Engineering Education for International Sustainability: Curriculum Design Under the Sustainable Futures Model

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Introduction: The complete description of this research can be found in the Proceedings of the American Society of Engineering Education's 5th Annual Global Colloquium (Fuchs and Mihelcic, 2006). Further data analysis and conclusions are found in Fuchs (2007). Note that this assessment is not an assessment of ABET requirements, although the programs, as part of the Michigan Technological University School of Engineering, are ABET accredited. The incorporation of ABET criteria into an international design experience has been discussed elsewhere (Hokanson et al., 2007; Mihelcic et al., 2006).

We propose rhetoric to assess engineering education programs that focus on international sustainable development. The Sustainable Futures model of Mihelcic and Hokanson (2005), balancing environment, economy and society, is modified to fit the context of the developing world (Figure 1).

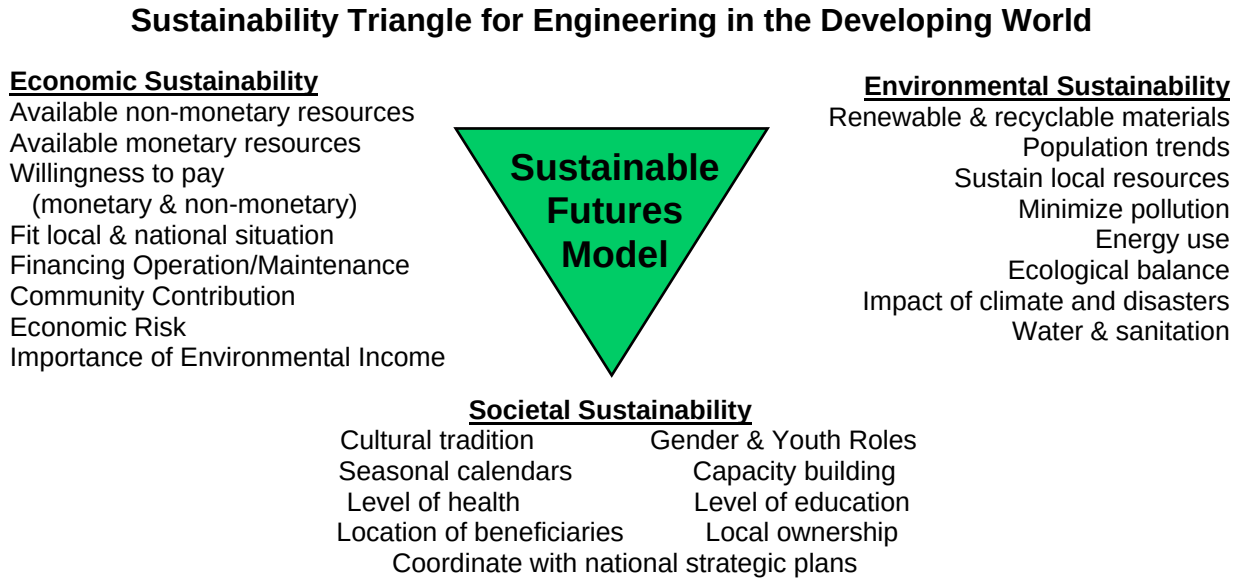

Figure 1. Sustainable Futures Model redefined for international development.

Several programs have been developed at Michigan Technological University (MTU) to train undergraduate and graduate engineering students in sustainability with a focus on international development. The objective of this study then is to examine international engineering education by using the Global Competency typology to see how well existing international programs fit the

Sustainable Futures Model. Combining these two tools (assessment with the Global Competency method and scope definition with the Sustainable Futures Model), we show that these programs are effective for training engineers for international sustainable development.

Methods: Following the Global Competency framework of Downey *et al*. (2006), learning criteria and objectives were written for Sustainable Futures programs. Because the model is based on a balance between economic, societal and environmental sustainability, the criterion and outcomes are defined in this balanced manner. These objectives define the scope of education that would fit into the Sustainable Futures model. The objectives are used to assess two MTU programs, Peace Corps Master's International and International Senior Design. In the Peace Corps program, Master's students spend 1 year taking credits at Michigan Tech, and 27 months abroad in the Peace Corps, where they integrate with a community, implement projects, and research a sustainable development topic. International Senior Design is a senior design program where senior engineering students spend 2 weeks abroad in Bolivia or the Dominican Republic, doing service-learning work and investigating a design project, then spend part of a semester back at Michigan Tech writing a site assessment and feasibility study report from their investigation. This paper is an overview of the assessment of these two programs for their ability to teach sustainable development concepts, through the following learning criterion and outcomes.

Learning criterion

Through coursework and international experience in sustainable development, students will acquire the knowledge, ability and predisposition to integrate economic, environmental and societal sustainability in defining and solving engineering problems.

Learning outcomes

1. Students demonstrate substantial *knowledg*e of economic, societal and environmental factors and their interactions in engineering for sustainable development.
2. Students develop the *ability* to analyze the balance between economic, societal and environmental factors in an international situation, and define problems and solutions according to that balance (not necessarily technical or engineering problems).
3. Students show a *predisposition* to view engineering for the developing world through the triple lens of economic, societal and environmental sustainability.

	Report	**Coursework**
Knowledge	Language use according to content analysis.	Students have been exposed to sustainability factors in engineering through their courses.
Ability	Equal amount of writing content devoted to each of the sustainable development topics.	Students gain ability to balance sustainability factors through balanced set of coursework.
Predisposition*	Interest in or achievement of sustainability certificates; non-engineering other degree/background/minor; non-English language background or proficiency; global reach; background.	

Table 1. Matrix for Global Competency-Sustainable Futures assessment method.
*Predisposition is not measured for reports and coursework separately; it is an overall measure of the student's background and "openness" toward sustainable development learning.

To assess whether students attained the learning outcomes, three areas were examined (Table 1):

1. Project reports from the International Senior Design (ISD) course and Peace Corps Master's International program (PCMI).
2. Course credits or coursework allotted to sustainability topics in the ISD and PCMI.
3. Sustainability certificates (Figures 2 and 3), second language proficiency, global reach, and background of students.

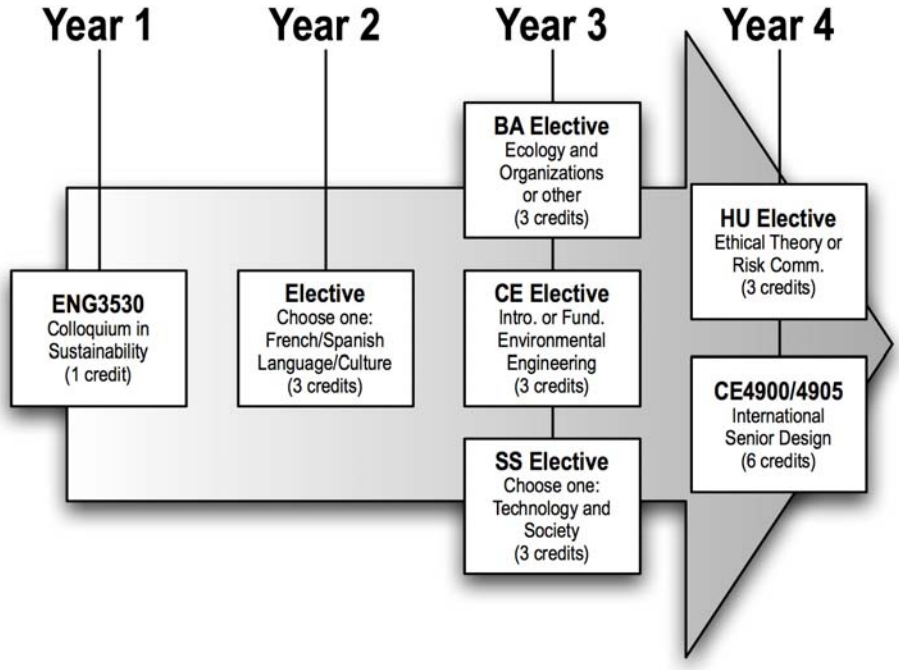

Figure 2. Courses for the Certificate in International Sustainable Development Engineering.

The Certificate in International Sustainable Development Engineering (Figure 2) supplements the regular undergraduate course schedule. The Certificate is available to all engineering students though the initial interest is expected from students seeking the Bachelor's degree in Civil or Environmental Engineering. The goal of sustainable engineering is to create ecologically and socially appropriate solutions within the capacity of nature without compromising future generations. This certificate provides students breadth in the areas of ethics and resource equity (HU Elective), interactions between technology and society (SS Elective), engineering connections with the environment (CE or BA Elective), engineering materials and water/sanitation (CE 4900/4905), all at a global perspective. Students begin the certificate with the colloquium on sustainability which introduces each of these concepts, and finish with the international senior design experience that requires students to work on an engineering problem set in the developing. French or Spanish language experience is also required (Language Elective) and is highly useful during the international senior design experience. Through each of these classes included in the certificate, students gain understanding of the interactions between society, economics and environment, and learn how to make positive effects on those interactions through sustainable development engineering. This certificate is being offered starting in the Fall semester of 2007.

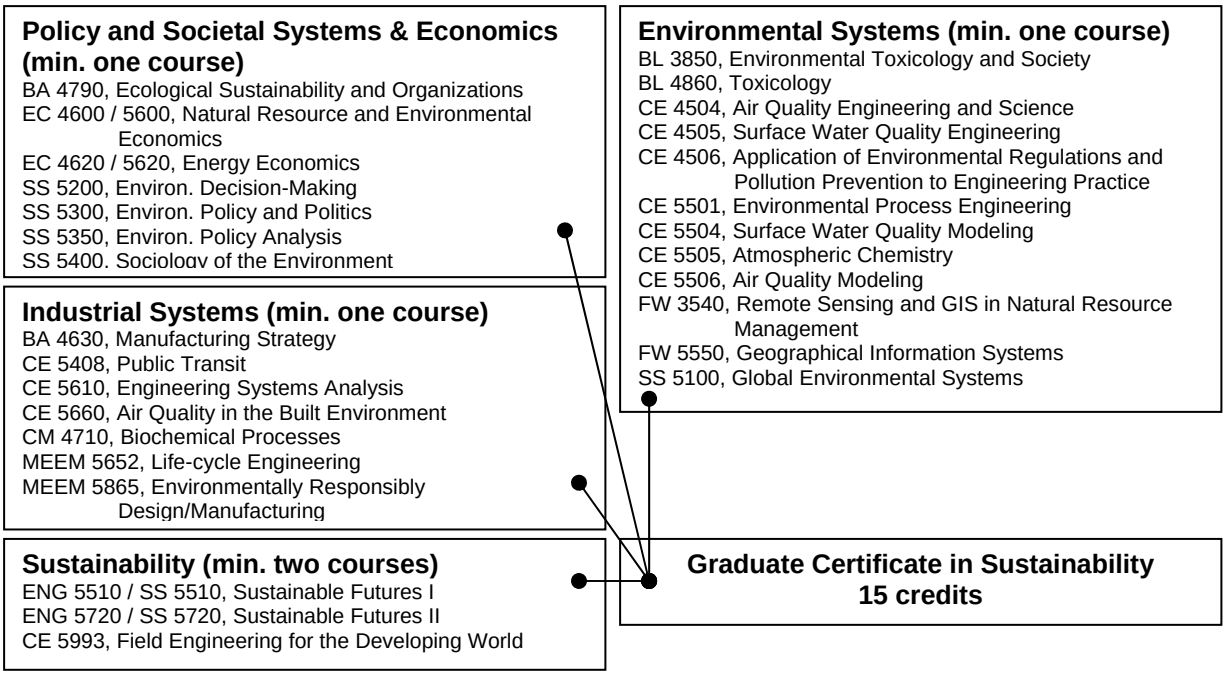

Figure 3. Course schedule for the Graduate Certificate in Sustainability.

The Graduate Certificate in Sustainability supplements the Master's or Doctoral degree in any graduate program at Michigan Tech (SFI, 2006). Graduate students choose one course from each of the Policy/Societal Systems & Economics, Industrial Systems, and Environmnetal Systems, and two courses from the Sustainability section (usually Sustainable Futures I and II; only Peace Corps Master's International students may substitute Field Engineering for the Developing World). By studying topics within each of the three sustainability pillars (society, economics or industry, and environment), and often outside the student's major discipline, graduate students gain the understanding and tools to apply sustainability concepts and integrate disciplines. Michigan Tech began offering this certificate in the Fall semester of 2004. Since then, 26 students have completed it, and of those, 7 students are in the Peace Corps Master's International program. These students will begin returning from the Peace Corps toward the end of 2007, so the effects of the graduate certificate on their work are yet to be assessed.

A content analysis of project reports, assessment of course credits and coursework, and analysis of student background provided the data for assessing the overall learning outcomes for *knowledge, ability,* and *predisposition* as stated in the learning criterion.

Results: For the *knowledge* outcome, knowledge is measured by whether students are exposed to sustainable development concepts in coursework and whether they use sustainable development language in their reports.

1. Students are exposed to the concepts for more of their coursework if they choose to complete a sustainability certificate (the undergraduate certificate will begin in Spring 2007). The tabulated results are shown in Table 2, below. A significantly greater fraction of course credits focus on sustainability when students pursue the certificate.

However, students in both the ISD and PCMI program complete an international experience which greatly increases their knowledge of sustainable development.

2. A content analysis of student reports (fully described in Fuchs and Mihelcic, 2006) showed that students have knowledge of sustainability "language" as determined from the Sustainable Futures model. Their use of certain words and not others may reflect a) the research or project topic, b) the project or client needs, or c) that certain concepts are taught better than others.

Credits	ISD	Credits	PCMI
No certificate	3-International Experience (2 weeks) 3-Capstone Design	No certificate	2-Field Engineering in Dev'g World 2-Community Planning & Analysis 7-International Training & Experience (27 months)
6/130*		**11/30**	
With certificate	+	With certificate	+
25/130*	1-Sustainability Colloquium 3-French or Spanish Elective 3-Ecology and Organizations 3-Civil Engineering Materials 3-Tech/Society Elective 3-Wastewater or Air Quality Elective 3-Ethics or Risk Comm. Elective	**23/30**	3-Policy/Societal Systems Elective 3-Environmental Systems Elective 3-Industrial Systems Elective 3-Sustainable Futures I or II

Table 2. Course credit totals for undergraduate and graduate programs. ISD and PCMI programs are shown independently and with either the Certificate in International Sustainable Development (undergraduates) or the Graduate Certificate in Sustainability (graduates). These totals do not include research credits. *Environmental Engineering students take 130 credits for a BS; Civil Engineering students take 131.

To assess the *ability* outcome, we measured whether students have maintained a balance in sustainable development topics regarding course schedules and in their writing. This was also determined from student course schedules and project reports.

1. As shown in Table 2, the ISD program is only 6 out of 130 or 131 credits, and because it is a "design" course, no topics are allowed to be taught. This means that students learning and ability to understand sustainable development through the course is largely self-taught. With the inclusion of the Certificate in International Sustainable Development, undergraduates will gain the balance of sustainability topics in their coursework. PCMI students gain a more balanced education in environment, economy and society through two focused courses and a 27 month international experience in the Peace Corps.

2. The content analysis of report text showed that students could generally balance the sustainable development concepts, but they were often subordinate to the specific engineering topics, as may be expected in a research or project report. Figure 4 shows how well students in the two programs balanced writing about environmental, economic, and societal issues as defined from the Sustainable Futures model. ISD students balance economy with environment while focusing less on society, and PCMI students focus largely on social and environmental issues while writing less about economics.

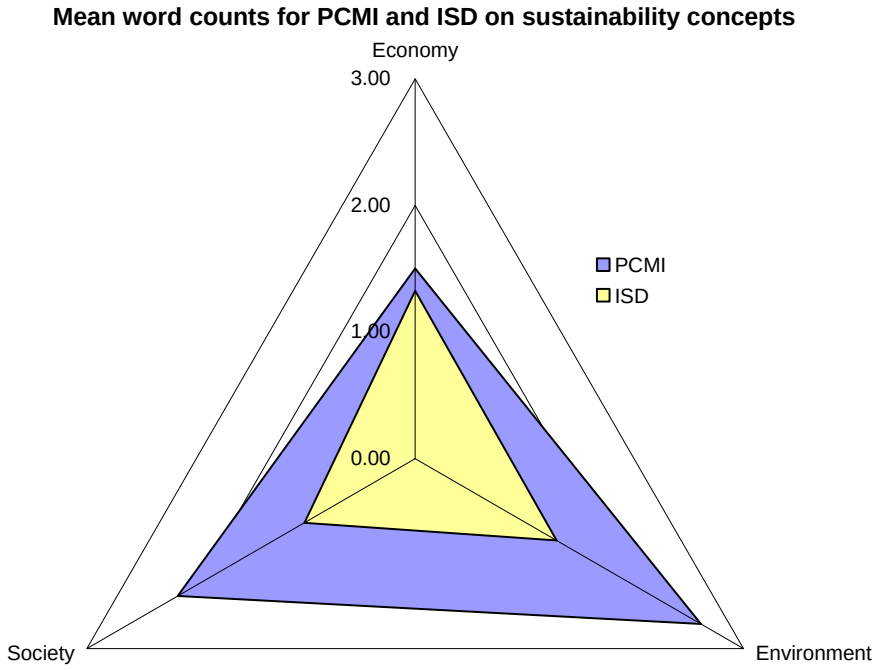

Figure 4. Ability of students to write about sustainable development.

The content analysis was completed by searching the body of PCMI research reports and ISD project reports for words in or derived from the Sustainable Futures Model. The word list was derived for each of the sustainability pillars: economic, social, and environment. 15 PCMI reports and 21 ISD reports were analyzed, representing all students graduated from these programs up to December 2005 (ISD students write team reports while PCMI reports are individual). 1 researcher scored all the reports by word count using the Find function for Microsoft Word documents or the Search function for Adobe PDF files. The scorer checked all "hits" to ensure that they were the correct search word, used in the appropriate context. The number of hits was normalized to the number of words in each word list, as well as to the number of words in the report body. The normalization made number of hits from each report comparable to other reports, and the number of hits in each sustainability pillar comparable to the other pillars.

Figure 4 shows the comparison of the sustainability pillars: the graph numbers are relative. The graph shows that PCMI students use sustainable futures language more than ISD students, and that within PCMI reports, environment is most often discussed, while society ranks fairly high, and economics are much lower. The ISD students, as a group, write equally about economics and environment, with less focus on society. As an assessment, this offers an indication of what Michigan Tech teaches well (environment and economics) and what could be better incorporated into the programs (societal interactions). However, the different purposes of the ISD and PCMI reports should also be kept in mind. PCMI students write a research report as a reflection of their work in 27 months in the Peace Corps. Their community is their natural focus, and in a research report, economics is of less importance. ISD students write engineering feasibility study and initial design reports for a client community or organization. These reports are more likely to

focus on cost-benefit analysis and environmental contamination, and do not tend to re-iterate societal observations for the client community. More information, complete description of the content analysis, and further assessment of the data are given in Fuchs and Mihelcic (2006) and Fuchs (2007).

The *predisposition* outcome was defined as "an inclination to view engineering for the developing world through the triple lens of economic, societal and environmental sustainability. That inclination requires a combination of knowledge and ability in sustainable development concepts and application, as well as a background that encourages a tendency toward international, sustainable thinking. We measure this as a combination of the students' interest in achieving an education set in sustainability beyond the required program courses, non-English language skills, and their degree and gender diversity as a group. The results are shown in Table 3. The students in ISD and PCMI are highly diverse, talented and gain a broad range of experiences, outside the typical engineering education. These factors encourage the tendency and predisposition toward a balanced worldview.

	Achievement of Sustainability Certificate	
PCMI	44%	8/18 PCMI students since grad certificate was offered.
ISD	Na	Undergraduate certificate will be offered starting in Fall 2007.
	Non-engineering degree, background or minor	
PCMI	24%	Out of 50 MS students, there were 12 non-engineering bachelors/minors. 3-Physics, 3-Geology, 2-Biology, 2-Environmental Studies 1-Math, 1-Linguistics/German
ISD	5%	5/105 ISD students study outside of the Civil/Environmental Eng department. 4-Education, 1-Geology
	Non-English language proficiency	
PCMI	94%	47/50 PCMI students were placed in non-English speaking communities. 20% French 28% Spanish 12% Patois (Jamaica) 16% Bambara (Mali, where students also learned French) 6% English (Ghana, students may also learn a local dialect) 4% Timorese 12% Other (Pidgeon, Macedonian, Samoan, Creole, Kiswahili)
ISD	20%	21/105 students had proficiency in Spanish during their field projects.
	Gender	
PCMI	40%	Women
ISD	55%	Women

Table 3. Predisposition evaluation—background of PCMI and ISD students.

Conclusions: The Peace Corps Master's International and International Senior Design programs at Michigan Technological University produce students who have ***knowledge*** of at least the basics of the three factors of sustainability, economics, environment and society.

The ***ability*** to integrate and balance the sustainability factors is evident in the PCMI students, who gain a balanced exposure through coursework and international experience and seek the Graduate Certificate in Sustainability. The ISD courses give students an introduction to sustainable development, and students learn many concepts on their own.

Predisposition measures show that these students have an interest in and tendency to understand engineering through sustainable development concepts. The PCMI students have a broader educational background and diversity than ISD, but the ISD program attracts women engineers, and this diversity will continue to strengthen the program. The reach around the world of both programs encourages the students to broaden their experience in sustainable development (Figure 5).

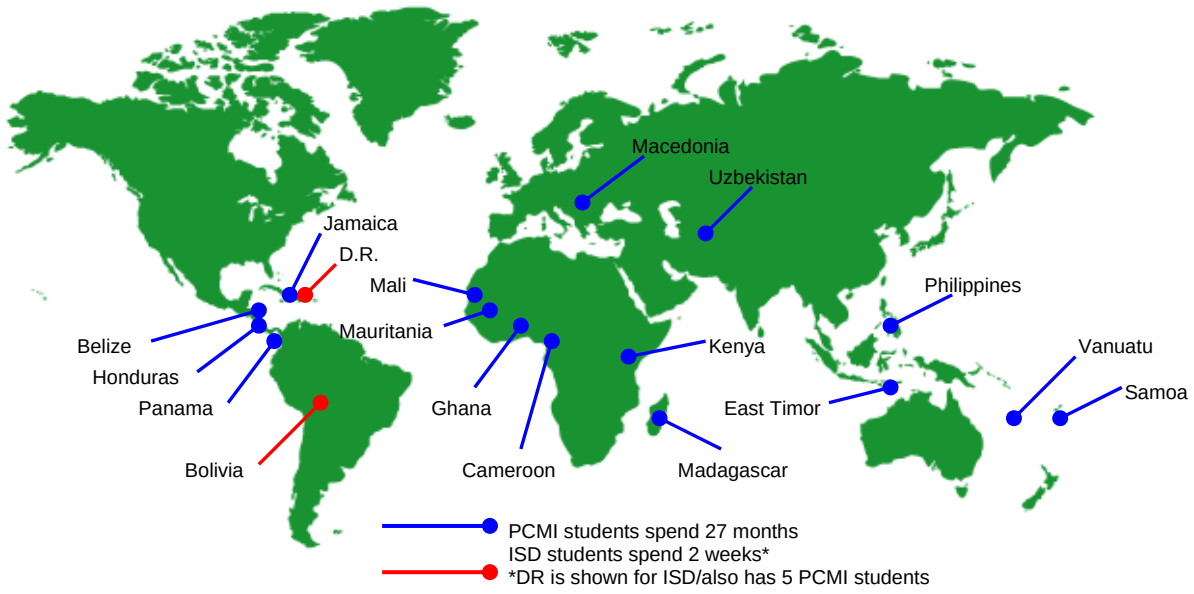

Figure 5. Global reach of students enrolled in PCMI and ISD.

The MTU programs are a strong step towards forming globally competent engineers who have the capacity to work in sustainable development. The addition of the Certificate in International Sustainable Development or the Graduate Certificate in Sustainability substantially increases a student's exposure to sustainability. Students who enroll in an international education program and seek a sustainability certificate are most likely to achieve the outcomes of the Global Competency Framework for Sustainable Futures, namely the knowledge, ability and predisposition to integrate economic, environmental and societal sustainability in defining and solving engineering problems.

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