA.
†† Author to whom correspondence should be addressed. Phone: (906) 487-2324. Email: jm41@mtu.edu.

principles of sustainable development adopted in the Rio Earth Summit (http://www.un.org/geninfo/bp/enviro.html) 10 years earlier. One outcome was the development of a set of 'Millennium Development Goals' (MDGs) (http://www.undp.org/mdg/), which are an ambitious agenda for reducing poverty and improving lives based on what world leaders agreed upon at the Millennium Summit (http://www.un.org/millennium/summit.htm) in September 2000. For each goal, one or more targets have been set, most for 2015, using 1990 as a benchmark. For example, MDG no. 7 deals with ensuring environmental sustainability, including targets of integrating the principles of sustainable development into country policies and programs to reverse the loss of environmental resources, as well as reducing by half by 2015 the proportion of people without access to safe drinking water.

The solutions to the world's current and future problems will require that engineers design and construct ecologically and socially just systems within the carrying capacity of nature without compromising future generations. In addition, as governments move toward policies that promote an international marketplace, educators need to prepare engineers to succeed in the global economy. Young people entering the workforce in the upcoming decades will also have the opportunity to play a critical role in the eradication of poverty and hunger and facilitation of sustainable development, appropriate technology, beneficial infrastructure and promotion of change that is environmentally and socially just.

In recognition of the emerging importance of sustainability, Michigan Technological University founded the Sustainable Futures Institute (SFI) in February 2003. SFI's mission is to create and disseminate new methods and processes that generate scientific knowledge and engineering products in support of sustainability decisions and education. Accordingly, SFI has taken a leadership role in promoting engineering curricular change at the undergraduate and graduate level, as will be described in this paper.

There are three important motivators for the curricular changes that are discussed in this paper. First, the MDG are a clear call to the engineering profession to participate in identifying sustainable solutions to global problems. Second, in response to this challenge, various professional societies described above and the WFEO are supporting programs that will enable this vision. The WFEO states:

> engineers play a crucial role in improving living standards throughout the world. As a result, engineers can have a significant impact on progress toward sustainable development [3].

Third, there is the recognition that engineering education does not do a good job of integrating technological development with development that is compatible with society and the environment [4].

The Sustainable Futures Model (shown in Fig. 1) can be used to address these needed fundamental changes in engineering curriculum because it provides a framework to educate engineers to consider sustainability in the context of environmental, societal and economic/industrial considerations. Furthermore, an important component of the 'societal systems' section of the sustainability triangle is social justice, which is a basis for the Millennium Development Goals.

Educators are slowly responding to this vision of graduating engineers that will provide solutions to the world's many problems as well as value service to society. For example, there are many documented cases of incorporation of service learning into engineering design (e.g. [5–7]) and some design

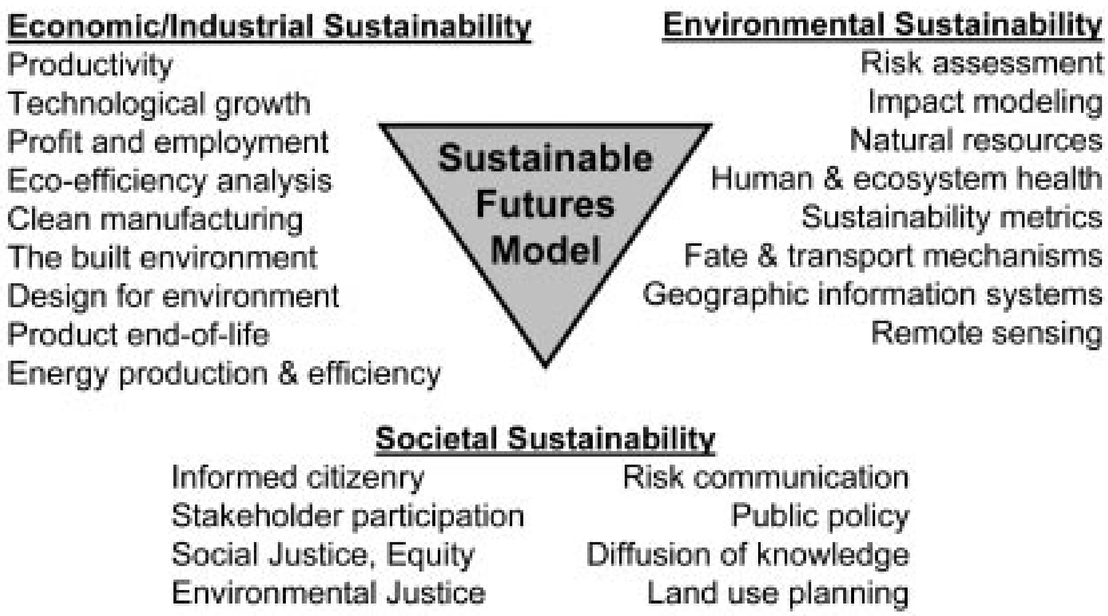

Fig. 1. Sustainability triangle showing the three facets of the metadisciplinary approach for solving environmental problems [2]

courses are structured to work on solutions to meet the needs of the poor [8] and contribute to disaster relief and refugee operations [9].

Various educators have also begun to think about incorporating sustainable development into university curriculum. For example, a university faculty member in the UK showed how the Institution of Civil Engineers (ICE), a UK-based international organization with 80,000 members, adopted a sustainability education strategy for civil engineering with implementation starting in 2002 and demonstrated that sustainable development is applicable to a systems approach to solving problems that are rigorous [10]. In the USA, a university faculty member discussed the discipline integration required to achieve sustainability and barriers to achieving the required education paradigm changes [11]. Others have argued that sustainable development must be incorporated into university curricula and that green engineering programs, Accreditation Board for Engineering and Technology (ABET) and professional societies (e.g. AAES, ASEE, EFS, American Association of Environmental Engineering and Science Professors) will be critical for the curricular reform in the presence of barriers to integration of disciplines [12]. In the Netherlands it has been argued that to incorporate sustainability in the undergraduate curriculum, there must be a fundamental course that all students take in the area, sustainability must be integrated into all regular disciplinary courses and there must be an option to graduate with a sustainability specialization that is available in all departments [13].

In response to the need for discipline integration in the engineering curriculum to implement a sustainability program, Michigan Technological University has combined sustainability with an international experience involving both undergraduate and graduate education. Figure 2 summarizes the elements of the program, which will be discussed in more detail below.

It is our primary goal to graduate engineering professionals who are educated not only to apply sustainable appropriate technology to a wide range of engineering projects but are also inspired to value service to the global community and consider the social, economic and environmental limitations of an engineering project. Many of the specific engineering projects discussed in this paper are related to improvement of public health. Sustainable development is clearly linked to this important issue. Three out of eight MDGs, eight of the 16 targets and 18 of the 48 indicators relate directly to health. Health is also an important contributor to several other goals. Principle One of the Rio Declaration states that:

> Human beings are at the centre of concerns for sustainable development. They are entitled to a healthy and productive life in harmony with nature.

Furthermore, the World Health Organization (WHO) states:

> Health is both a resource for, as well as an outcome of, sustainable development. The goals of sustainable development cannot be achieved when there is a high prevalence of debilitating illness and poverty and the health of a population cannot be maintained without a responsive health system and a healthy environment. Environmental degradation, mismanagement of natural resources and unhealthy consumption patterns and lifestyles impact health. Ill-health, in turn, hampers poverty alleviation and economic development [14].

Fig. 2. Summary of program for educating engineers on sustainability at Michigan Technological University, including unifying themes, undergraduate and graduate education program elements and expected outcomes.

UNDERGRADUATE EDUCATION

International Senior Design

For several years, our department has administered capstone design projects for seniors, which allow students to obtain university credit for working on engineering projects in the developing world [15]. Practitioner involvement and affiliation with international partners has been a key to the success of the project classes as it has been shown that capstone senior design projects overseen by a licensed, professional engineer are a valuable mechanism to prepare students for success in engineering practice, similar to experience gained during the initial year on the job [16].

The goal of International Senior Design (ISD) is to provide students a service-learning design experience situated in the developing world so they can explore the technical, economical and social implications of engineering design and construction as embodied in the Sustainable Futures Model (see Fig. 1). Integration of the US ABET accreditation criterion throughout the design experience is crucial to this activity. To date, students have collaborated with communities in Bolivia and the Dominican Republic. Review of the International Senior Design students' written reports, oral presentations and learning logs, as well as examination of syllabi of the required courses and post exit interviews of students, confirm that the goal to have students address and integrate the various components of Sustainable Futures Model shown on Fig. 1 is being satisfied.

ISD was created as a response to consistent student requests in a third-year Professional Practice course required by all civil and environmental engineering majors. At that time, the Professional Practice course included a contract document preparation project for developing world construction projects. Students completing the project frequently requested an opportunity to travel to the international project site and actually implement their ideas. ISD began as a single semester three-credit* major design experience that could also fulfill a technical elective requirement. At Michigan Technological University, a three-credit course requires at least 42 hours of in-class time and 84 hours of out-of-class time. Recently the course underwent revision to a six-credit course. This change in credits was precipitated after a review of the student hours required for completion of the experience and ABET criterion satisfied in each segment. Currently, 20–25% of our undergraduate civil and environmental engineering majors take this course.

The ISD course is structured to emulate the business of a design/build firm in industry, since the student will likely find themselves in this work environment, within 6–12 months after the class experience. Students form a 'design team', which is directed by the team-elected project manager. Teams of three to four students are expected to complete the final project design; each team working on a different design project, just as in industry. Specific tasks and assignments are made within the team by the students themselves, sharing the work equally. Student teams complete feasibility studies, preliminary and final designs on their own time, which is monitored by individual timesheets to track project progress. Project managers update the CEO (instructor) via required weekly meetings. The most important aspect of the course is that students experience the evolution of a project from conception through completion of final design drawings and specifications including preparation of an engineering report. The engineering report analyses feasibility of various design options, complete with cost/benefit analyses, cost estimates and construction schedules. Construction and cultural experience is also gained while students are in-country gathering design data. Students are evaluated much as they will be in industry, on attitude and effort as well as quality of documents produced.

Due to the number and variety of design projects, in addition to corporate and alumni interest, industry mentorship has been included beginning with the second course offering. Mentors may travel abroad with the group and advise on a daily basis, or may choose to 'mentor from afar', coaching the students on project delivery and procedures as well as the technical concepts. The mentors are either seasoned professional engineers or recent graduates working towards professional registration who have participated in the program. Both provide helpful and at times different, wisdom and experiences. As traditional approaches may not be an option, students and mentors need to 'think outside the box' to develop alternate methods of obtaining data or approaching the design problem.

The program has been offered since January 2001 and, to date, 118 students have chosen the 'international senior design experience' in ten offerings. Ownership of the student design projects is so great that 10 students have returned for 14 additional in-country experiences. Table 1 provides examples of engineering projects performed in ISD and Table 2 provides details on students' course requirements and how these fit requirements made by ABET, specifically ABET Criterion 3, which addresses the skills, knowledge and behaviors that students should have at graduation.

Integration of the ABET criterion throughout the experience, both for the in-country and on-campus design experience, is evaluated by each student with the requirement to maintain a learning log. For each entry or experience, the ABET requirement(s) that apply to the project task, experience or lesson are to be documented. A

* At Michigan Technological University, a 3-credit course requires at least 42 hours of in-class time and 84 hours of out-of-class time.

Table 1. Examples of engineering projects performed by International Senior Design students

Area	Example projects
Wastewater treatment	Designed and constructed new on-site septic systems for schools
	Designed retrofits for malfunctioning existing school systems
Water supply	Designed gravity-fed water transmission lines from springs to village
	Designed and constructed solar powered water distribution system (i.e. spring box, pump box and tank) to collect and distribute spring water
Water resources/management	Designed and constructed neighborhood storm water drainage plans
	Developed master drainage plan for 20-acre school and university site
	Developed master drainage plan for city area
Site master planning	Designed a suspended bridge river crossing
	Designed, developed and constructed school site master plan and site fill plan
	Designed and developed community center site master plan
Site reclamation and solid waste management	Developed area reclamation and solid waste management plan

Table 2. Student requirements for International Senior Design and US ABET accreditation fulfillment

Student requirements	Relationship of student requirement to ABET criteria
Maintain learning log	Students are required to maintain a daily learning log which includes reflections on how each activity, action, observation, question or revelation meets the ABET criteria 3 and 4, as well as Departmental Vision and Mission. Students discover that every criterion is met to varying degrees
Maintain daily time sheet	Timesheets mimic industry and were a major factor in revamping the program to 6 credits. It also elicits an understanding of professional and ethical responsibility as it relates to engineering contracts and client invoices (Criterion 3f)
Present professional safety talk	This exercise mimics industrial construction site activities and provides students an understanding of professional and ethical responsibility (Criterion 3f), provides them an opportunity to communicate effectively (Criterion 3g) and their research for the talk provides knowledge of contemporary issues (Criterion 3j)
Gather design project data	Students, working within the local community structure, are required to survey, conduct tests and analyses, etc as required by their design project in fulfillment of: an ability to apply knowledge of mathematics, science and engineering (Criterion 3a); an ability to design to design a system, component, or process to meet desired needs with realistic constraints such as sustainability (Criterion 3b); an ability to function on multi-disciplinary teams (Criterion 3d); an ability to identify, formulate and solve engineering problems (Criterion 3e); an ability to communicate effectively even across language and cultural barriers (Criterion 3g); the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental and societal context (Criterion 3h); and an ability to use the techniques, skills and modern engineering tools necessary for engineering practice (Criterion 3k)
Develop a design project schedule and cost estimate with cost/benefits	Students must attain the ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability and sustainability (Criterion 3c)
Compile engineering design, calculations, assumptions, tables, charts, notes on solutions, references	The following criteria are fulfilled: (3a–g, k)
Prepare and present the final engineering report in written, verbal, web page and poster form	The final report requires students to: develop and analyse alternate design solutions; code analysis and review; conduct feasibility evaluation; discuss economic and health factors, social impact, sustainability, safety, reliability, aesthetics and ethics; develop and analyse proposed construction schedules, engineering estimates & cost/benefit analyses; prepare team engineering study and design report; final design drawings; project specifications; senior design poster; and web page (Criteria 3 a–h, k)
Student requirements	Relationship of student requirement to ABET criteria

synopsis of how each ABET criterion was met is also required from each student at the end of the in-country and on-campus portions of the experience, as a method for the student to reflect on the importance of each criterion, the number of ways the criteria were met and what the student actually learned with respect to each.

Integration of International Senior Design with undergraduate minor

A proposed undergraduate minor in International Sustainable Development Engineering (Fig. 3) integrates components of the sustainable futures model (Fig. 1) into our international senior design. A previously mentioned driver for this change is to not only provide students context to ISD, but also to recognise that engineering education does not adequately integrate technological development with development that is compatible with society and the environment [4]. Rarely have engineering courses attempted to obtain and utilize information concerning the impact technology has on human, societal and environmental systems [17]. As shown in Fig. 3, the sustainable development engineering minor is integrated over the 4 years of engineering education and culminates with the international design experience.

The goal of the minor is to educate engineers to create ecologically and socially just systems within the capacity of nature without compromising future generations. This minor provides students breadth in the areas of ethics, resource equity, community participation, interactions between technology and society and engineering connections with the environment. Though the focus of the minor is for students to study and experience sustainable development in an international context, the skill set provided from this educational experience is just as applicable to developing sustainable engineering solutions as to problems facing the developed world.

GRADUATE EDUCATION

Graduate Certificate in Sustainability

In the past few years, a few universities have established certificate programs targeting graduate students to recognise integrative educational focus in areas related to sustainability. For example, the

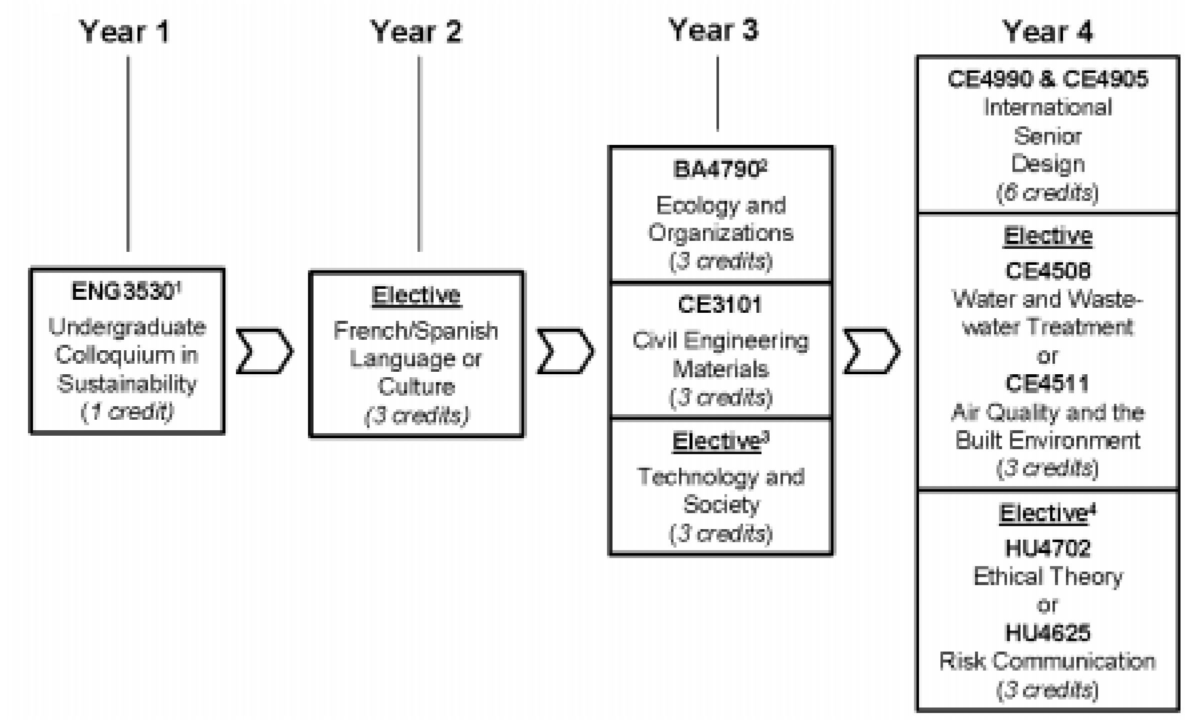

Figure 3. Example of how International Senior Design fits into the undergraduate minor in international sustainable development engineering. [a] Descriptions of courses are available at URL: http://www.admin.mtu.edu/em/students/plan/index.php. ENG = Engineering, BA = Business Administration, CE = Civil and Environmental Engineering, SS = Social Sciences, HU = Humanities.
[1]ENG3530 uses readings and speakers to teach concepts of sustainable development and global sustainability.
[2]BA4790 examines the problems and solutions associated with creating and maintaining ecologically sustainable organizations (primarily businesses).
[3]For the technology and society elective, students elect at least one social science course that examines how technology affects society. The elective course is the selected from the following list: SS2800 Science, Technology, and Society; SS3580 Technology and Western Civilization; SS3620 International Environmental Technology Policy; SS3800 Energy Technology and Policy; SS3810 Culture, Science and Technology; SS3890 Industry and the World Economy.
[4]HU4702 examines several ethical and philosophical issues including human relations to the environment and HU4625 examines models for communicating risks including the diverse roles assumed by the public under each of these models.

University of Michigan (Ann Arbor, MI, USA) offers a Graduate Certificate Program in Industrial Ecology affiliated with their School of Natural Resources and Environment, which links courses in five thematic areas including industrial ecology, environmental policy and strategies, risk and economic analysis, energy systems, as well as system analysis and sustainability [18]. Portland State University (Portland, OR, USA) offers a multidisciplinary Graduate Sustainability Certificate involving coursework in economic, environmental and social sustainability [19]. Michigan Technological University has offered a Graduate Certificate in Sustainability since fall 2004, as discussed below.

This 15-credit graduate certificate was established in September 2004 and formally recognises curricular breadth in the following areas: a) policy, societal and economic systems; b) environmental systems; and c) industrial systems and focused coursework in sustainability. A growing number of institutions that offer graduate course work and degrees has recognised the need for coherent sub-degree units of course work, laboratory work and/or fieldwork in specific areas for which special recognition is warranted, hence the emergence of Graduate Certificate programs. Table 3 shows representative courses required for the Graduate Certificate in Sustainability. Any graduate student may obtain this Certificate and in its first year of existence, six students received the Graduate Certificate and an estimated 30 students are currently working towards the Certificate. Graduate students affiliated with the Sustainable Futures Institute, which involves over 50 faculty members from across campus, regularly pursue the Graduate Certificate, which creates an integrative learning environment involving students from numerous disciplines across campus in the College of Engineering, College of Sciences and Arts and the School of Forest Resources and Environmental Science. As with the undergraduate experience, graduate students in the Master's International program (discussed below) can now combine their degree requirements with a Graduate Certificate in Sustainability.

Master's International Engineering program: a global perspective

A graduate program that partners with the US Peace Corps has been developed that allows students to explore concepts of sustainable development by obtaining graduate credit for 2+ years of training and service in the Peace Corps as water/sanitation engineers. The US Peace Corps has developed partnerships with 50 universities in what they

Table 3. Representative courses required for the graduate certificate in sustainability

Course number	Course title	Academic department or college/school
Core courses (two required)[1]		
ENG5510/ss5510	Sustainable Futures I	Engineering/Social Sci.
ENG5520/ss5520	Sustainable Futures II	Engineering/Social Sci.
Sample courses in environmental systems[1]		
BL3850	Environmental Toxicology and Society	Biological Sciences
CE5501	Environmental Process Engineering	Civil and Environ. Engineering
CE5504	Surface Water Quality Modeling	Civil and Environ. Engineering
CE5505	Atmospheric Chemistry	Civil and Environ. Engineering
FW5550	Geographical Information Systems	Forest Res. and Env. Sci.
Sample courses in industrial systems[1]		
ENG4500	Engineering for the Environment	Engineering
BA4630	Manufacturing Strategy	Business and Economics
MEEM5653	Life-cycle Engineering	Mechanical Engineering
MEEM5685	Env. Responsible Design and Manufacturing	Mechanical Engineering
CM4720	Design for the Environment	Chemical Engineering
Sample courses in policy and societal systems and economics[1]		
BA4790	Ecological Sustainability and Organizations	Business and Economics
EC4600/ec5600	Natural Resource and Environmental Economics	Economics
SS5100	Global Environmental Systems	Social Sciences
SS5350	Environmental Policy Analysis	Social Sciences
SS5400	Sociology of the Environment	Social Sciences

Descriptions of courses are available at URL: http://www.admin.mtu.edu/em/students/plan/index.php
Master's International students may substitute two credits of CE5994 and one credit of CE5993 for Sustainable Futures II.
[1] At least one course required.

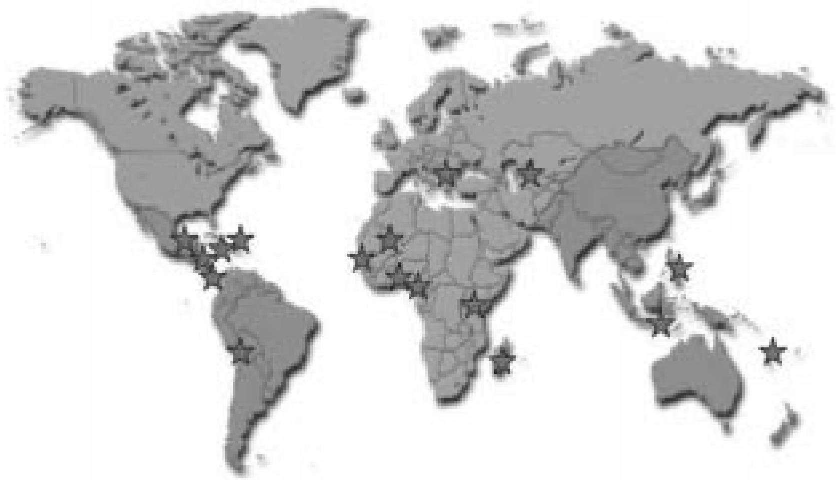

Fig. 4. Countries where undergraduate International Senior Design and graduate Master's International Engineering students currently serve and perform research. The seventeen countries are: Belize, Bolivia, Cameroon, Dominican Republic, East Timor, Ghana, Honduras, Jamaica, Kenya, Macedonia, Madagascar, Mauritania, Mali, Panama, Philippines, Uzbekistan and Vanuatu.

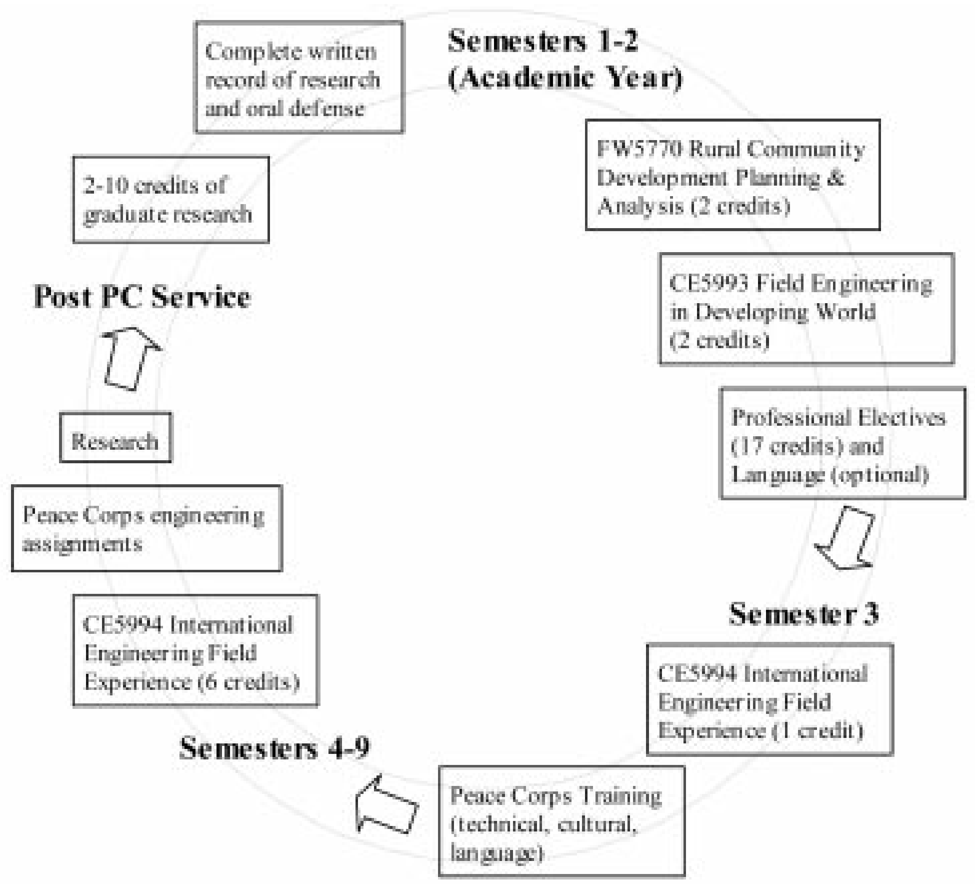

Fig. 5. Example of how coursework and research are integrated with Master's International program and graduate degree in civil or environmental engineering. Students may also incorporate a Graduate Certificate in Sustainability into their program.

[1] Master's International program: 31% of students became fluent in French, 42% became fluent in Spanish and 27% learned another language (e.g. Patois, Bislama). Many of the students become proficient in two languages during their Peace Corps service (e.g. French and Bambora, Spanish and Nobe).

[2] Master's International program: 72% of students have pursued the MS Environmental Engineering degree and 28% have pursued the MS Civil Engineering degree. Less than one half of these students have a first degree in civil or environmental engineering. Other students come with a first degree in Mechanical, Chemical, Nuclear, Electrical, Industrial, or Forestry Engineering, or a non-engineering degree (e.g. Physics, Mathematics, Geology, Biology).

Table 4. Examples of how research is incorporated into the engineering assignment in the US Peace Corps

Engineering assignment	Subsequent research
Plan, design and construct water supply systems (wells, pumps) and sanitation systems (wash areas, soak pits) in Mali	Determine how socio-economic, organizational and political factors that contribute to a sanitation development project, differ in rural, urban and peri-urban areas
Plan, design and construct ventilated improved pit latrines and springboxes in Cameroon	Conduct a complete yearlong health survey in two villages to research the specific link between water projects, sanitation and public health in the communities
Plan, design and construct systems to treat wastewater in urban and rural areas of Jamaica	Evaluate performance of subsurface wetlands to treat BOD, TSS, N and P generated in rural communities
Plan, design and construct gravity fed water supply systems and double pit compost latrines in Panama	Determine fundamental relationships between pathogen destruction and compost latrine operation and maintenance

term 'scarce-skill areas' and these currently represent approximately 520 graduate students.

The program in civil and environmental engineering is the only program of its kind in the USA. Drivers of this educational initiative are the United Nations. Millennium Development Goals, the direct link of public health and protection of ecosystems and natural resources to sustainable development; and the need for engineering educators to better incorporate societal and economic issues with the environment [20].

Master's International Engineering students have served in 16 of the countries shown in Fig. 4.

Figure 5 shows how graduate students complete their coursework, research and service requirement over an approximately 3.5-year period. Students first complete two semesters of graduate coursework on campus followed by 3 months of cultural, language and technical training with the Peace Corps. The required coursework before leaving for their overseas assignment includes a course in Rural Community Development Planning and Analysis, which covers the context, analysis and monitoring of development processes of rural communities in the developing world. A second required graduate course, Field Engineering in the Developing World, covers concepts of sustainable development and how to implement appropriate technology to engineering problems in the developing world.

After leaving campus, students must complete several months of training followed by 2 years of service in the Peace Corps working as a water/sanitation engineer, while also completing a research project related to their Peace Corps experience. During this period, students are enrolled for one-credit every semester in CE5994, International Engineering Field Experience. This not only allows students to maintain their status as full-time, but also requires that they remain in touch with their graduate advisors. Students must complete a research report or thesis that is typically related to some aspect of their engineering assignment (for a more detailed assessment of the program, see [20]). Table 4 provides examples of how research is integrated into the assignment. All assignments incorporate the elements of the Sustainable Futures Model (see Fig. 1) including some degree of public health education. After completing the program, students receive an MS degree in either civil engineering or environmental engineering. An assessment that includes review of the Master's International students' written research requirements for their reports or theses, examination of syllabi of the two required courses and post exit interviews of students confirm that the goal to have students address and integrate the various components of the Sustainable Futures Model, shown on Fig. 1, is being met [20, 21].

ISSUES OF A MORE DIVERSE WORKFORCE

On another front, some countries are facing a severe crisis that could have a far-reaching future impact. Simply stated, in some parts of the world (e.g. USA) enrollment in engineering and scientific professions is falling dramatically. To quote William A. Wulf, president of the US National Academy of Engineering:

> We need to understand why in a society so dependent on technology, a society that benefits so richly from the results of engineering, a society that rewards engineers so well, engineering isn't perceived as a desirable profession. Our profession is diminished and impoverished by a lack of diversity [22].

Our recent experience in educational/research programs related to sustainability and engineering experiences that have a global perspective suggests that women and underrepresented minorities may be attracted into careers with this focus. In addition, the curricular innovations discussed in this paper are believed to support a more diverse engineering student population, because they provide a link between fundamentals and application, require team experiences and create an atmosphere of inclusion, rather than exclusion [23].

Table 5 shows the number of women and underrepresented minorities participating in several of our university's sustainability initiatives. These preliminary data suggest that underrepresented groups in engineering, particularly women, are attracted to careers in which they feel that they can have a positive impact on society. For ex-

Table 5. Student diversity of Michigan Technological University's sustainability and international educational initiatives.

Specific program	Total students	Male (%)	Female (%)	Underrepresented minority (%)
Master's International in CEE [1,2]	39	62	38	8
CEE International Senior Design	105	45	55	Data not known
National Science Foundation IGERT—doctoral engineering program in sustainable futures	8	62	38	38
National Science Foundation IGERT—doctoral public policy program in sustainable futures	4	75	25	75
National Science Foundation undergraduate research program in sustainability	18	44	56	25
Graduate Certificate in sustainability	6	50	50	0

[1] Master's International program: 31% of students became fluent in French, 42% became fluent in Spanish and 27% learned another language (e.g. Patois, Bislama). Many of the students become proficient in two languages during their Peace Corps service (e.g. French and Bambora, Spanish and Nobe).
[2] Master's International program: 72% of students have pursued the M.S. Environmental Engineering degree and 28% have pursued the MS Civil Engineering degree. Less than one half of these students have a first degree in civil or environmental engineering. Other students come with a first degree in Mechanical, Chemical, Nuclear, Electrical, Industrial, or Forestry Engineering, or a non-engineering degree (e.g. Physics, Mathematics, Geology, Biology).

ample, the number one reason why women do not enter the engineering profession is a lack of connection between engineering and the problems of our society and a lack of understanding of what engineers do [24]. Furthermore, when responding to a query about how engineering can attract more women, it was noted:

> 'the challenge for engineering programs is not to show that mathematics and science are fun, but that these disciplines have social value and relevance' [25].

Interviews of incoming male and female Master's International students that have a first degree in engineering, but not in civil or environmental engineering, clearly indicate that they are looking for a connection between engineering and problems of our society [20].

Review of enrollment in some of the initiatives discussed in this paper supports the belief that educational experiences in sustainability, with their focus on societal impact and interconnectedness, can have a broad appeal, especially to young women. Working towards solving environmental and societal problems resonates with women (e.g. high female enrollment in environmental and biomedical engineering programs); young women will be motivated to study science and engineering if they understand that careers in these fields will enable them to positively affect society. For example, female Master's International students with first degrees in mechanical, chemical and electrical engineering have joined the program for reasons that include: merging personal convictions with career; wanting to learn how to apply technology that is culturally, economically and socially suitable; and, seeking a change so they can apply their engineering skills for the protection of ecosystems and natural resources [20, 26]. This message may also resonate with other underrepresented groups who may also be attracted into these types of programs to take the opportunity to improve the living conditions in their cultural origins.

CONCLUSIONS

Engineering solutions to the problems facing the global community will require a change in the way engineers are educated. This paper discusses the professional, international and educational motivators for change and resulting curricular outcomes for several undergraduate and graduate engineering educational initiatives that instruct students in the concepts of sustainable development in an international context. One overriding goal of the Sustainable Futures Model, which is employed in guiding this change, is that it provides a clear framework to integrate concepts of economic, environmental, societal sustainability into engineering curricula. An important aspect to be considered when providing an international experience along with this framework is that global problems of sustainable development clearly require students to consider equally the three components of the sustainability triangle. Because of the community-based approach required for engineering successful solutions to problems of the world, graduates of these programs are especially aware of societal and community issues that affect the success of engineering projects throughout the world [20]. Data presented from our initiatives discussed in this paper also appear to attract a more diverse group of students to engineering than previously found.

Acknowledgements—The authors gratefully acknowledge support from the Sustainable Futures IGERT project sponsored by the US National Science Foundation (under Grant No. DGE 0333401), the Graduate and Undergraduate Initiative for Development and Enhancement (GUIDE) program sponsored by the US National Science Foundation (under Grant No. DUE 0220500), the support of the US Peace Corps and a 3M Research Grant in Aid provided to Dr Mihelcic. More information about the programs discussed in this article can be found at: www.sfi.mtu.edu; www.cee.mtu.edu/peacecorps and, http://www.cee.mtu.edu/projects/index.htm.

REFERENCES

1. J. R. Mihelcic, J. C. Crittenden, M. J. Small, D. R. Shonnard, D. R. Hokanson, Q. Zhang, H. Chen, S. A. Sorby, V. U. James, J. W. Sutherland and J. L. Schnoor, Sustainability science and engineering: emergence of a new, metadiscipline, *Environmental Science & Technology*, **37**(23), 2003, pp. 5314–5324.
2. J. R. Mihelcic and D. R. Hokanson, Educational solutions: for a more sustainable future. *Environmental Solutions.* N. L. Nemerow and F. J. Agardy, eds, Elsevier, (2005).
3. *Engineers and Sustainable Development*. WFEO-ComTech (Word Federation of Engineering Organizations and ComTech), Version I, (2002).
4. W. H. Vanderburg and N. Khan, How well is engineering education incorporating societal issues. *Journal of Engineering Education*, **83**(4), 1994, pp. 357–361.
5. S. A. Jones and R. A. Houghtalen, Using senior design Capstone as model for graduate education. *Journal of Professional Issues in Engineering Education and Practice*, **126**(2), 2000, pp. 83–88.
6. C. McIntyre, Assessing problem-based learning in a construction engineering Capstone course, *ASCE Construction Research Congress*, Honolulu, HI, (2003).
7. A. S. Hanna and K. T. Sullivan, Bridging the gap between academics and practice: a Capstone design experience, *Journal of Professional Issues in Engineering Education and Practice*, **131**(1), 2005, pp. 59–62.
8. O. J. Helweg, Directing senior design and research projects toward societal needs, *ASCE World Water Congress*, Philadelphia, PA, (2003).
9. M. A. Butkus and M. B. Kelley, Approach for integrating professional practice issues into undergraduate environmental engineering design projects. *Journal of Professional Issues in Engineering Education and Practice*, **130**(3), 2004, pp. 166–172.
10. P. W. Jowitt, Sustainability and the formation of the civil engineer, *Engineering Sustainability*, **157**(ES2), 2004, pp. 79–88.
11. N. A. Ashford, Major challenges to engineering education for sustainable development, *International Journal of Sustainability in Higher Education*, **5**(3), 2004, pp. 239–250.
12. F. G. Splitt, Environmentally smart engineering education: a brief on a paradigm in progress, *Journal of Engineering Education*, **91**(4), 2002, pp. 447–450.
13. K. Mulder, Engineering education in sustainable development: sustainability as a tool to open up the windows of engineering institutions, *Business Strategy and the Environment*, 13, 2004, pp. 275–285.
14. World Health Organization (WHO) *World Summit on Sustainable Development*, Johannesburg, South Africa (2002) http://www.who.int/wssd/en/, accessed 2005.
15. L. D. Phillips, J. R. Mihelcic and M. Paddock, How academic programs can be integrated into EWB-USA activities. *Engineers Without Borders–USA 2004,* National Conference, Denver, CO, (2004).
16. R. C. Knox, D.A. Sabatini, D. E. Hughes, R. Lambert and R. Ketner, Teaching engineering design with practitioner supervision: a case study, *Journal of Professional Issues in Engineering Education and Practice*, **124**(4), 1998, pp. 105–109.
17. W. H. Vanderburg, The measurement and integration of sustainability into engineering education, *Journal of Engineering Education*, **88**(2), 1999, pp. 231–235.
18. UMich, Graduate certificate program in industrial ecology. University of Michigan, School of Natural Resources and Environment, URL: http://www.css.snre.umich.edu/3_1_Graduate-PIE.htm, Accessed 23 Jun 2005.
19. Graduate sustainability certificate. Portland State University, URL: http://www.sustain.pdx.edu/ap_certificates.php, accessed 23 Jun 2005.
20. J. R. Mihelcic, L. D. Phillips and D. W. Watkins, Jr, Integrating a global perspective into education and research: engineering international sustainable development. *Environmental Engineering Science*, **23**(3), 2006, 426–438.
21. J. R. Mihelcic, Educating the future's water professional, *Water Environment Technology*, 16(9), 2004, pp. 86–92.
22. W. A. Wulf, *Diversity in Engineering*. NAE Publications, *The Bridge,* **28**(4), 1998.
23. I. J. Busch-Vishniac and J.P. Jarosz, Can diversity in the undergraduate engineering population be enhanced through curricular change? *Journal of Women and Minorities in Science and Engineering*, **10**, 2004, pp. 255–281.
24. S. Widnall, Digits of pi: barriers and enablers for women in engineering, presented at the *SE Regional NAE Meeting*, Georgia Institute of Technology, April 26, 2000.
25. E. F. Farrell, Engineering a warmer welcome for female students: the discipline tries to stress its social relevance, an important factor for many women, *Chronicle for Higher Education*, (2002).
26. J. R. Mihelcic, Educating tomorrow's global engineer through a unique partnership with the US Peace Corps, *Woman Engineer*, **25**(1), 2004, pp. 30–33.

David Hokanson, PE, was the Operations Manager of the Sustainable Futures Institute and a Research Engineer and Adjunct Assistant Professor of Civil and Environmental Engineering at Michigan Technological University. Dr Hokanson has experience in working on several federally funded projects in the area of pollution prevention, water treatment and sustainability, including educational and outreach applications at many levels. Dr Hokanson was also instrumental in the development of the textbook *Water*

Treatment: Principles and Design, 2nd ed. (John Wiley and Sons, 2005). Dr. Hokanson is currently employed as a Supervising Engineer at Trussell Technologies, Inc. in Pasadena, California and has an appointment as an Adjunct Assistant Professor of Civil and Environmental Engineering at Michigan Technological University.

Linda Phillips, PE, is a lecturer of Civil and Environmental Engineering at Michigan Technological University and Director of the International Senior Design program that allows undergraduates to combine the engineering Capstone Design course with field construction in a developing country. Linda Phillips brings over 20 years of project and company management experience to her professional practice-type classes.

James Mihelcic is Professor of Civil and Environmental Engineering at Michigan Technological University, Co-director of the Sustainable Futures Institute and Director of the Master's International program in Civil and Environmental Engineering. He currently serves on the Board of Directors for the Association of Environmental Engineering and Science Professors (AEESP) and has been awarded the AEESP-Wiley Interscience Award for Outstanding Contributions to Environmental Engineering and Science Education. Dr Mihelcic is the lead author of *Fundamentals of Environmental Engineering* (1999), which has been translated into Spanish.