Development for the Other 80%: Engineering Hope

Kurt Paterson, Ph.D., P.E.
Michigan Technological University, Houghton, USA
paterson@mtu.edu

Valerie Fuchs
Michigan Technological University, Houghton, USA
vjfuchs@mtu.edu

***Abstract**: Engineering faces many challenges: most of the world's population is under-served by designers, and interest in engineering is declining among students. Clever solutions will be required from dynamic engineers to meet the needs of the growing human population. International sustainable development engineering programs provide hope. Hope for those overlooked by engineers, and hope for academics to rejuvenate interest in engineering education, research, and practice. At Michigan Technological University multiple international sustainable development programs focused on developing communities have coalesced into the D80 Center, focused on providing hope to the 80% of the world's population poorly served by engineered goods, services, and infrastructure. Based on ten years of experience, the programs clearly resonate with a more diverse student body and produce more well-rounded, global-minded engineers, as compared to traditional programs. Future obstacles include dealing with the demand of such programs with limited faculty, staff, and financial support, overcoming constraints to participation, and dealing with unusual personal demands of such programs.*

Introduction

Multiple problems confront engineering. The world's population is rapidly closing in on seven billion people among which there are tremendous inequities. Average life expectancy is around 40 years in some countries, more than 80 years in others; average infant mortality ranges from 3 in some countries to nearly 300 per 1000 births in others; and average national per capita income ranges from 500 USD in the poorest to nearly 65,000 USD in the wealthiest. These inequities result in substantial human suffering, diminishing hope and elusive happiness. Engineering solutions must be brought to bear to level these inequities, providing basic human rights to clean water and air, adequate food, education, appropriate housing and beneficial infrastructure. These rights form the basis of the U.N. Millennium Development Goals (UN 2005).

A parallel, yet seemingly disconnected challenge to engineering is the lack of adequate numbers of engineers who can work in a dynamic global community. In the US, after hitting lows in the late 1990s, engineering enrolments are increasing at the undergraduate and graduate level (EWC 2004). Yet, the increase hides some troubling truths: among university students interest in engineering, as expressed by percent enrolled, is at an all-time low, about 6% of all American university students are engineering majors (Sims 2004); and yet while engineering enrolments are increasing in numbers due to growing numbers of children in the States, graduate engineering education continues on a 15-year downward trajectory in enrolments of white Americans (NSF 2004). In 2000 the number of international students exceeded the number of white Americans studying graduate engineering in the States for the first time ever. On a brighter note, the numbers of women at the graduate level of engineering education continue to rise; women now account for more than 20% of engineering graduate students (NSF 2004). Clearly the engineering profession has an image problem.

If engineering is not resonating with students entering college, then what does? A recent national survey (AMP 2006) showed incoming college students to be most interested in humanitarian issues:

education, poverty, environment, health, human rights, disaster relief and hunger topped the list. This list provides clues to alleviating the above problems – the Millennial Generation wants to make a difference in the world (Gordon 2007).

Since 1997 Michigan Technological University has created opportunities to engage engineering (and other) students in the solution to problems confronting people who have not historically been well-served by engineering. Over the course of the past decade, six distinct programs have been created to provide multiple opportunities and pathways through undergraduate and graduate education, supplemented by a rich international sustainable development experience. More recently these programs have coalesced into the D80 Center (www.d80.mtu.edu). This paper highlights the structure and outcomes of this bold initiative.

D80 Center

The D80 Center's mission is to assist the most vulnerable 80% of humanity in meeting their basic needs for food, water, shelter, sanitation, waste disposal, energy, income, and education. During their years at Michigan Tech, D80 participants learn to view the challenges and opportunities facing humanity via a multi-disciplinary lens. Through extensive opportunities on campus and in emerging communities, participants acquire the skills, knowledge, and confidence necessary to make a positive impact in the lives of the world's most under-served, while becoming leaders in their chosen fields.

D80 Programs

D80 encourages grass-roots development of companion programs by faculty, staff, and students. There are currently six programs affiliated in the Center:

1. Engineers Without Borders
2. Aqua Terra Tech Enterprise
3. International Sustainable Development Engineering Certificate
4. International Senior Design
5. International Sustainable Development Engineering Research Experiences
6. Peace Corps Master's International

Engineers Without Borders (EWB) at Michigan Tech is one of 160 university chapters in the States. Our chapter started in early 2005 and has rapidly grown, much like EWB-USA. EWB-Michigan Tech's student participation, and project work are summarized in Table 1.

Aqua Terra Tech (ATT) is one of several groups in Michigan Tech's innovative Enterprise Program (www.enterprise.mtu.edu). ATT works on water projects, simulates a small engineering consulting firm and provides three years of experience to students, from their sophomore to senior years.

The International Sustainable Development Engineering Certificate is a new academic program, which officially started in September 2007. This program requires a flexible set of twenty-two semester hours of coursework focusing on social, economic, and environmental sustainability and culminating in an international senior design project.

International Senior Design (ISD) is a six semester hour sequence that requires design and construction of an engineering project in a developing community. ISD projects are executed on multidisciplinary teams, augmented by professional mentoring.

The International Sustainable Development Engineering Research Experiences program teams doctorate and undergraduate students from Michigan Tech with students at the Universidad Tecnologica Boliviana in La Paz, Bolivia. These student teams research existing engineering development projects, notably their successes and failures. The projects culminate in a one-month residency in the communities being served.

The Peace Corps Master's International (MI) program in civil and environmental engineering is the only one of its kind in the States. While there are nearly 50 universities with MI programs, Michigan

Tech has the only program in engineering. The MI program requires two semesters of on-campus graduate level coursework, focusing on engineering in emerging communities. Students then serve in the U.S. Peace Corps for twenty-seven months and use their major project as the basis of their master's research report. Upon completion of service the MI students return to campus to defend their research.

Table 1. D80 program and student participant information to date

Program	Founded	Students	Female (%)	Student Undergraduate Disciplines	Project Countries
ATT	2001	30	50	Applied Geophysics, Biology, Chemical Engineering, Civil Engineering, Environmental Engineering, Geological Engineering	U.S.A., Nicaragua
EWB	2005	150	45	Applied Ecology, Biomedical Engineering, Business, Chemical Engineering, Civil Engineering, Electrical Engineering, Environmental Engineering, Environmental Policy, Forestry, Geological Engineering, Materials Engineering, Mechanical Engineering, Psychology, Technical Communication	Bolivia, Guatemala, Honduras, Mexico
ISD	2000	137	53	Civil Engineering, Environmental Engineering, Mechanical Engineering, Geological Engineering, Technical Communications, Education	Bolivia, Dominican Republic
Certificate	2007	13	69	Civil Engineering. Environmental Engineering	?
Research Experiences	2006	13	62	Civil Engineering, Electrical Engineering, Environmental Engineering, Environmental Policy, Mechanical Engineering	Bolivia
MI	1997	65	42	Aerospace Engineering Biology Civil Engineering Chemical Engineering Earth Systems Engineering Electrical Engineering Environmental Engineering Environmental Science Forest Engineering Geology Math Mechanical Engineering Nuclear Engineering Physics	Belize, Benin, Cameroon, Dominican Republic, East Timor, Fiji, Ghana, Honduras, Jamaica, Kenya, Macedonia, Madagascar, Mali, Mauritania, Palau, Panama, Philippines, Samoa, Uganda, Uzbekistan Vanuata

D80 Educational Model

The programs in D80 are all voluntary and open to students in all engineering disciplines. Most of the programs have also had participation by students in non-engineering fields. Additionally, students can participate in any combination of the programs. The D80 programs are presented in a timeline in Figure 1. Numerous pathways exist for students, should they become interested in multiple programs. Program flexibility is a key feature for students, as D80 participation is supplementary to major degree studies (with the exception of the MI program).

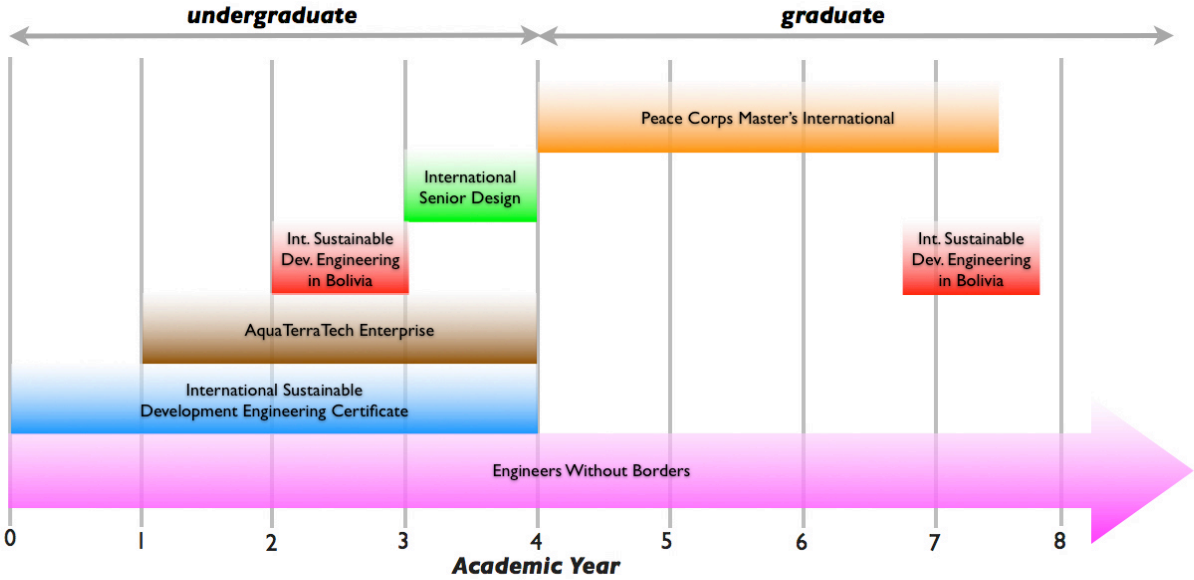

Figure 1. D80 programs timeline spanning undergraduate to graduate degrees.

A key tenet in all programs in D80 is based on a quote from New York Times journalist, Thomas Friedman, "if you don't go, you don't know." All D80 programs have engineering project work in developing communities. Spending time working and learning from such a community is critical to the professional and personal growth needed to create the dynamic engineers required for contemporary engineering solutions. The in-country community-based learning experiences for D80 programs are shown in Table 2.

Table 2. Length of community-based learning (CBL) in partner countries for each program

D80 Program	Typical CBL Period
ATT	1 week
EWB	2 weeks
ISD	2 weeks
Certificate	2 weeks
Research Experiences	1 month
MI	27 months

Learning science provides a basis for the assemblage of D80 programs. Kolb's Cycle (Kolb 1984; Stice 1997) is a well-researched pedagogical method, usually applied to assignments, and occasionally whole-courses. It should be similarly applicable to program design (see Figure 2). This model has been expanded in D80 to encompass the evolution of abilities , skills, and confidence with time of involvement in such programs; the shape is a spiral leading the student on a growing circle of influence with each subsequent international sustainable development experience. As one ultimate outcome of the D80 programs is creating engineers who understand the power of public service, this educational model is referred to as the Learning to Serve Spiral (Figure 3). This model is based on providing a venue for students to enter international sustainable development motivated by service or volunteerism. EWB and the MI programs are such programmatic opportunities. From there the student would be step into a traditional learning in classes offered in the Certificate program (for undergraduates) or the MI program (for graduate students). Service learning is a way to apply the theory and the ISD and ATT programs are rooted in such learning. Lastly research in developing communities is a way to wrestle with the ambiguities of the analysis phase of learning, the MI and Research Experiences programs are designed for this purpose. Collectively, the growing aggregate of programs in the D80 Center shape future program development. Careful planning to provide missing opportunities for segments of our student body (e.g. doctoral students, active learners, etc.) is guided by using Figures 1-3.

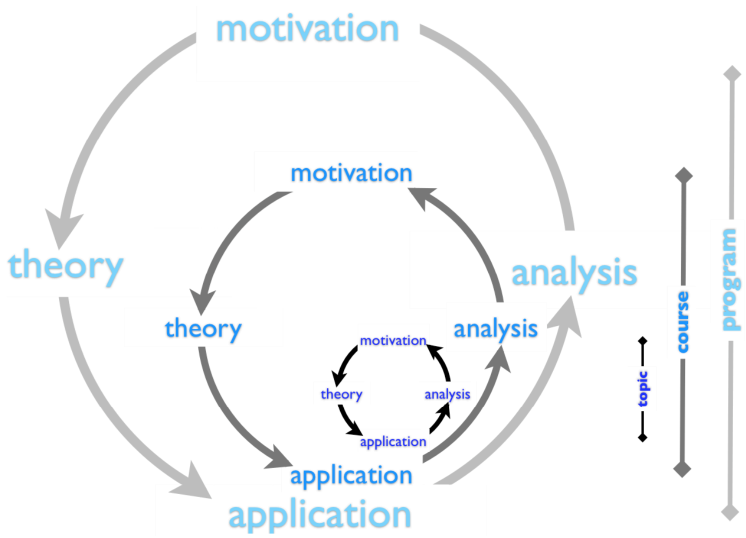

Figure 2. Kolb's learning cycle (motivation > theory > application > analysis) provides a fractal pedagogical basis for D80: similar structure can be built into topics, courses, and programs.

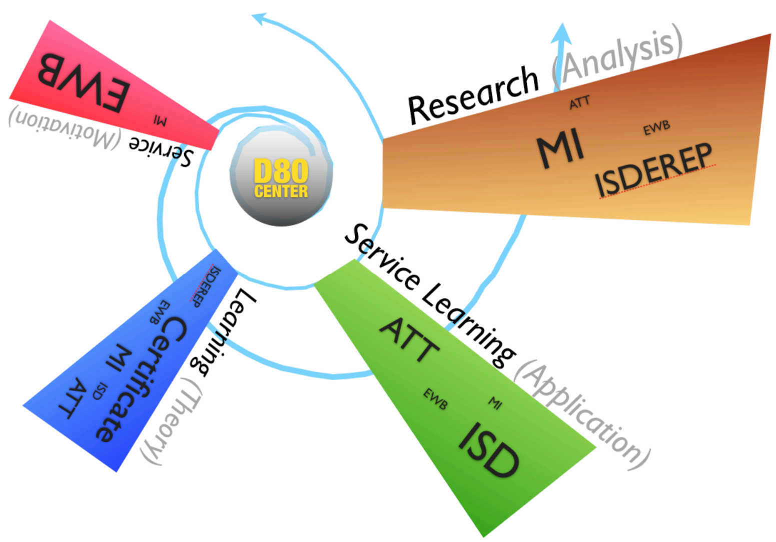

Figure 3. The D80 Learning to Serve Spiral. Kolb's cycle phases are adapted to international sustainable development engineering programs (e.g. Motivation is best achieved by Service in these programs, etc.). The size of the program names in each learning phase is proportional to the amount of learning of that type that is experienced in that program (e.g. ISD is mostly a Service Learning experience, and to a much lesser extent a traditional classroom, aka Learning, experience). By participation in several programs, students are challenged in various learning methods, which targets more learning styles, and translates to deeper learning.

D80 Outcomes

Table 1 shows some of the student participation numbers to date. Collectively, nearly 350 students have participated in D80 programs since 1997. As programs have been added, D80 is now graduating nearly 50 students a year, and has approximately 175 students (first-year through doctorate) currently involved in one or more programs (Figure 4). Nearly half (49.1%) of the students are female, and D80 has attracted students from twelve engineering and eight non-engineering disciplines. Minority participation has been low, except the Research Experiences program which has high Latino student involvement. Five engineering faculty (in environmental, civil, and geological engineering) and two staff are chiefly involved in D80 with assistance from several others. Communities in 25 developing countries (plus the US) have partnered with D80 students on engineering development projects (see Figure 5).

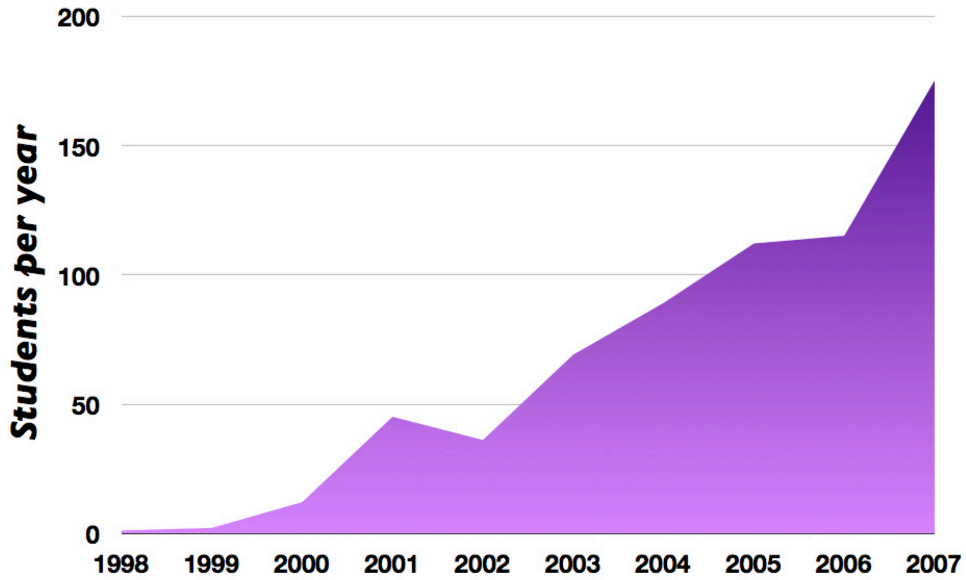

Figure 4. Number of students involved annually in D80 programs.

Figure 5. Partner countries for D80 student projects to date (26 nations in total)

D80 now has a substantial cadre of students interested in international sustainable development; this community of scholars has changed the dialogue inside and outside the classroom. Cross-fertilization of programs by these students has occurred; many students sample one program and enthusiastically seek out others. Currently, D80 students are participating in 1.7 D80 programs on average; however, D80 students report wanting to participate in 2.2 on average, if all obstacles could be removed.

A March 2007 survey of environmental and civil engineering undergraduate and graduate students investigated current participation and interest in D80 programs. The results are shown in Figure 6. The chart reveals that the fraction of students opting to participate increases with years of study. Conversely, student interest in wanting to participate diminishes with year of study. Note that the peak is for our Masters students, which is heavily influenced by the MI program. These results illustrate that undergraduates in the first couple years are eager to participate but are slow to engage. The figure also suggests that seniors in particular who have not participated in a D80 program are much less likely to do so. These findings can guide the timing of promotion and recruitment efforts.

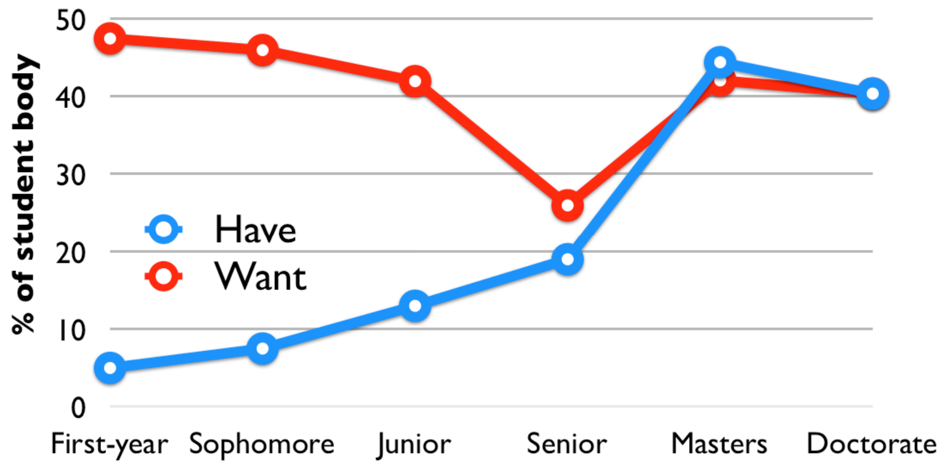

Figure 6. Percentages of environmental and civil engineering student body that have participated and want to participate in one or more D80 programs. (n=254).

Participation in D80 is not only dependent upon year of study; major field of study also seems to have a strong influence. Results comparing environmental engineering and civil engineering students show a three-fold difference – nearly 32% of all environmental engineering students are in at least one D80 program, whereas only 11% of civil engineering students are. Yet, an examination of the students expressing a desire to participate, but have not done so, indicates 35% of civil engineering students want an international sustainability experience compared to 49% of the environmental engineering students. Clearly, while the "want to" gap is smaller, environmental engineering students see a greater need for such international experience in their development as engineers. Table 3 presents the top three reasons students participate in D80 programs, and top three reasons why they do not. Again, there is a difference between the disciplines surveyed. While exceptions exist, the typical environmental engineering student is driven by altruism, civil engineering student by pragmatism. Reasons for not participating were mostly consistent among disciplines; time and money topped the list. Interestingly, not all the programs carry financial costs, and the time commitment varies tremendously among programs and throughout the calendar year. Future promotional efforts need to more clearly address these issues.

Several internal studies have begun to demonstrate learning outcomes from D80 participants. ABET guides many such studies in the States, most notably through its infamous Criteria A-K (ABET 2007). Of these criteria, roughly half (an ability to function on multidisciplinary teams; an understanding of professional and ethical responsibility; and ability to communicate effectively; the broad education necessary to understand the context of engineering solutions; a recognition of the need of life-long learning; and a knowledge of contemporary issues) are more challenging to implement, and see meaningful outcomes, in traditional engineering programs. D80 programs are infused with experiences that enrich students with these skills, abilities, and attitudes while building on the "easy" criteria that are delivered through their major studies (ability to apply knowledge of mathematics, sciences, and engineering; ability to design and conduct experiments; ability to identify, formulate, and solve problems; and an ability to use techniques, skills, and tools necessary for practice). A recent comparison of ISD students to traditional senior design students illustrates this point. Whereas ISD students reported a 10% higher self-rating of technical writing and speaking abilities, ISD students demonstrated an eleven-fold ability over their traditional senior design peers (87% correct versus 8% on a post-project quiz) to understand the global and societal context of their project work. Such is the power of international community-based learning in developing countries.

Table 3. Top three reasons identified by environmental and civil engineering students for participating and not participating in D80 programs (n=254).

Reasons	Environmental Engineering	Civil Engineering
To participate	1. I want to help the people with the greatest unmet needs 2. I want to travel 3. I want to fulfil ethical/moral obligations of the engineering profession	1. I want to gain professional experience 2. I want to challenge myself in new and difficult ways 3. I want to be an engineering leader
To not participate	1. I don't have the money to participate 2. I don't have the time to participate 3. I am more concerned about my major studies	1. I don't have the money to participate 2. I don't have the time to participate 3. I am more concerned about my major studies

An analysis of narratives, reports, and documents underscores the changes in thinking, context, and language. Both emergent and *a priori* content analyses have been conducted on MI, ISD, and Research Experiences students. Emergent content analysis of the Research Experiences students showed increasing usage of words related to their team and host community over the course of the one-month Bolivian community-based project work. The *a priori* analysis investigated the usage of sustainability-related words in MI theses and ISD reports (Fuchs 2007). Figure 7 shows the average word use in economic, environmental and social sustainability groupings. The graduate students are wordier (such is the nature of theses versus reports), but they also use a richer language descriptive of social and economic sustainability (note: the ISD students talk much about costs, but not much else in economic sustainability). These language differences are the result of twenty-seven months of community-based learning in the MI program versus two weeks in the ISD. Figure 8 reveals the relative frequency of sustainable development language used by students in these two programs. While the ISD students are fairly balanced, substantial growth is seen in the MI graduate students, notably in their breadth and frequency of environmental and social sustainability concepts.

D80 programs are very different than traditional study abroad programs and programs that take place in rich countries. Cultural, emotional, and physical challenges are often intense. Recent efforts to assess these impacts in D80 programs have shed some light on these demands and resulting impacts. A daily self-assessment has been used in the Research Experiences program to determine how students are doing physically, emotionally, technically, and overall. An example for one student is shown in Figure 9. While the student "vital signs" chart is unique to each student, all program participants (American and Bolivian) experienced physical, emotional and technical highs and lows. A comparison of the American to Bolivian students shows the Bolivian students to be consistently better off in all dimensions, and the Americans have a much greater range of scores over the course of the month. The latter point in particular illustrates the impacts of cultural adaptation. Another consistent finding is that undergraduate students consistently rate that things are going better than graduate students who were leading the projects. This suggests a real price for knowledge and leadership.

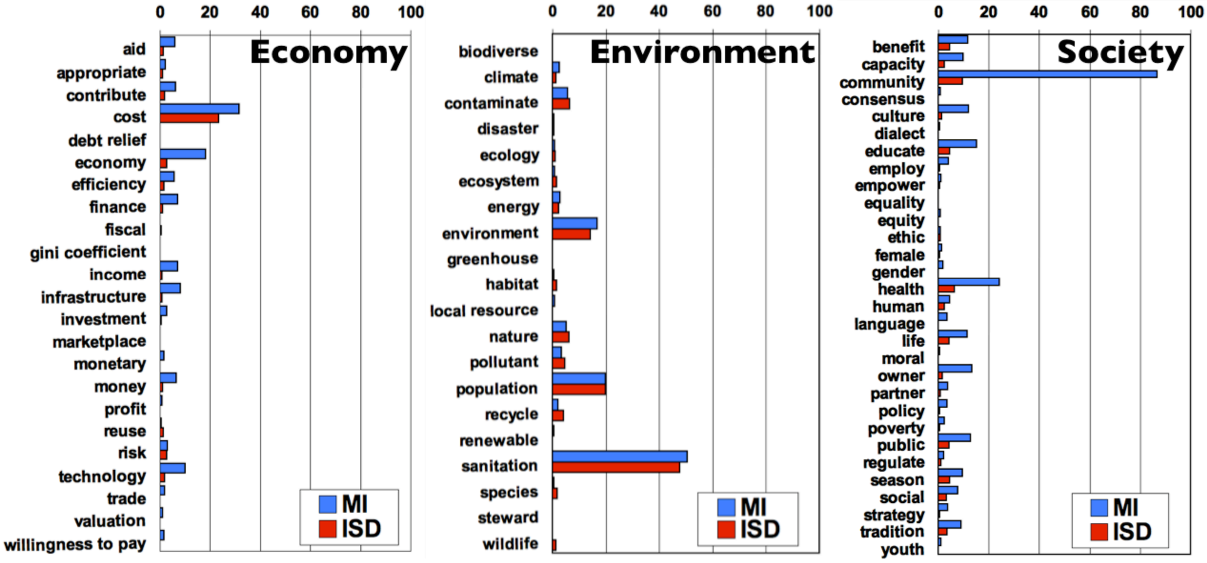

Figure 7. Sustainability concept *a priori* content analyses of MI thesis reports and ISD project reports. Word use counts are presented for each term in the three pillars of sustainability: economy, environment, and society.

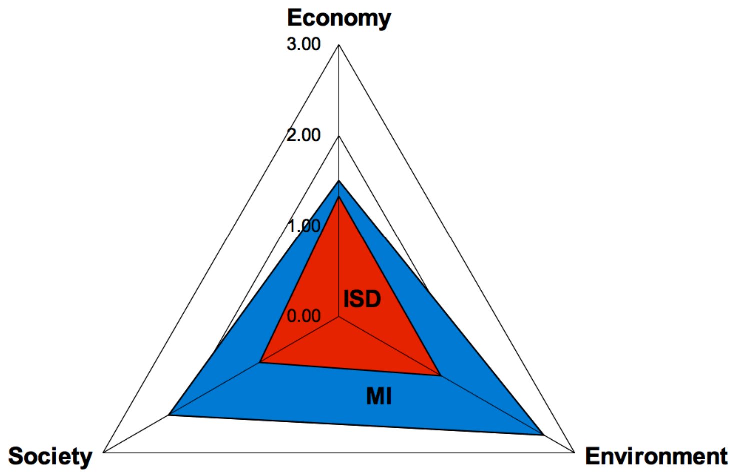

Figure 8. Sustainability concept usage for MI and ISD students. Numbers represent relative frequency normalized by word count totals from project reports.

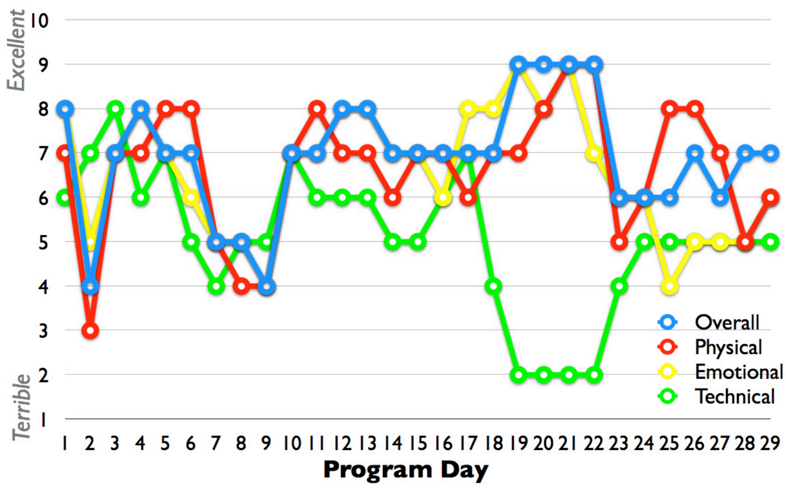

Figure 9. Daily self-assessment results for one student during the month-long Research Experiences program community-based project work in Bolivia.

Future Work

Programs like those in D80 work – students are immensely interested (students numbers that want to participate are nearly twice that currently participate), participation level is high (in environmental engineering, 32% of seniors, 50% of masters, 52% of doctorate students, and 36% of faculty are in D80 programs), and students clearly benefit in skill, ability, and attitude compared to their traditional peers. The latter is difficult to assess qualitatively, but clear qualitatively. Participation in international sustainable development engineering programs is immensely motivational to students, researchers, and faculty alike. The problems are complex and difficult to solve. A sense of contribution is inherent. These factors translate to enthused and hard-working engineers. It also attracts the best students, many of whom are women.

Despite our successes, several near-term challenges lay ahead for D80:

• Demand is high for our programs. It is unclear how to accommodate such high numbers. Additional resources from university and external supporters help, but the limiting step may be in adequate numbers of faculty and staff (Figure 10). Young faculty are supportive, but conflicted by promotion and tenure requirements. Older faculty tend to be constrained by family obligations. A greater role for program staff will be pursued to adapt to program demand.

• While student interests and outcomes are becoming clearer, the motivations, benefits, and challenges for faculty are only conversationally explored. An assessment of faculty involved in programs similar to those in D80 is underway.

• By 2010 we plan to reach 50% across-the-board participation rate for all students in environmental engineering. Based on current numbers, this has already been attained at the graduate level, and would require nearly 50% growth from current undergraduate levels (32% participation). This should happen easily through the new Certificate program, which is demonstrating early widespread interest among students. Outside of environmental engineering, D80 is aiming for 10% student participation rate by graduation in all other majors. This would result in a nearly 75% growth from our current student body of approximately 175 D80 students to more than 300. This will be met by encouraging program growth rooted in other academic units. A program from Humanities faculty may be the next to join D80, for example.

• Better data needs to be gathered on the impacts of programs such as those in D80 versus other educational approaches (traditional, high-tech based, co-op, domestic service learning, etc.). Such a long-term study is underway.

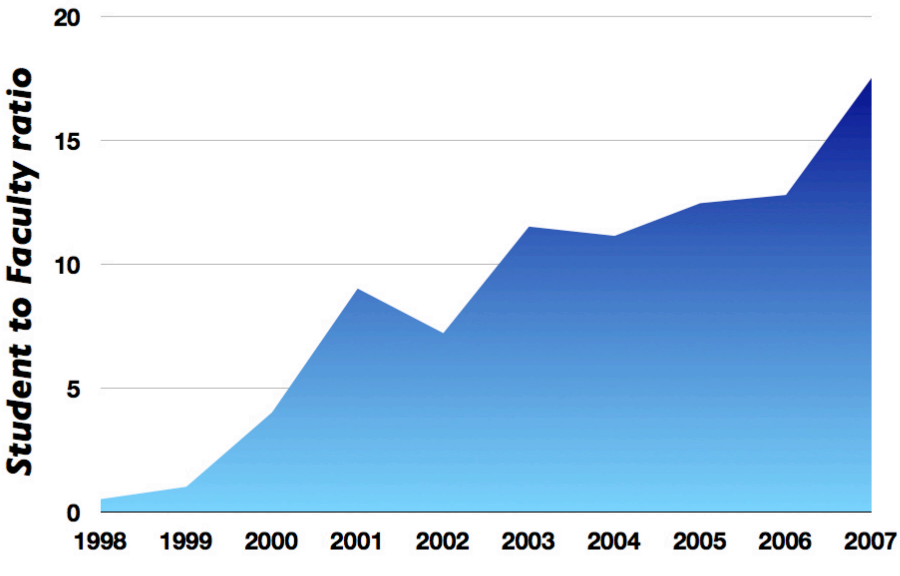

Figure 10. Student-to-faculty ratio within the D80 programs.

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