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Engineering for Poverty Reduction: Challenges and Opportunities

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ABSTRACT

Students in the University of Colorado at Boulder (CU-Boulder) College of Engineering and Applied Science have the opportunity to participate in a unique, hands-on program where they can apply their skills to solving the needs of developing communities worldwide. The Engineering for Developing Communities (EDC) program educates globally responsible engineering students and professionals who can offer sustainable and appropriate solutions to the endemic problems faced by developing communities worldwide. It presents a unique opportunity for educating a new generation of engineers who can contribute to the relief of the endemic problems faced by developing communities worldwide. The program contributes to meeting the United Nations Millennium Development Goals and involves engineering education, research and development, and outreach/service. The EDC program serves as a blueprint for the education of engineers of the 21st century who are called to play a critical role in contributing to peace and security in an increasingly challenged world.

Keywords: Sustainable development, service learning, outreach

1. INTRODUCTION

With a current population of more than 6.5 billion, the world is becoming a place in which human populations are more crowded, more consuming, more polluting, more connected, and in many ways less diverse than at any time in history. There is growing recognition that humans are altering the Earth's natural systems at all scales from local to global at an unprecedented rate in the human history. The question now arises whether it is possible to satisfy the needs of an exponentially growing population while preserving the carrying capacity of our ecosystems and biological and cultural diversity. Another related question is what needs to be done now and in the near future to allow *all* humans to enjoy a quality of life where basic needs of water, sanitation, nutrition, health, safety, and meaningful work are fulfilled. The eight Millennium Development Goals set forth by the United Nations General Assembly in 2000 represent a major effort by all of the world's countries and leading development institutions to meet the needs of the world's poorest (United Nations Development Programme, 2003). The goals provide countries around the world a base for development and targets whose progress can be quantified. Now, more than seven years later, some progress has been made in some regions of the world while other regions are still struggling towards meeting those goals (United Nations, 2006).

In the next two decades, almost 1.5 billion additional people are expected to populate the Earth with 97% of that growth in developing or under-developed countries (Population Division, 2006). Such growth will create demands on an unprecedented scale for energy, food, land, water, transportation, materials, waste disposal, earth moving, health care, environmental cleanup, telecommunication, and infrastructure. The role of engineers will be critical in fulfilling those demands at various scales ranging from remote small communities to large urban areas (megacities), and mostly in the developing world (United Nations, 1998). If engineers are not ready to fulfill such demand, who will? As remarked by Bugliarello (1999), the emergence of large urban areas is likely to affect the future prosperity and stability of the entire world. Today, it is estimated that more than 900 million people live in some type of city slum (UN-Habitat, 2003) and that the urban share of the world's extreme poverty is about 25% (UN Habitat, 2001). One hundred twenty-eight million slum dwellers (comprising 14 per cent of the world's slum population) live in Latin America and the Caribbean (UN Habitat, 2005).

Considering the problems facing our planet today and the problems expected to arise in the first half of the twenty-first century, the engineering profession must revisit its mindset and adopt a new mission statement—to contribute to the building of a more sustainable, stable, and equitable world. As Maurice Strong, Secretary General of the 1992 United Nations Conference on Environment and Development, said, "Sustainable development will be impossible without the full input by the engineering profession." For that to occur, engineers must adopt a completely different attitude toward natural and cultural systems and reconsider interactions between engineering disciplines and non-technical fields.

For the past 150 years, engineering practice has been based on a paradigm of controlling nature rather than cooperating with nature. Despite a reductionistic view of natural systems, this approach led to remarkable engineering achievements during the nineteenth and especially twentieth centuries. For instance, civil and environmental engineers have played a critical role in improving the condition of humankind on Earth by improving sanitation, developing water resources, and developing transportation systems. Ironically, these successes have unintentionally contributed to current problems by enabling population growth. Despite some attempts to consider alternative engineering solutions in the 1970s (especially in renewable energies), most engineering achievements of the past were developed without consideration for their social, economic, and environmental impacts on natural systems. Not much attention was paid to minimizing the risk and scale of unplanned or undesirable perturbations in natural systems associated with engineering systems.

As we enter the twenty-first century, we must embark on a worldwide transition to a more holistic approach to engineering. This will require: (1) a major paradigm shift from control of nature to participation with nature; (2) an awareness of ecosystems, ecosystems services, and the preservation and restoration of natural capital; and (3) a new mindset of the mutual enhancement of nature and humans that embraces the principles of sustainable development (Wallace, 2005), renewable resources management, appropriate technology, natural capitalism (Hawken et al., 1999), biomimicry (Benyus, 1997), biosoma (Bugliarello, 2000), and systems thinking (Meadows, 1997).

In addition, engineering educators must take a closer look at how engineering students are being prepared to enter the "real world." Current graduates will be called upon to make decisions in a socio-geo-political environment quite different from that of today. In their lifetimes, engineering students now attending college can expect to see an increase in world population from six billion to between nine billion and ten billion people, major global warming phenomena, and major losses in biological and cultural diversity on Earth. Whether colleges and universities are doing enough proactively to teach students what they need to know to operate in a future environment is an open question (Orr, 1998). Clearly, engineers must complement their technical and analytical capabilities with a broad understanding of so-called "soft" issues that are non-technical. Experience has shown that social, environmental, economic, cultural, and ethical aspects of a project are often more important than the technical aspects but are not often emphasized in conventional engineering education.

An issue of equal importance is the education of engineers interested in addressing problems specific to developing communities. These include water provisioning and purification, sanitation, power production, shelter, site planning, infrastructure, food production and distribution, and communication, among many others. Such problems are not usually addressed in engineering curricula in developed and developing countries, however. Thus, traditionally trained engineers are not educated to address the needs of the most destitute people on our planet. This is unfortunate, because an estimated 20% of the world's population lacks clean water, 40% lacks adequate sanitation, and 20% lacks adequate housing.

Furthermore, engineers will be critical to addressing the complex problems associated with refugees, displaced populations, and the large-scale movement of populations worldwide resulting from political conflicts, famine, shortages of land, and natural hazards. Some of these problems have been brought back to our awareness since the tragedy of September 11, 2001. The engineer's role is critical to the relief work provided by host governments and humanitarian organizations as witnessed in the aftermath of the Asian Tsunami in 2004 and Hurricane Katrina in 2005. The whole field of "Engineering in Emergencies" is yet to be created and is much needed. According to the World Health Organization (WHO), 1.8 billion people (30% of the world's population) currently live in conflict zones, in transition, or in situations of permanent instability.

It is clear that engineering education needs to be changed (or even reinvented) to address the challenges associated with these global problems. There is still a large disconnect between what is expected of young engineers in engineering firms, the magnitude of the problems in our global economy, the recommendation for general education suggested by accreditation boards (for instance, the Accreditation Board for Engineering and Technology (ABET) in 2000 and the American Society of Civil Engineering (ASCE) Body of Knowledge for the 21st Century, in the U.S.), and the limited skills and tools traditionally taught in engineering programs in universities.

Engineers of the future must be trained to make intelligent decisions that protect and enhance the quality of life on Earth rather than endangering it. They must also make decisions in a professional environment in which they will have to interact with people from both technical and non-technical disciplines. Preparing engineers to become facilitators of sustainable development, appropriate technology, and social and economic changes is one of the greatest challenges faced by the engineering profession today. Meeting that challenge may provide a unique opportunity for changing the way that engineers are trained worldwide.

2. ENGINEERING FOR DEVELOPING COMMUNITIES

Engineering schools typically do not address the needs of the most destitute people on our planet, many of them living in industrialized countries (including the U.S.). This is unfortunate because the needs of the developing world for engineering solutions are likely to increase in as population grows. How can engineers in the industrialized world contribute to the relief of the unnecessary hunger, exploitation, injustice, and pain of people trying to survive day by day? How can they contribute to meeting the United Nations Millennium Development Goals (World Development Report, 2003; World Federation of Engineering Organizations, 2002)? Clearly, we need to train a new generation of engineers to meet the challenges and needs of the developing world.

A VISION TO MEET THE CHALLENGE

The College of Engineering and Applied Science at CU-Boulder has started a new program called the Engineering for Developing Communities (EDC) Program (http://www.edc-cu.org). The overall mission of the program is to educate globally responsible engineering students and professionals who can offer sustainable and appropriate solutions to the endemic problems faced by developing communities worldwide (including the United States). The EDC program fits under the Earth Systems Engineering Initiative in the College of Engineering and Applied Science and is one of several "active learning" opportunities (http://engineering.colorado.edu/activelearning/) available to engineering students at the CU-Boulder.

The EDC program, which involves both engineering and non-engineering disciplines, is offered to engineering students interested in community service and international development. The program is being developed in partnership with academic and nonacademic groups in the U.S. and developing countries to address a wide range of issues, such as water provisioning and purification, sanitation, health, power production, shelter, site planning, infrastructure, food production and distribution, communication, long-distance education, and jobs and capital for developing communities, including villages, refugee settlements, etc. The three components of the program are outreach and service, research and development and education.

OUTREACH AND SERVICE – STUDENT LEARNING AND WORK IN DEVELOPING COMMUNITIES

The outreach and service component of the EDC Program was launched in fall 2001 with a national initiative, Engineers Without Borders. This new activity was created as a follow-up to fieldwork in May 2001, when the second author took ten undergraduate students from the Department of Civil, Environmental, and Architectural Engineering to help with the construction of a water distribution system and a pump for a small Mayan village in southern Belize.

The work in Belize led to the creation of a nonprofit 501(c)(3) tax-exempt corporation, called Engineers Without Borders-USA (EWB-USA, http://www.ewb-usa.org). The first chapter was formed at CU-Boulder in late fall 2001. Five years later, EWB-USA has more than 200 student and professional chapters across the United States and involves about 12,000 engineering students, faculty, and professional engineers.

In general, the purposes of EWB-USA are: (i) to help disadvantaged communities improve their quality of life through implementation of environmentally and economically sustainable engineering projects, and (ii) to develop internationally responsible engineering students. Projects are initiated by, and completed with, contributions from the host communities, which are then trained to operate the systems without external assistance. The projects are carried out by groups of engineering students under the supervision of professional engineers and faculty. The students select a project and go through all phases of conceptual design, analysis, and construction during the school year; implementation is done during academic breaks and summer months.

EWB-USA has currently about 130 engineering projects in 38 different countries. In 2006 alone, more than 1,000 students across the U.S. were involved in such hands-on projects. Each chapter is responsible for raising their own financial support through grants and donations. More specifically, at CU-Boulder (http://ceae.colorado.edu/ewb/), about 30 students were involved in projects in Rwanda and Peru during that time. Past projects have been conducted in Haiti, Mali and Bolivia. Future projects are planned in Nepal and Chile. All CU Boulder projects have been financed through small grants from CU-Boulder (Outreach Committee; Engineering Excellence Fund; Undergraduate Research Opportunity Program; Service Learning Office), foundations, and private donations.

The EWB-USA model of education goes beyond traditional service-learning concepts and models in engineering (Tsang, 2000). By involving students in all steps of the projects from concept to implementation, and through experiential learning, students become more aware of the social, economic, environmental, political, ethical, and cultural impacts of engineering projects.

RESEARCH AND DEVELOPMENT IN APPROPRIATE TECHNOLOGY

The field work conducted by EWB-USA has revealed an urgent need for appropriate technologies specific to the developing world. Appropriate technology is usually characterized as small scale, energy efficient, environmentally sound, labor-intensive, and controlled by the local community. It must be simple enough to be maintained by the people who use it. In short, it must match the user and the need in complexity and scale and must be designed to foster self-reliance, cooperation, and responsibility (Schumacher, 1989; Hazeltine and Bull, 1999 and 2003).

Because appropriate technology is often perceived as "low-tech" and unimportant, it is not usually addressed in engineering education or university research within industrialized nations. Studies by the World Bank and the United Nations have shown, however, that appropriate technology is critical to bringing more than three billion people out of poverty.

To respond to the need for research and development in appropriate technology, a Center for Appropriate and Sustainable Technology (CU-CAST) is under development in the CU-Boulder College of Engineering and Applied Science. The center has three goals: (1) to provide a university research environment where teams of undergraduate and graduate students can work under the supervision of faculty and professional engineers; (2) to foster the innovation, development, and testing of technologies that can be used to address water, sanitation, energy, shelter, and health issues in the developing world; and (3) to provide services in database development and maintenance; the testing and improvement of existing technologies; technology transfer; and education and training.

Examples of ongoing studies by students and faculty include: prototype rope pumps for water wells and ram pumps; pesticide removal during basic treatment of drinking water; attenuation of pathogens from latrines to nearby water sources; phyto-remediation effects on wastewater treatment; thin-shell acrylic concrete roofing; solar pasteurization, cooling, heating, cooking, and pumping; production of biofuel and biomass; fog harvesting; slow sand and UV water filtration systems; and rain water catchment systems. The third and fourth authors are actively working on one research project, "*Sustainability of the Filtrón for Microbial Disinfection,*" that was partially supported by a USEPA P3 grant in 2005-2006.

EDUCATION – TEACHING SUSTAINABILITY AND APPROPRIATE TECHNOLOGY

The EDC program brings together courses in engineering, sustainability, public health, appropriate technology, renewable energy, international education and development, business, and various fields of humanities. It provides an opportunity for undergraduate and graduate students in engineering to enroll in a regular program of study in the College of Engineering and Applied Science and, at the same time, take some of their social science/humanities electives, technical electives, and independent study classes in courses emphasizing engineering for developing communities.

Students interested in community service and international development have several options through the EDC Program in the Civil, Environmental, and Architectural Engineering (CEAE) Department at CU Boulder. They include a graduate EDC track in the MS/PhD program in Environmental Engineering which has been offered since spring 2004 and has involved 25 graduate students. EDC can also be custom designed as an emphasis area in the graduate Building Systems and Construction Engineering and Management programs. For undergraduate students, an EDC track was developed within the Civil Engineering (CVEN) undergraduate degree, and work has begun on proposed tracks for the undergraduate degrees in Environmental Engineering (EVEN) and Architectural Engineering (AREN).

Since 2004, in part thanks to a National Science Foundation-Department Level Reform of Undergraduate Education Planning Grant, the EDC program has made major advancements in educational offerings. Several courses have been developed in CEAE for graduate and undergraduate students interested in EDC. They include:

- Sustainability and the Built Environment (http://ceae.colorado.edu/~amadei/CVEN4700)
- Environmental Engineering Design (http://www.colorado.edu/engineering/civil/CVEN4434/syllabus.html)
- Natural Capitalism For Engineers (http://www.edc-cu.org/NaturalCapitalism.htm)
- Public Health for Developing Communities (http://www.edc-cu.org/pdf/HealthCourseMatrix.pdf)
- Appropriate Treatment Technology
- Engineering for the Developing World (http://www.edc-cu.org/cven4838.htm)

Other courses (technical and non-technical) on the CU Boulder campus can be taken as part of the EDC program. Their listing can be found in the advising guide: http://www.edc-cu.org/pdf/EDC_track_advising_guide.pdf.

In spring 2005, an outdoor teaching laboratory was created on the CU Boulder campus that gives students the opportunity to practice sustainable building techniques in an outdoor setting. The *Field Laboratory for Applied Sustainable Technologies* (FLAST) allows students to gain experience with low cost, low maintenance green building materials through active and experiential learning (http://www.edc-cu.org/FLAST.htm). In 2005, the laboratory was used as an integral part of the teaching of *Sustainability and the Built Environment*, which was taught to graduate and undergraduate students. Topics covered in the class as hands-on modules included: eco-materials, sustainable water and waste water systems, renewable energy, waste and waste products, green building construction, straw bale construction, natural plasters, and building with earth and straw. In 2006, the laboratory's photovoltaic array was expanded to provide 450 watts of power. The ultimate goal of the FLAST facility is for it to be self-sufficient, generating its own power and collecting and processing enough rainwater to complete all on-site projects. The FLAST has also been a training ground for students who are learning about well drilling, photovoltaic water pumps, and biogas reactors.

Finally, appropriate technology for the developing world can be a great opportunity to teach basic engineering design to freshmen students and contribute to higher retention rates in engineering. In the College of Engineering and Applied Science at CU Boulder, freshmen engineering students can sign up for a three-credit hour course offered each semester through the Integrated Teaching and Learning Laboratory (http://itll.colorado.edu). *GEEN 1400-Engineering Projects* (http://www.edc-cu.org/geen1400.htm) is a first-year interdisciplinary and hands-on engineering project course for entry level engineering students. The purpose of this course is to provide students an introduction to engineering design through a series of small projects done in interdisciplinary teams. Students learn in a hands-on way valuable engineering skills including communication, how to function in teams, the basic steps in engineering design process, and a variety of computer tools as appropriate to their projects, such as spreadsheets, dynamic modeling software, or computer-aided design (CAD).

Since 2002, CU students have been able to sign up for a section of GEEN 1400 that emphasizes appropriate technology for the developing world. In that section, students are given a thorough understanding of some of the most common and important technologies being introduced in small-scale community developments. Students are asked to create, design, and construct appropriate technological systems, processes, and devices for a variety of settings associated with the developing world. Examples include production of biodiesel or biomass; generation of electricity using water turbines; heating of water for refugee camps; water filtration systems; solar-powered refrigeration; and solar-powered water pumping. All past projects since 2002 can be found at http://www.edc-cu.org/geen1400pastprojects.htm.

The educational component of the EDC Program also includes continuing education and training for U.S. engineers and foreign personnel in international development and capacity building. The EDC Program sponsors and organizes workshops and conferences, bringing world experts and leaders to CU-Boulder for discussions and sharing of research and applications in areas dealing with the developing world. For instance, the EDC Program co-organized *Sustainable Resources 2003 and 2004* in Boulder, Colorado. Then, in January 2006, EDC co-organized an *International Workshop on Technologies for Sustainable Rural Livelihoods* in Hyderabad, India, and in February 2006, EDC co-organized an *Invention to Venture Workshop* (explaining the basics of technology entrepreneurship) in Boulder. Starting in 2007, the first and second authors will be involved in two capacity building projects in Afghanistan on sustainable technology entrepreneurship and on-line education of engineering faculty.

3. CONCLUSION AND DISCUSSION

Creating a sustainable world that provides a safe, secure, healthy, productive, and sustainable life for all peoples should be a priority for the engineering profession. Engineers have an obligation to meet the basic needs of all humans for water, sanitation, food, health, and energy, as well as to protect cultural and natural diversity. Improving the lives of the five billion people whose main concern is staying alive each day is no longer an option; it is an obligation. Educating engineers to become facilitators of sustainable development, appropriate technology, and social and economic changes represents one of the greatest challenges faced by the engineering profession today. Meeting these challenges will require coordinated efforts by engineers around the world. The current challenge also provides a unique opportunity to bring more women and diversity into engineering education; this has been clearly observed at CU-Boulder since the EDC Program started several years ago.

The EDC Program described in this paper provides a unique opportunity to promote engineering, a discipline that has traditionally been taken for granted by government agencies and political groups. It also provides higher visibility to a profession that will certainly play a critical role in creating structures and technologies to sustain a decent quality of life for current and future generations, especially in the developing world. Currently, the EDC Program is limited to the Civil, Environmental, and Architectural Engineering Department on a pilot basis. The plan is to extend it to the entire College of Engineering and Applied Science during the next five years. Hopefully, the program can become a model for similar efforts worldwide.

EDC offers many opportunities for practicing engineers to become involved in engineering education through projects in developing communities around the world (including the United States). It also provides opportunities for young engineers to work with professionals from various fields such as anthropology, social and economic sciences, and healthcare. The interaction between engineering decision and decisions made by non-engineers is often ignored in conventional engineering education. The outreach/service component of EDC forces students to work in real communities and interact with a wide spectrum of stakeholders.

Finally, the new EDC program provides an innovative way to educate young engineers interested in addressing the problems of developing countries and communities. It is clear that engineers of the twenty-first century are called upon to make critical contributions to peace and security in our increasingly challenged world.

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