Educating Engineers in the Sustainable Futures Model with a Global Perspective

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Abstract
The solutions to the world's current and future problems require that engineers and scientists 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 students 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.

Many universities espouse the idea that discipline integration is a prerequisite for successful implementation of sustainability in education. However, few engineering curriculum have taken the step to integrate concepts of sustainable development with an international experience. This paper discusses the educational and global drivers for curricular change in this important area and demonstrates how several undergraduate and graduate programs initiated at Michigan Technological University can provide a more interdisciplinary basis for educating engineers on global concepts of sustainability. To date these programs have taken place in 21 countries and reached approximately 300 students (49% women) that represent 11 engineering disciplines and 9 non-eng disciplines.

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1.0 Introduction

The concept of economic, environmental, and 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. 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.

In this paper we describe several programs developed at Michigan Technological University to train undergraduate and graduate engineering students in sustainability within a global context (more detail on these programs can be found elsewhere; Mihelcic et al., 2006; Paterson et al., 2006; Fuchs and Mihelcic, 2006; Hokanson et al., 2007). We have begun to use a global competency typology to investigate how well existing international programs fit our Sustainable Futures Model (data not shown here, see Fuchs and Mihelcic, 2006). Combining these two tools (assessment with the global competency method and scope definition with the Sustainable Futures Model), we believe that these programs are an effective process to train successful engineers for international sustainable development. Students engaged in these programs should also be able to solve problems in international settings through sustainability concepts.

2.0 Background

2.1 Global Environmental Issues. Currently, the world's population has reached 6 billion and 80 million people are added each year. As the world's population increases, so does the urgency of maintaining the environments which people depend on. This, however, presents numerous challenges to the global community. The United Nations Environment Programme (UNEP) lists ten existing or emerging environmental issues (Table 1).

Table 1. Existing and Emerging Environmental Issues (UNEP, 2002).

1. Globalization, trade & development
2. Coping w/ climate change & variability
3. The growth of megacities
4. Human vulnerability to climate change
5. Freshwater depletion and degradation
6. Marine and coastal degradation
7. Population growth
8. Rising consumption in developing countries
9. Biodiversity depletion
10. Biosecurity

2.2 Global Health. In the developing world, the United Nations reports that polluted water affects the health of over one billion people, which contributes to the annual deaths of 11 million children under five. Additionally, 2.4 billion people lack access to any type of sanitation equipment. HIV/AIDS, tuberculosis, and malaria are among the world's largest killers; all have their greatest impact on developing nations; they interact in ways that make their combined impact worse; and create an enormous economic burden on families and communities, especially in those where economic livelihood is dependent on good health (UNESA, 2004).

At the 2002 World Summit on Sustainable Development (Johannesburg), world leaders reaffirmed the principles of sustainable development[2] adopted at the Earth Summit ten years earlier. One outcome was the development of Millennium Development Goals (MDGs). The MDGs provide a global vision of development in which health and education are equal pillars of importance. The eight MDGs represent commitments to reduce poverty and hunger, and to tackle ill health, gender inequality, lack of access to clean water, and environmental degradation. For each goal, one or more targets have been set, most for 2015, using 1990 as a benchmark. Three out of eight goals, eight of the sixteen targets, and eighteen of the forty-eight indicators relate directly to health.

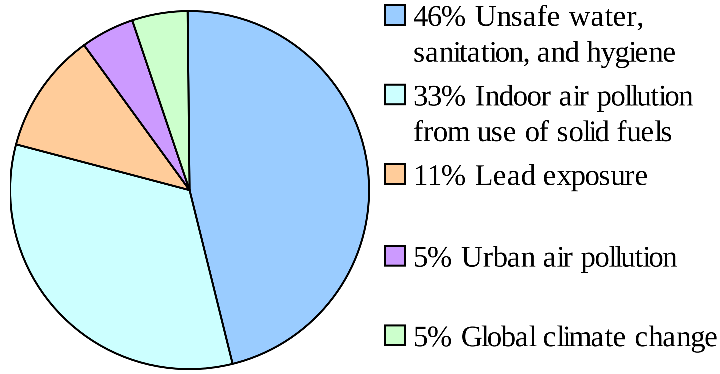

Figure 1. Types of Environmental Risk that Lead to Greatest Loss of Disability-Free Days of a Person's Life in the Developing World (data from Ezzati et al., 2004).

Figure 1 shows the types of environmental risk that lead to the greatest loss of disability-free days of a person's life in the developing world. Note that almost one half of the risk is associated with poor access to drinking water and sanitation, and most of the other half due to air pollution exposure.

2.3 Health and Sustainable Development. "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" (WHO, 2002).

The World Health Organization states that for people living in poverty, illness and disability translate directly into loss of income, which can be devastating for individuals and their families. The effects of ill health have significant ramifications at the macroeconomic scale as well. For instance, a significant portion of Africa's economic shortfall may be attributed to climate and disease burden. With respect to the environment, the income derived from ecosystems (*i.e.*, environmental income) is also recognized to provide a "fundamental stepping stone in the economic empowerment of the rural poor" (WRI, 2005).

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[2] Sustainable development is defined here 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., "Sustainability Science and Engineering: Emergence of a New Metadiscipline," *Environmental Science and Technology*, 37(23):5314-5324, 2003).

2.4 Educating the Global Competent Student for Sustainability. Sustainable development in both the developed and developing world has the common fundamental themes of advancing economic and social prosperity while protecting and restoring natural systems. The operational model for sustainable development would therefore be a global partnership, enhanced by integrating the best and most appropriate knowledge, methodologies, techniques, and practices from both the developed and developing worlds. In order to be sustainable, engineers need to apply appropriate technology versus resource intensive technology that can pollute, create social injustices, and disrupt communities. Engineers and scientists also need to be trained to innovate new ideas and services (which will create employment and exports), so they do not just address the needs of the wealthiest five percent of people in the world, but instead they create and export knowledge and products to the billions of people who are in need of safe and affordable technology. Future technology leaders also need to eco-innovate new services and products embedded in concepts of sustainable development that will create employment and expand markets.

Since engineers must be able to work globally, students must be trained to think globally, and from the perspective of global sustainability, this should include education about the developing world as well as industrialized nations. In addition, preliminary evidence suggests that education and work in sustainable development can strengthen and diversify the engineering field because it may attract the interests of women and under-represented minorities who are interested in service and broader societal impacts (Seymour, 1999; Mihelcic, 2004a; Bielefeldt, 2006; Mihelcic et al., 2006; Hokanson et al., 2007; Zimmerman and Vanegas, 2007).

While engineering students can take general education courses in world cultures, history, and geography, a much more direct education in international topics would include a significant international experience. Of the nearly 175,000 American students that studied abroad in 2003, only 3% were engineering students, which is only 1% of the Americans students enrolled in engineering programs (Fuchs and Mihelcic, 2006). Over the last twenty years the number and proportion of engineering students studying abroad has increased, but very slowly. For decades, international programs have not offered options designed for engineering students, but universities are beginning to see benefits in study-abroad for engineers, and some engineering students are also branching into humanities studies such as languages, social science, cultural studies, and public policy.

Many of the recent international engineering programs have focused on enabling the engineering student to maintain technological expertise, to function in multi-cultural business, and to compete globally (e.g., Jain, 1997; Eljamal et al., 2005; Mayhew et al., 2005). In those programs, students study or intern in industrialized nations, learning about global markets and internationally competitive engineering firms. While this perspective ensures that engineers may continue to compete in this period of globalization, we believe that a broader view of engineering education for stewardship and ethical reasons provides a context for engineering students to become leaders in global sustainability (see Fuchs and Mihelcic, 2006).

Review of existing “study-abroad” programs around the world suggests that international engineering programs can thus be divided in two types. One group focuses on the engineer as a technical problem solver, an industry-oriented engineer who needs to be globally competitive.

The other group focuses on the engineer as public-service agent, a development-oriented engineer who needs to have an understanding of diverse cultures, economies and geographies (Fuchs and Mihelcic, 2006).

We propose a more detailed rhetoric to describe the engineering education focused on developing the international development engineer. Mihelcic and Hokanson (2005) developed a conceptual model for the metadiscipline of sustainability science and engineering (this metadiscipline was first proposed in Mihelcic et al., 2003). The proposed Sustainable Futures Model (see Figure 1), shows sustainability as a triangle comprised of economic/industrial sustainability, environmental sustainability, and societal sustainability. The Sustainable Futures Model identifies the key components of the three facets, to date focusing primarily on industrialized, technologically advanced societies.

This model works well for addressing sustainability in industrialized nations and for incorporating societal and environmental concepts into engineering education, but to be truly applied to international education, the components under each leg (society, economy, and environment) could also be listed in the context of the developing world. In this case, the model would be useful for defining the scope of engineering programs that concentrate on international sustainable development.

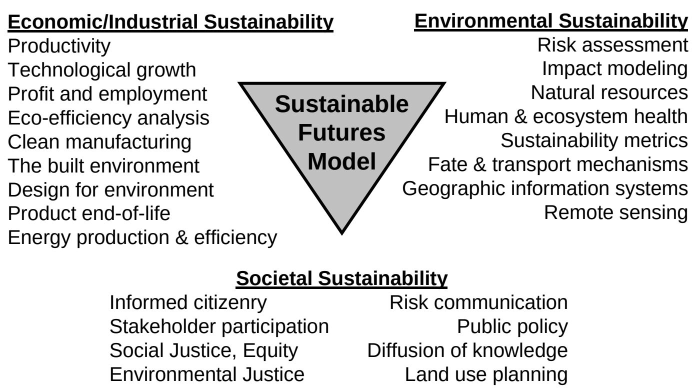

Figure 1. Definition of the three facets of the sustainable science and engineering metadiscipline (from Hokanson and Mihelcic, 2005).

The original Sustainable Futures triangle focused on sustainability in industrialized nations, not the developing world. Accordingly, Fuchs and Mihelcic (2006) proposed an adapted model to discuss sustainability in international development (Figure 2). Here the Sustainable Futures Model becomes an "appropriate technology", applicable to developing communities.[3] The terms listed under each of the three sides of the triangle are impacts or factors related to sustainability in the developing world. For example, many developing countries still experience high population growth, while this is not a factor in the sustainable development of industrialized nations. Willingness-to-pay also plays a larger role in developing than developed countries,

[3] Appropriate technology has been defined as the use of materials and technology that are culturally, economically, and socially suitable to the area in which they are implemented.

where local development is dependent on community members' desire and ability to contribute to the overall sustainability of the group.

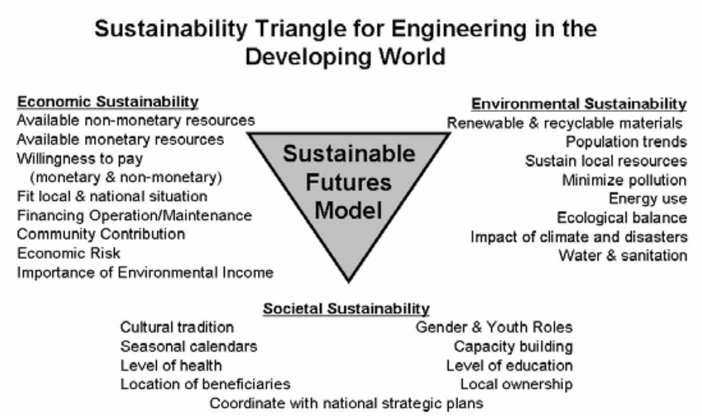

Figure 2. Sustainable Futures Model redefined for international development (from Fuchs and Mihelcic, 2006).

3.0 Programs to fit the need for Sustainability-Focused Globally Competent Engineers

The Sustainable Futures Model (shown in Figures 1 & 2) can be used to address these 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.

Several programs have been developed at Michigan Technological University to train undergraduate and graduate engineering students in sustainability with a focus on international development. Programs are explained in more detail below.

3.1 Service: Engineers Without Borders. The Michigan Technological University chapter of Engineers Without Borders-USA (ewb.students.mtu.edu) provides an example of the cross-disciplinary passion that exists for international development experience. Started in 2005, the chapter has more than tripled its membership, from 20 to over 100 members. Membership began with environmental engineering and civil engineering majors, but now includes eight different engineering majors plus five non-engineering majors. This service organization is attractive to women; 45% of the participants are female, well above the engineering college's student body percentage (approximately 21%). Importantly, the chapter appears to motivate students to engage in some of the educational and research initiatives described below.

3.2 Service-Learning: International Senior Design. For six years, the Michigan Technological University Department of Civil & Environmental Engineering has administered a capstone design project for 4^{th} year students, which allows a student to obtain university credit for working on engineering projects in the developing world (Mihelcic et al., 2006; Hokanson et al., 2007). The goal of *International Senior Design* (ISD) (currently a 6-semester credit course) is to provide students a service-learning design experience situated in the developing world so they can explore the technical, economic and social implications of engineering design and construction. Integration of the U.S. Accreditation Board for Engineering and Technology (ABET) accreditation criteria throughout the design experience is crucial to this activity. To date 118 students have partnered with communities in Bolivia and the Dominican Republic (53% of participants are female) to perform various design projects addressing storm water drainage, on-site sanitary waste systems, site planning, building analysis and other feasibility studies. Students have come from 5 engineering disciplines and 2 non-engineering disciplines.

3.3 Service Learning and Knowledge Creation: The Master's International Program in Civil & Environmental Engineering. This graduate engineering program (that partners with the U.S. Peace Corps) was developed to allow students to perform in-depth studies of sustainable development in an international context (for more detail see Mihelcic 2004a&b, Mihelcic et al., 2006). Students obtain graduate credit for training, service, and research while working abroad, for a minimum of 7 academic semesters, as engineers in the U.S. Peace Corps. The Michigan Technological University Master's International program in Civil & Environmental Engineering is currently the only program of its kind in the United States. The program's overall goal is to graduate engineers who are grounded in the fundamentals of engineering, but are also educated and trained in the many critical, non-technical skills that are required of today's engineer. It is also a stated goal of the program to educate engineers to value service to the global community. Graduates from the program have stated that the program allowed them to investigate the economic, environmental, and societal limitations of engineering projects. To date, 58 engineering graduate students (42% female) have served and performed research in 19 countries. The program has attracted students with a wide range of first degrees; 9 different engineering disciplines and 6 non-engineering disciplines.

3.4 Undergraduate and Graduate Certificate Programs. Two certificate programs (undergraduate and graduate) have recently been initiated to integrate the education experience with the Sustainable Futures Model. This past year we obtained approval for a 22-credit undergraduate certificate in *International Sustainable Development Engineering*. This certificate provides students breadth in the areas of ethics, resource equity, interactions between technology and society, engineering connections with the environment, engineering materials and water/sanitation, all at a global perspective. It also requires students to take at least one cultural or language course. The certificate ends with the 6-credit international senior design experience discussed previously. Figure 3 shows how the undergraduate certificate is integrated with a student's four years of study and also with the international senior design experience.

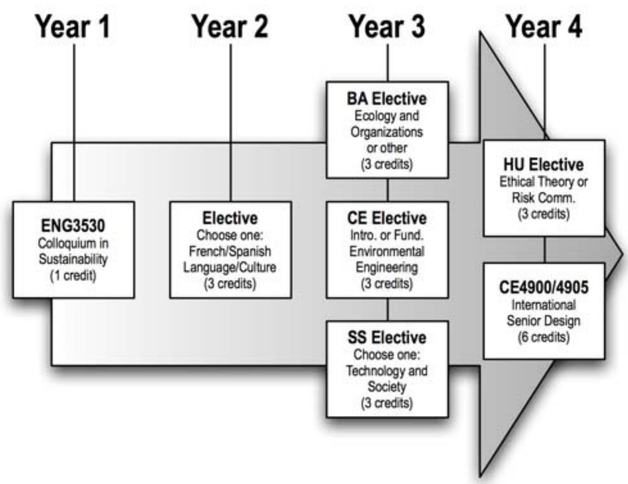

Figure 3. Course schedule for the *Undergraduate Certificate in International Sustainable Development Engineering*.

In 2004 our Sustainable Futures Institute created a 15-credit *Graduate Certificate in Sustainability*. The *Graduate Certificate in Sustainability* formally recognizes curricular breadth in the following areas: i) policy, societal, and economic systems, ii) environmental systems, and iii) industrial systems. It also requires a two-course specialization in sustainability. Figure 4 provides more detail. Many of the Master's International students integrate this certificate into their coursework requirements. In fact, 44% of the Master's International students who were enrolled when the certificate was available have met the certificate requirements.

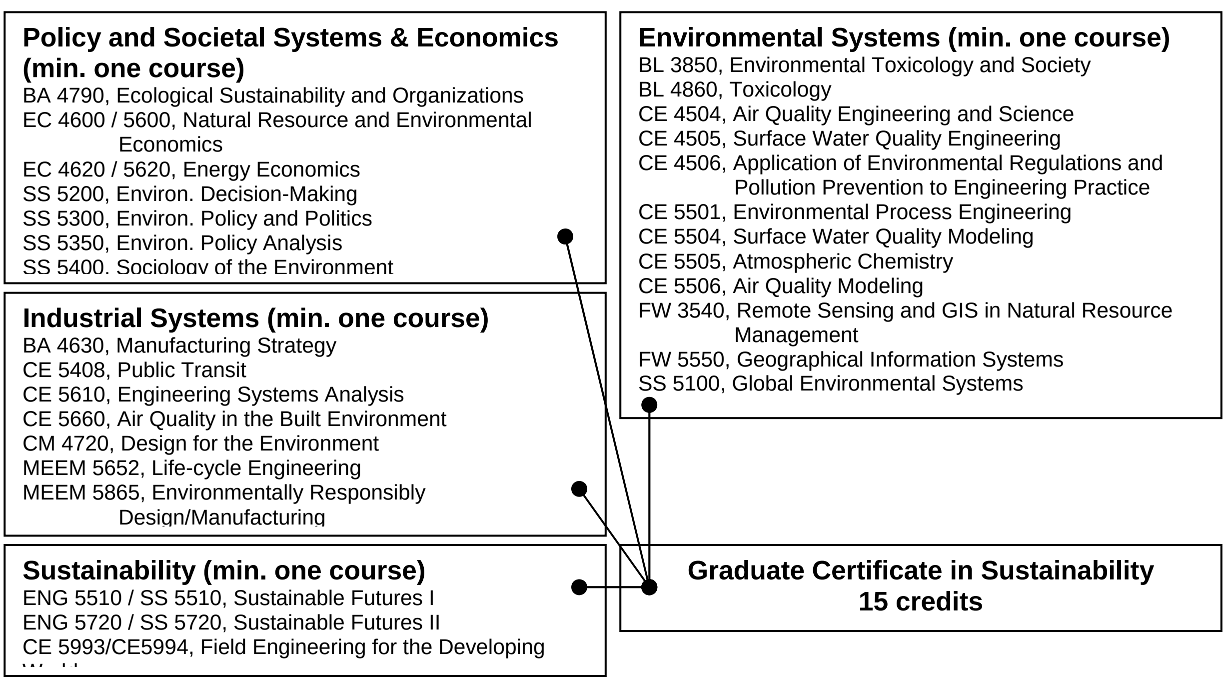

Figure 4. Course schedule for the *Graduate Certificate in Sustainability*, supplementing the Master's or Doctoral degree in any graduate program at Michigan Technological University (from Fuchs and Mihelcic, 2006).

4.0 Conclusions

Engineering solutions to the problems facing the global community will require a change in way that engineers have previously been educated. This paper discussed some of the 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. All these programs are based on integration of economic, environmental, and societal issues embedded in the Sustainable Futures model.

This paper examined several educational initiatives developed at Michigan Technological University to enable engineering students to achieve international competency and become stewards for global sustainable development. We are currently collecting assessment data on these programs (e.g., see Paterson et al., 2006; Fuchs and Mihelcic, 2006). Over the last decade, Michigan Technological University has organized the Sustainable Futures Institute, granted engineering graduate degrees through a partnership with the U.S. Peace Corps, offered an International Senior Design course, and created a Graduate Certificate in Sustainability and an undergraduate Certificate in International Sustainable Development Engineering.

One overriding goal of the Sustainable Futures Model that is employed in this change is that it provides a clear framework to integrate concepts of economic, environmental, societal sustainability into engineering curricula. An important aspect of providing a global experience along with this framework is that global problems of sustainability clearly require that students 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 should be more aware of societal and community issues that impact the success of engineering projects throughout the world. Preliminary data also suggest these types of initiatives appear to be attracting a more diverse group of students to engineering.

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