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Humanitarian Engineering: Global Impacts and Sustainability of a Curricular Effort*

BARBARA M. MOSKAL, CATHERINE SKOKAN, DAVID MUÑOZ and JOAN GOSINK
Colorado School of Mines, Golden, Colorado, 80401, USA. E-mail: bmoskal@mines.edu

The Humanitarian Engineering program at the Colorado School of Mines seeks to prepare engineering students for careers that will interface with and benefit the underserved global community. Through an interdisciplinary collaboration, a sequence of courses has been designed and implemented to support engineering students in developing an understanding of the ethical, cultural, historical and technical dimensions of engineering work applied to community development in the United States and abroad. This article discusses the analysis of several indicators of the local and global impacts of the program and the sustainability of this project beyond the period of funding.

Keywords: global engineering; humanitarian engineering; undergraduate curriculum

INTRODUCTION

The United States National Academies, which consist of the National Academy of Science, the National Academy of Engineering, the Institute of Medicine and the National Research Council, have predicated that by the year 2020 the world's population will approach 8 billion with the majority of growth occurring in nations that lack an appropriate infrastructure. As a result, difficulties are anticipated in meeting basic human needs, such as water, food, shelter and education, of the people residing in these nations [1]. Engineers have always used their talents and skills to solve problems; globalization has expanded the potential impact of engineers' problem solving capabilities to benefit people who live beyond their own national borders [2]. In order for engineers to contribute to the solution of international problems, students of engineering will require a different education from that of their predecessors [3–5]. In the U.S.A., the Accreditation Board for Engineering and Technology (ABET) has anticipated some of these needs in the establishment of accreditation criterion 3. A portion of this criterion specifies that engineering programs need to provide an education that supports " . . . an understanding of professional and ethical responsibilities . . ." (3f) and " . . . the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context" (3h) [6].

Engineering schools in the U.S.A., as well as abroad, have started the process of developing and implementing appropriate instruction to support the attainment of these and similar outcomes. For example, Georgia Institute of Technology, U.S.A., the University of Illinois at Urbana-Champaign, U.S.A, and Delft University of Technology, Netherlands, have implemented courses and modules designed to assist future engineers in developing an ethical awareness of the potential impact of their discipline [7–9]. Journals in engineering education have also recognized the importance of including this content in the curriculum; for example, this journal hosted a Special Issue titled, "Engineering Ethics, An International Overview," in 2005 [10].

Curriculum developments are also underway that address the second of the two previously stated ABET outcomes, 3h. Arizona State University, U.S.A., offers an elective course on "Global Awareness" to students in Biomedical Engineering with the goal of " . . . increase[ing] the students' awareness of environmental, economic, legal, social, and ethical consideration that relate to the global impact of bioengineering technology . . . [11]." The Barton School of Business and the College of Engineering at Wichita State University, U.S.A., has teamed with the Industrial Engineering in the Faculty of Engineering and Natural Sciences at Sabanci University, Turkey, to offer elective graduate level courses that require international collaboration via the World Wide Web on logistics and supply chains [12]. This journal has also presented research on how to use the industrial psychology and business literature on global awareness to inform engineering education [13]. A logical next step in these curricular efforts is the creation of engineering curriculum that supports students in developing not only an ethical awareness and global understanding of the worldwide human condition but also a sense of responsibility to use their engineering knowledge to solve problems that address basic human needs.

Concerns have further been raised in the U.S.A. that enrolment in engineering has been declining since the early 1980s [5, 14–16]. Fewer and fewer undergraduate students regardless of ethnicity or

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gender are entering engineering studies. As a result of the overall decrease in enrolment in engineering and the economic expansion that has resulted from technological advancements, the U.S.A. has been experiencing a shortage of trained engineers. The government responded in 1998 by increasing the annual number of temporary, professional-worker visas from 65 000 to 115 000 [17] for a three year period in the American Competitiveness and Workforce Improvement Act of 1998. This number was increased for another three year period [18], to 195 000, through the American Competitiveness in the Twenty-First Century Act of 2000. By 2004, it was hoped that the availability of U.S.A. trained engineers would increase to the level needed to fill the available positions. Since this hope did not become a reality, a new initiative is underway: the American Competitiveness Initiative of 2006 [19].

One method for increasing the overall number of students that pursue engineering degrees is to attract subpopulations to the field that are currently underrepresented. Based on the most recent statistics available through the National Science Foundation [20], women comprised approximately 20% of earned bachelor's degrees in engineering in the U.S.A. in 2005. This percentage has seen little change since the beginning of the millennium. Research suggests that women are attracted to careers when they recognize the broader impact of that field on society [21–25]. Engineering is often perceived as a field that supports individual gains rather than the advancement of society at large [3]. One manner in which to increase female participation in engineering may be to offer a curriculum that not only illustrates the broader impacts that engineering has on society but also that supports students in making immediate, positive contributions to society using their developing engineering skills [26]. An example of such a program can be found at Purdue University, U.S.A. [27]. Their Engineering Projects in Community Service (EPICS) program provides students with an extended experience, freshman through senior year, implementing engineering skills in a manner that serves local community needs.

The Engineering and the Liberal Arts and International Studies Divisions at the Colorado School of Mines (CSM), with funding from the William and Flora Hewlett Foundation through its Engineering Schools of the West Initiative grants [28], have undertaken an initiative that addresses the concerns described here using a global approach. The Humanitarian Engineering program seeks to prepare engineering students for careers that will benefit the underserved international community. This type of curriculum not only addresses ABET's criterion 3f and 3h but also it is designed to have a strong appeal to female students. Through this interdisciplinary collaboration a sequence of courses has been designed and implemented to support engineering students in developing an understanding of the ethical, cultural, historical and technical dimensions of engineering work applied to community development in the U.S.A. and abroad. This dimension of the project is consistent with the recommendations of The Steering Committee of the National Engineering Education Research Colloquies who have argued that research is needed that explores the role of the humanities, social sciences and the natural sciences in the engineering curriculum [29].

There are several reasons for establishing such a program at CSM. First, the Engineering Division offers an ABET accredited interdisciplinary engineering degree program with areas of emphasis in civil, electrical, environmental and mechanical engineering. All students who pursue this degree are required to complete a capstone course called Senior Design in their final year of study. As part of this course, students complete interdisciplinary projects that are consistent with the four areas of departmental emphasis and that have been solicited from local, national and international businesses. A large number of these projects have had a community service component, and this has provided our Senior Design faculty with background knowledge and interest in this area.

A second rationale for establishment of the Humanitarian Engineering program at CSM relates to the current mission. In 2000, CSM modified its mission statement to include an emphasis on stewardship of the environment; this change calls for an education that instills in students the importance of creating engineering solutions that have long-term sustainability. A prerequisite skill for addressing sustainability issues is developing an understanding of the local issues, needs, and expectations at an engineering site. These skills, often referred to as the "soft skills," are as necessary to successful problem solving as are the required technical skills. Therefore, the Humanitarian Engineering program has been designed to support students in developing the necessary skills, soft and technical, for both local and international problem solving.

A third rationale relates to the changing requirements of our recruiters. Traditionally, CSM students have sought employment in resource development. Lack of community support in the resource development industry has real consequences on companies in the form of bad publicity. Many of these employers are seeking engineering graduates who have knowledge and experience interacting with diverse cultures. These employers enthusiastically support the objectives of the Humanitarian Engineering program, viewing it as a source of engineering recruits with both technical skills and cultural awareness.

The final rationale for establishing the Humanitarian Engineering program was the desire to increase the recruitment of underrepresented groups to engineering majors at CSM. As discussed previously [26], there is research evidence that engineering programs that focus on commu-

nity service are appealing to female students; anecdotal evidence at CSM further suggests that this is likely to be true for other underrepresented populations. Many people incorrectly believe that engineering is impersonal and insensitive to human needs, a belief that discourages many talented individuals from pursuing degrees in the field. Given this, the Humanitarian Engineering program was designed to provide students with clear evidence of the social relevance of the engineering profession.

This five-year project began at the start of the academic year 2003–2004, during which new courses, projects, and assessment activities were pilot tested. A major component of this curriculum is the completion of a humanitarian engineering design project during students' final year in Senior Design. For the purposes of Senior Design, humanitarian engineering activities are defined in their broadest sense. According to Smyser [30], "People do not need only water, food and medicine. They need a sense of stability, some notion of a future. They want to be able to plan for more than a day, let alone a week." Education is one manner in which to provide this sense of stability and self-reliance. Humanitarian engineering is defined here to include projects that immediately address the human needs of water, food, shelter and education and projects that support the development of an infrastructure that will support the on-going attainment of these needs.

The end goal of the Humanitarian Engineering curriculum is not only to improve the education of future engineers but also to contribute to the solution of the problems that currently challenge the local and international community. This article examines the broader impacts of the Humanitarian Engineering project as well as the potential sustainability of this program beyond the period of funding. Prior papers have described the development and measurement of the intended student and faculty outcomes [3, 4]. The research questions that guide the current investigation are:

- What has been the documented impact of the Humanitarian Engineering Program on the local and international community?
- What evidence is there to support that these activities can be sustained beyond the period of funding?

PROGRAM OVERVIEW

In 2003, the William and Flora Hewlett Foundation began a new initiative, the Engineering Schools of the West Initiative, and awarded ten million dollars in grants, distributed among nine engineering institutions located in the western United States [28]. The nine schools are Boise State University, Colorado School of Mines, Montana State University, New Mexico State University, Northern Arizona University, Oregon State University, University of Nevada, Reno, University of Utah, and the University of Wyoming. The purpose of the Engineering Schools of the West Initiative is to support efforts that seek to improve the recruitment and retention of engineering students and the learning that occurs in the undergraduate engineering classroom. The Humanitarian Engineering program at the CSM is funded through this initiative.

The Humanitarian Engineering Program is developing a community service component as part of the undergraduate engineering curriculum at CSM. This aspect of the curriculum teaches students how to utilize their technical knowledge and skills to solve real-world problems faced by economically disadvantaged populations throughout the world. The Humanitarian Engineering curriculum combines both technical and non-technical coursework in a manner that supports students in understanding the history of humanitarianism and of the importance of pro-active community service. Students also learn how to use technical tools and engineering knowledge to implement humanitarian based projects.

Existing courses have been modified at CSM to include a humanitarian emphasis and two minors in humanitarian studies are available: Humanitarian Studies and Technology and Humanitarian Engineering [31]. Students who complete the Humanitarian Engineering minor are also required to complete a capstone senior design course that involves a hands-on community service engineering project at a local, national or international level. Projects include those that address the water, food, shelter and educational needs of people in disadvantaged communities. These curricular efforts as well as the projects that have been completed are described in this paper.

METHODS

This investigation uses several sources of data to examine the local and international impact and potential sustainability of the Humanitarian Engineering program. The primary sources of data are the Engineers of the West Database [32] and CSM's Humanitarian Engineering website [31]. Documents maintained by the university and the Humanitarian Engineering program have also been examined to inform this effort.

Engineers of the West Database

The Engineers of the West Database was constructed by researchers at the University of Nevada, Reno, and is the result of the on-going efforts of the Engineers of the West Subcommittee on Assessment. This subcommittee has representatives from eight of the nine schools that received funding through Engineering Schools of the West Initiative. The purpose of the database is to provide a tool to collect and analyze information across the nine Engineering Schools of the West

universities. The database contains information in the following categories: Programs, Participants, Partners and Students. The focus of the current investigation is on the information that has been collected through this database that describes the Humanitarian Engineering program at CSM.

Data collected through this database is in both qualitative and quantitative forms. In other words, some of the information is in numerical tables and other is qualitative descriptions. Given that the database was still in its developmental stages at the time of this analysis, queries could not be completed either within or across institutions. Therefore, for the purposes of this paper, data were transferred to either Excel spreadsheets or Word documents for analysis purposes.

Humanitarian Engineering website

The Humanitarian Engineering Program seeks to increase engineering students and faculty awareness of the impact that engineering can have on the global community and of the career options that are available in humanitarian engineering. This is done, in part, through curriculum development. As part of this initiative, a website has been constructed and this website is designed with the purpose of attracting students to and guiding them through the Humanitarian Engineering curriculum. This website [31] includes detailed information concerning the resultant courses and programs.

Document analysis

CSM's Registrar's Office maintains documentation of student enrollment across the institution and within its programs. Each year, the Registrar's Office produces a campus report. In order to confirm the enrollment data reported through the Engineers of the West Database, the 2004, 2005 and 2006 Registrar's Reports were examined [33–35]. Additionally, the Humanitarian Engineering program maintains its own documentation of students who have enrolled in the minors and of course syllabi that have been created through this initiative. The Humanitarian Engineering program also submits a report to the William and Flora Hewlett Foundation each year and a variety of papers have been published concerning the project's efforts. Each of these sources of data was reviewed for the purpose of this investigation.

Investigator confirmation

The first author of this paper is the evaluator for the Humanitarian Engineering grant at CSM. In this role, she has attended the majority of the team meetings for the Humanitarian Engineering project at CSM and has been an active participant in the Engineers of the West Subcommittee on Assessment. She has not, however, been a contributor to the curriculum development effort in the Humanitarian Engineering program, allowing her to make unbiased interpretations of the project results. Since her efforts have been in the form of a non-participant, third party, it is also important to acquire feedback on the interpretations of these results from the project investigators [36]. Therefore, the leaders of the Humanitarian Engineering program and a member of the curriculum development team are included as co-authors on this article. In this role, they have reviewed, discussed and responded to the results reported here and their feedback has been included in the interpretation of these data.

RESULTS

The results presented here summarize the major outcomes of the Humanitarian Engineering program for three academic years, 2003–2004, 2004–2005, and 2005–2006. As with any curricular effort, these sources continue to expand as the program progresses. This analysis captures a snapshot of the program during the first three years.

Participants

Twenty faculty members participated in this project as instructors, curriculum developers, student advisors or investigators. Fifteen are part of the Engineering Division at CSM; five are from the Liberal Arts and International Studies Division. Three graduate and three undergraduate engineering students have also been partially supported through this grant. Undergraduate students have further participated in this project through the completion of the courses and minors with a Humanitarian Engineering emphasis.

Program development

Four curricular initiatives have been undertaken as part of the Humanitarian Engineering program:

1. Redesign of a core, required course, Nature and Human Values.
2. Establishment of an Area of Special Interest in Humanitarian Engineering.
3. Establishment of a Minor in Humanitarian Studies and Technology.
4. Establishment of a Minor in Humanitarian Engineering.

The first initiative is the redesign of a core, required freshman course at CSM, Nature and Human Values. Through this redesign, a one week module has been added that addresses the roles of humanitarian engineers in society and the potential impact that humanitarian engineers may have on the developing world. This course is completed by all entering freshman, regardless of major. According to the Registrar's Report, there were 530, 605, 706, and 692, entering Freshman at CSM in the years, 2003, 2004, 2005, and 2006, respectively. In summary, this component of the project has already impacted more than 2500 students.

The second initiative is the development of an area of special interest in Humanitarian Engineer-

ing. Areas of special interest at CSM are designed to allow undergraduate students the opportunity to utilize elective courses to develop specialized knowledge in a discipline outside their major. Areas of special interest require 12 credit hours whereas minors require a minimum of 18 credit hours.

The third and fourth curricular initiatives are the establishment of minor programs. The first minor is in Humanitarian Studies and Technology and is offered to all majors across the CSM campus. This minor requires the completion of 18 credit hours in humanitarian engineering coursework. The second minor is in Humanitarian Engineering and is primarily offered to engineering majors. The distinction between the two minors results from the curricular differences between engineering and non-engineering majors. The Humanitarian Engineering minor has several courses that are also required of all engineering majors, Multidisciplinary Engineering Laboratories (a sequence of required engineering measurement laboratories) and Senior Design (a two semester course sequence). These courses account for nine credit hours of the 27 credit hour minor and they are already completed by engineering majors. Therefore, to complete the Humanitarian Engineering minor, engineering majors must complete an additional 18 credit hours beyond the requirements of their major whereas other majors must complete an additional 27 credit hours.

The Multidisciplinary Engineering Laboratories requirement accounts for three credit hours and is included as a requirement for the minor because it is a pre-requisite for Senior Design. Senior Design is a six credit hour course completed in the students' last semester of study. As part of Senior Design, students complete a capstone design project. Students who take the Minor in Humanitarian Engineering complete a senior design project that has a humanitarian emphasis, i.e. a project that addresses the water, food, shelter or educational needs of a disadvantaged community. Examples of these projects are provided later in this paper.

To guide the development of the curriculum and assessment, student learning outcomes were developed for the Humanitarian Engineering program. These outcomes appeared in a prior publication [37] and are listed here.

Nature and Human Values—All CSM students will be able to:

1. explain how engineering solutions can be used to support the basic human needs of the world's population;
2. explain how engineering solutions are impacted by the surrounding economic, environmental and societal context; and
3. explain how engineering solutions may impact the global society.

Area of Special Interest—CSM students who complete the Humanitarian Engineering Area of Special Interest will additionally be able to:

4. explain how culture and political philosophies impact the appropriateness and sustainability of engineering solutions.

Humanitarian Studies and Technology Minor—CSM students who complete the Humanitarian Studies and Technology Minor will additionally be able to:

5. explain the influence that a given culture has had on the engineering solutions that are used in that culture (tracks: U.S.A., Asian, African and Middle East, Latin).

Humanitarian Engineering Minor—CSM students who complete the Humanitarian Engineering Minor will additionally:

6. design and implement an engineering solution that addresses the needs, from both a practical and cultural perspective, of a disadvantaged community.

The first three outcomes are consistent with ABET's criterion 3h and are initially addressed through a one week module as part of a required core course, Nature and Human Values. All students at CSM are expected to reach these outcomes. The remaining outcomes gradually progress students who are participating in the Humanitarian Engineering program to deeper levels of knowledge and understanding with respect to 3h. Students who participate at the more advanced levels of the program are expected to achieve all of the prior outcomes. For example, students who complete the Humanitarian Engineering Minor are expected to reach all six of the above defined outcomes and this is anticipated to support the attainment of ABET's criterion 3f.

As was previously mentioned, approximately 2500 undergraduate engineering students have already completed the required course, Nature and Human Values. Thus far, only two students have graduated with a Humanitarian Engineering Minor and an additional ten students are pursuing this minor. Both graduates of the program are female; eight of the ten current students are also female, a very high rate of participation by women given that the student population at CSM is only 23% female. No students thus far have elected to complete the Humanitarian Studies in Technology minor or the Area of Special Interest in Humanitarian Engineering. One of the graduates of the Humanitarian Engineering program is currently completing a Masters of Science in "Engineering in Developing Countries" in the Civil, Environmental and Architectural Engineering Department at the University of Colorado, Boulder. The other graduate is working as an environmental consultant at a local office of a multinational environmental engineering firm.

One of the graduates of the program had the following reflections on her experience:

> On a personal level, I was struck by the generosity and indefatigable spirit of the community residents—and by my own naiveté—assuming that poverty implies unhappiness. I realized that I had carried the misconception that people in poverty lead emotionally stunted lives because their energy is constantly focused on overcoming economic hardship. However, many residents of Colinas de Suiza do not consider themselves impoverished. While I perceived some people's scrap aluminum and cardboard dwellings to be shacks, these structures were homes—places to begin families and to nurture bonds as strong as those in my own family.
>
> On a professional level, I realized that I do have the potential to effect positive change in the world. It is not simply a matter of what I do, but also what I don't do. Now I study Building Systems Engineering and sustainable building design. My experience working in Central America has altered the way I approach engineering design challenges. I try to move through the process holistically, taking into account the cultural, social and economic differences that shape engineering practice . . .

Course development

By the conclusion of the 2005–2006 academic year, ten courses had been developed and implemented at CSM that include a Humanitarian Engineering component. Table 1 provides a summary of these courses. As this table indicates, five are offered through Liberal Arts and International Studies Division and five are offered through the Engineering Division. Eight of the ten courses are offered at a senior level; the remaining two are offered at a junior level. An additional nine courses are in the developmental phases. As has been discussed elsewhere [3, 4, 38], this curriculum has been created with the purpose of supporting students in obtaining global competency and ethical awareness in engineering.

Anecdotal evidence further supports that students' reactions to the humanitarian engineering courses have been positive. Many students indicated that participation in the course increased their general interests in humanitarian studies. One student explained her experiences in a newly designed course, Subsurface Groundwater

Table 1. Courses developed as a result of the Humanitarian Engineering Program

Division	Level	Course	Brief course description
Liberal Arts and International Studies	Junior	Engineering Cultures	Seeks to improve students' abilities to understand and assess engineering problems solving from different cultural, political, and historical perspectives.
		Political Philosophy and Engineering	Students' critically explore how engineering may be related to different philosophies of the common good.
	Senior ↓	Engineering Cultures for the Developing World	Seeks to improve students' understanding of engineering problem solving in the developing world through historical and cultural case studies.
		Technology and International Development	Students examine from a historical perspective the role of technology in humanitarian and social improvement projects
		Writing Proposals for a Better World	Students write funding proposals for Colorado-based nonprofit organizations (NPOs) that serve people across the globe. This includes researching the funding agency and the community in need.
Engineering		Practical Design of Small Renewable Energy Systems	Students examine practical topics related to the design of alternative energy sources, including hydropower, wind power, photovoltaic, gas, biomass and energy storage, and their use in a societal context.
		Service Learning	Students develop an appreciation of volunteerism and examine the impact of local cultures on grass root efforts. They also build a house as the final project during a week-long service trip.
		Subsurface Groundwater Mapping	Students investigate the physical properties of groundwater contaminants and surrounding media with an emphasis on applying these techniques in remote or economically disadvantaged areas.
		Timber and Masonry Design—Applications for Unconventional Materials	Students develop an understanding of the basic engineering properties of timber and masonry materials and become familiar with design methods and philosophies for timber and masonry structures. This is applied to the design and analysis of structures constructed with "unconventional" materials (adobe, timber pole, bamboo) such as those used in constructing structures in developing countries.
		Understanding Landslides	Introduces students to the occurrence of landslides, their worldwide distributions, their triggering mechanisms, their investigation and remediation, and their socioeconomic impacts.

Mapping, as follows, "This is one of the best classes I've had—an interdisciplinary, extremely hands-on course incorporating many different disciplines, geophysics, humanitarian engineering, civil engineering, and hydrology" [38].

Partners

The Humanitarian Engineering program has established partnerships with seven nonprofit, non-governmental organizations in the development of the Humanitarian Engineering curriculum. These are: Community Uplift Ministries [39], Engineers Without Borders [40], Engineers for a Better World [41], Global Hope [42], International Center for Appropriate and Sustainable Technology [43], Namlo International [44] and Sustainable Village [45]. A description of each organization is provided in Table 2.

Partnership relationships offer several benefits to the program. First, partnership organizations identify components of their projects that require engineering expertise and these components are converted to design projects that are completed by CSM engineering students. Second, during the design process, students have the opportunity to interact with employees of the partner organization. Through these relationships, members of the partnership organizations provide role models and professional contacts to the participating undergraduate engineers. Third, partners offer potential funds and/or labor to support humanitarian projects. Although the designs for humanitarian projects are developed as part of the Senior Design course, the implementation of these designs can occur in two ways: either CSM students or members of the nonprofit organization travel to the appropriate location and implement the proposed design. Occasionally, the partner organization has funds that may be used to support the participation of CSM undergraduate students in the projects' implementation.

Senior design projects

A major component of the Minor in Humanitarian Engineering is the completion of a capstone, engineering, humanitarian project, during the students' senior year. As of the 2005–2006 academic year, thirty-three projects with humanitarian components have been completed. Humanitarian projects are broadly defined here as those that address the needs of all people for water, food, shelter and education. At least six projects are offered through Senior Design during the fall semester and at least two in the spring semester. Six of the projects completed thus far have impacted the mathematics or science education received by students in disadvantaged K-12 schools in Colorado (K-12 is a common acronym in the U.S.A. which is used to refer to formal education that precedes college). Seventeen have improved the living conditions of people in countries outside the U.S.A. Four U.S.A. states and twelve nations have benefited from these efforts.

A summary of the projects, along with the location, is provided in Table 3. As this table suggests, 172 undergraduate students have directly participated in these projects, which have impacted four states and twelve countries. Fifty percent of the students who selected to complete humanitarian projects in Senior Design were female [46]. As was previously discussed, women comprise approximately 23% of the total population of undergraduate students at CSM.

There are concerns in the implementation of the Senior Design projects described above. First, the implementation of the projects by the Senior Design teams often requires travel to foreign locations. This comes with a cost. Second, in order for the Humanitarian Engineering project to continue, efforts are needed to curtail the costs or to acquire additional funding sources to support foreign and domestic travel. The sections that follow provide examples of the projects that have

Table 2. List of nonprofit, non-governmental partners

Organization	Description
Community Uplift Ministries	A non-denominational Colorado based ministry started by John K. Coors to provide clean, affordable energy to the rural regions of Africa [39]
Engineers without Borders	Nonprofit humanitarian organization, partners with developing communities worldwide to improve the quality of life [40]
Engineers for a Better World	CSM based organization designed to assist students in using engineering and technical skills to improve the world [41]
Global Hope	A Colorado based nonprofit corporation that provides support to the orphans of Romania [42]
International Center for Appropriate and Sustainable Technology	Seeks to provide technical and business solutions to support the sustainable growth of the international community [43]
Namlo International	Seeks to help people of developing countries help themselves through education and grassroots programs while providing an opportunity for US students to learn about global issues and experience the joy of helping others [44]
Sustainable Village	Colorado based company that consists mainly of volunteers which seeks to assist developing countries with sustainable solutions, such as renewable energy and appropriate technology [45]

Table 3. Senior design projects in humanitarian engineering

Semester	Project	Site	Students
Spring, 2003	Water Infrastructure	Lemraiveg, Mauritania	5
Fall, 2003	Arsenic/ Water Study	Conejos County, Colorado, U.S.A.	5
	Cedaredge Middle School Engineering Curriculum	Delta School District, Colorado, U.S.A.	4
	Solar-powered electrification of church, community center, and women's health clinic	San Pablo, Belize	5
	Onion Storage Facility	Rao, Senegal	4
	Biomass Usage	Colorado, USA	5
Spring, 2004	Orphanage Design	Arad, Romania	4
	LPG Distribution	Kitale, Kenya	5
	RoboWeekends	Colorado, USA	6
	Educational Project		
Fall, 2004	Centennial Elementary School Curriculum	Colorado, USA	5
	Drip Irrigation	Rao, Senegal	5
	Installation of a pump and piping	San Pablo, Belize	6
	Water and waste-water treatment	Colinas de Suiza, Honduras	7
	Water Filtration	Yarmasing, Nepal	3
Spring, 2005	Salvation Army—Bridge	Colorado, USA	4
	Village Lighting	Amazon Region, Ecuador	5
Fall, 2005	Cedaredge Middle School Learning Wall	Colorado, USA	5
	G&T Engineering Curriculum	Colorado, USA	6
	Gulkana RV Park Design	Alaska, USA	8
	Water System	Colinas de Suiza, Honduras	6
	Maranatha School	Mityana, Uganda	4
	3rd world wheel chair	Colorado, USA	4
Spring 2006	Hydro-electric Project	Ecuador	5
	Oglala Sioux Housing	South Dakota, USA	4
Fall, 2006	Middle School engineering learning stations	Colorado, USA	8
	Bicycle Irrigation System	Ghana	6
	Gulkana RV Park Design	Alaska, USA	7
	Water System	Colinas de Suiza, Honduras	8
	CURE—recycle medical supplies—testing facility design	Colorado, USA	4
	100-watt-hr. dwelling	Colorado, USA	5
Spring, 2007	Clay Bricks	Congo	4
	Hydro-electric Project	Ecuador	5
	Native American RV Park	Oklahoma, USA	5
Total	33		172

been implemented and describe how the above concerns are being addressed.

Example projects

All U.S.A. projects, and almost all international projects have involved travel by teams of students to project locations, and in some cases, several trips were required for completion. Local residents provided some materials and labor, assuring their commitment to the project goals. As with all Senior Design projects at CSM, the customers, in this case the local residents, had final approval of the design elements, methods and materials of the project.

Twelve Senior Design projects have been completed within the State of Colorado, U.S.A. Half of these have focused on the development of curricular or educational innovations in mathematics or science at the K-12 level. All K-12 outreach projects have been implemented in disadvantaged, high minority school districts, where students have had limited exposure to engineering concepts or to engineers. One project created miniaturized prototype-engineering devices, such as a scaled model water treatment facility, that could be used for engineering demonstrations and investigations in the K-12 classroom. Another project concentrated on the development of a curriculum that was appropriate for introducing fourth grade students to the scientific concepts of weather, land, water, skeletons, and electricity.

One school, Cedaredge Middle School, had two projects completed by engineering design students in the last two years. This school was named as a Gain-Maker School by the State of Colorado in mathematics for 2005 and for science in 2006 and 2007. Gain-Maker schools are those that display at least a twenty percent increase in average student performance over a three year period in a given subject area as measured by the Colorado Student

Assessment Program. Cedaredge Middle School attributes these accomplishments, in part, to the connections with the Humanitarian Engineering project.

Twenty-one Senior Design projects have had an impact beyond the borders of Colorado. For example, one on-going project is underway in Gulkana Village, Alaska. This project is designing an RV Park that includes: a Visitor's center, Park office and store, laundry facility, restrooms and showers, waste treatment system, electrical utilities, dump station, RV sites and hookups, recreation trails, and access roads. Student engineering teams are responsible for the development of the park's general layout and for the technical details of developing each facility.

A sequence of projects is also being completed to assist the farmers of Rao, Sengal. One such project was designing and constructing a facility that stored onion crops until the market demand is high, increasing the farmers' profits and thus, their income. Another project is the design of a drip irrigation system. Farmers in Rao have traditionally watered onions by hand, using a bucket. This is a very inefficient method and greatly limited a farmer's capability of raising and selling a large crop. As a result of the successful implementation of these projects, farmers in Rao have reported that they can now rotate their fields and grow additional crops, such as tomatoes, increasing their overall productivity. This was not an option prior to the implementation of the irrigation system.

The largest project that has been undertaken by the Humanitarian Engineering Program to date is being completed in Colinas de Suiza, Honduras. Colinas de Suiza is a rural village with a population of over 10 000. Prior to the start of this project, potable water was delivered to the village via truck. Although this water was of good quality at the well head, it became contaminated with bacteria through handling and the cost of truck delivery was prohibitive for many residents. The first phase of this project is to design and oversee the implementation of a potable water supply system. The second phase is the introduction of an eco-toilet system which will complete the local water cycle. Currently, the villagers use pit latrines and hope to move to flush toilets. However, there is not enough water available to transport the solids within the waste to a centralized waste treatment facility. The eco-toilet design allows the separation of urine from fecal matter in a manner that waste becomes a valuable commodity (fertilizer and soil conditioner). The third phase of this project is the establishment of a Center for Sustainable Living within the village that incorporates eco-toilets and a garden. This facility along with volunteer families who agree to try the eco-toilet will provide examples and a means of education to the surrounding community. Also, this facility will be used to house visiting faculty and students, thus establishing a long term relationship between the village and CSM. The enthusiasm for this idea by the village elders has been demonstrated through a donation of approximately 1000 m^2 of land as a site for the Center.

Costs

Typical expenses for projects completed in Latin America are approximately US$1300 per person per week. Students travel in teams of four or five and are accompanied by a faculty advisor who is compensated for both travel and salary. The students typically stay within the foreign country for about a week. Approximately 50 students and faculty have traveled to four different international project sites in eight separate trips, with a project expense of approximately US$8000 per trip. The overall travel expenditure for the past four years (which comprises three full fiscal years) is just over US$80 000. Of that amount, US$65 000 was spent on international travel and US$15 000 on domestic travel. The cost associated with travel to Africa is approximately US$2000 per person per week including airfare. In Africa, the students spent one to two weeks working onsite. Thirteen students traveled to Africa on three different trips, resulting in an overall project expense of US$24 000.

A major concern with foreign travel is student and faculty health. In all of the countries visited, general vaccination requirements included Hepatitis A and B, Typhoid, and an updated Tetanus booster. Some countries also require vaccines for Yellow Fever and tablets for Malaria. Addressing these health concerns adds to the overall expense of project implementation by approximately US$200–300 per student [47].

Equipment is another major expense of the program. Several Senior Design projects have involved providing a community with safe drinking water. To support these projects, two Trimble Pathfinder Pro XRS® receivers, which are Global Positioning Systems (GPS), have been purchased at a total expense of US$18 000. These receivers allow the student teams to map the villages accurately, allowing them to design the water systems in a manner that maximizes their efficiency and ensures equity of distribution. Other equipment is too expensive for the project to purchase and, therefore, must be rented or borrowed. For instance, a geophysical soil resistivity measurement system was borrowed and used to determine the aquifer subsurface homogeneity for the Honduras and Senegalese projects. This equipment, whether it is purchased, rented or borrowed, must also be shipped to and from the project locations, resulting in additional project expense.

Future funding needs

In order to curtail the above expenses, several actions have been taken. First, the number of trips to Africa has been reduced. Although there are many appropriate projects in Africa, there are also many in the U.S.A. and Latin America. Second,

greater efforts are being dedicated to the identification of projects that serve local needs, such as K-12 outreach and efforts on Native American Reservations. These projects require limited travel and greatly reduce project expenses.

The Humanitarian Engineering project leaders, however, do not wish to eliminate the international component of this project after the period of funding. This aspect of the project is unique and positively impacts the participating students' development of global understanding and ethical awareness. Given this, efforts are underway to acquire additional funding and these efforts have seen some success.

Support has been acquired from private and industrial donors in the amount of US$50 000. For one project, the Honduras project, a student team wrote and submitted a proposal to International Mondialogo Engineering Design Award [48] which resulted in US$19 000 in support. Efforts are also underway to include students from other universities in the implementation phase, dispersing the expense across a wider participant group. An overriding goal of the Humanitarian Engineering program is to maintain at least two foreign projects each year after the period of funding ends. This, along with the local expenses, will require funds in the amount of approximately US$50 000 each year.

Campus initiatives

Two campus initiatives are currently underway that are a direct extension of the Humanitarian Engineering project. The first is an expansion of the program to the graduate level. This project, "Enhancing Engineering Responsibility with Humanitarian Ethics: Theory and Practice of Humanitarian Ethics in Graduate Engineering Education," is funded by the National Science Foundation (NSF) (EEC-059777) and builds on concepts and practices of humanitarian engineering, extending these concepts to graduate-level seminars and engineering courses [49]. This project began in 2005 and concludes in 2008. By 2008, it is anticipated that a graduate level minor will be offered at CSM in Humanitarian Engineering Ethics through the Liberal Arts and International Studies Division. Formalizing this effort into a graduate level minor helps to ensure the sustainability of this project beyond the period of funding.

The second project, "National Science Foundation Scholarship Program: Retaining Students in Mathematics, Computer Science and Engineering," is also funded by NSF (DUE-0630888). This project provides scholarships to qualified individuals who are completing undergraduate or graduate minors in the humanitarian programs described above. Undergraduates who are pursuing a minor in Humanitarian Engineering may receive up to US$5000 and graduate students completing minors in Humanitarian Engineering Ethics may receive up to US$10 000 annually in scholarship funds. This is a four year project, which began in 2006 and continues until 2010. The intention of this project is to attract student attention to minors in Humanitarian Engineering or Humanitarian Engineering Ethics. By the conclusion of this project, it is hoped that the undergraduate and graduate level minors will be established to the point that they can be marketed in a manner that attracts future student participation without the motivation of scholarship funds.

Several other projects are also underway that complement the efforts of the Humanitarian Engineering program. For example, CSM participates in the NSF funded GK-12 Learning Partnerships and the Colorado Department of Education funded Physical Science in the Middle School Classroom. Both of these programs support graduate students who provide direct support in the K-12 mathematics and science classroom [50]. These outreach activities provide opportunities to the Humanitarian Engineering program to participate in additional projects that benefit the local K-12 community while the Humanitarian Engineering program provides K-12 classrooms with concrete examples of engineering efforts that serve the international community, potentially stimulating students interests in humanitarian efforts and engineering.

Another outcome of the Humanitarian Engineering program is the influence that it has had on the curriculum offered in other departments. As was previously discussed, the Liberal Arts and International Studies division is creating a graduate level minor in Humanitarian Engineering Ethics. Another effort is underway in the Mathematical and Computer Sciences department. Recognizing the appeal the humanitarian efforts have to students, especially female students, the Mathematical and Computer Sciences Department is investigating the possibility of including humanitarian components in its curriculum. Once established, these components of the curriculum will be used to recruit students to the major.

Beyond CSM

A great deal of interest with respect to this project is also evident beyond the CSM campus. For example, one of the principal investigators was invited to give a paper at the American Society for Engineering Education Global Colloquium in Rio de Janeiro, Brazil [51]. In the final day's seminar, "Humanitarian Engineering" was listed as one of four areas of interest. Presentations have also been made at the American Society for Engineering Education Service Learning Conference in Washington, DC, and the Universidad Simon Bolivar Student American Society of Mechanical Engineers Congress in Caracas, Venezuela. Future invited presentations are planned at Lafayette College, Pennsylvania, and San Diego, California, and one of the investigators is working with a Ph.D. candidate from Queens University in Kingston, Ontario who is seeking to establish a Humanitarian Engineering undergraduate degree within

his university. As these examples indicate, the investigative team for the Humanitarian Engineering program is acquiring national and international recognition for its humanitarian engineering efforts.

CONCLUSIONS

Thus far, the Humanitarian Engineering program at CSM has directly impacted approximately 172 students through Senior Design. Since Nature and Human Values is a required core course, the Humanitarian Engineering module that has been implemented in this course will have an on-going impact on the entire CSM undergraduate student population. To date, this includes over 2500 students. This impact is anticipated to increase through the continued offering of the curriculum as well as the expansion of this curriculum to other departments and to the graduate level. Furthermore, the establishment of the Area of Special Interest and the two minors in Humanitarian Engineering is a fundamental change in the CSM system. These are now formalized programs at CSM, allowing the use of university funds for their maintenance, improvement and sustainability. Interest by students has been witnessed through enrollment and completion of the Humanitarian Engineering minor. Efforts are currently needed to recruit student participation in the Humanitarian Studies and Technology Minor and the Area of Special Interest in Humanitarian Engineering.

The concept of including humanitarianism in the curriculum is not an isolated effort of the Engineering division. From its very conception, the Liberal Arts and International Studies division has participated in this endeavor. Furthermore, the Liberal Arts and International Studies division is currently developing courses at the graduate level for students interested in Humanitarian Ethics [49]. The Mathematical and Computer Sciences Department, a department that was not part of the original grant, is also investigating the use of humanitarian concepts to stimulate student interest in its undergraduate curriculum. The Mathematical and Computer Sciences Department's interest in humanitarian studies has primarily been motivated by the observation that the Humanitarian Engineering curriculum attracts strong participation by female students, a target recruitment population. Funds have further been acquired through the National Science Foundation to support scholarships for students who are interested in the undergraduate or graduate level humanitarian programs. The expansions of the ideas developed as part of the Humanitarian Engineering Program suggest a cultural shift at CSM. Humanitarianism is becoming a core component of several major programs.

Beyond the CSM campus, the projects that undergraduate students have completed have impacted the lives of people residing in twelve nations and four U.S.A. states. These projects have improved the water quality, living conditions and education of these people. A large number of K-12 students have also benefited from these efforts through exposure to engineering curricula in their mathematics and science classrooms. These efforts are expected to continue through K-12 outreach activities at the CSM, such as the GK-12 Learning Partnerships and the Physical Science in the Middle School Classroom projects. Although the long term impact of these efforts on K-12, undergraduate and graduate students' career and educational aspirations cannot be measured, we would anticipate that increased exposure to engineering at a young age will increase future student interest and participation in the field.

A major challenge to the sustainability of this program is the travel that has been undertaken to implement projects outside the USA. As was discussed, to maintain this effort at a minimal level, on-going funds of approximately US$50 000 per year are needed. Toward this goal, funding from private and industrial donors has been obtained and this is expected to increase in the future. A systematic fundraising effort is being pursued. Additionally, the Humanitarian Engineering program has established collaborative relationships with several nonprofit, non-government organizations. Through these relationships, CSM students can continue to contribute to the design of projects, while the implementation process may be left to the nonprofit organizations.

In response to the research questions presented at the start of this article, the Humanitarian Engineering Program at CSM has had a broad impact on the local, national and international community. Both students (K-12, undergraduate, and graduate) and society have benefited from these efforts. For example, with the Drip Irrigation Project completed in Rao, Senegal, the farmers report that they can now rotate their fields and grow additional crops that they were unable to previously plant, increasing profit. The Humanitarian Engineering Program is further changing the way that students of engineering and of other disciplines are being educated at CSM. Across campus, there has been a documented increase in the curricular emphasis that is being placed on humanitarian and global concepts. Furthermore, female students select to participate in humanitarian engineering projects at a greater rate than do men. This has the potential of increasing the appeal of engineering to this subpopulation. Finally, the members of the Humanitarian Engineering team have received recognition in this area through invited presentations and papers, increasing the impact of this project to other institutions.

The sustainability of the Humanitarian Engineering Program at CSM is also promising. By establishing this program as part of the formal course offerings, the institution is responsible for

the maintenance of the Humanitarian Engineering curriculum. The only component of the program that is at risk at the conclusion of the period of funding is the travel to countries outside the U.S.A. to implement the engineering design. However, collaboration with nonprofit organizations has helped to ensure that although CSM students may not be the individuals to implement the designs, they will continue to have opportunities to develop these designs. Efforts are also underway to acquire additional support for international travel.

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Barbara M. Moskal received her Ed.D. in Mathematics Education with a minor in Quantitative Research Methodology and her M.A. in Mathematics from the University of Pittsburgh. She is an Associate Professor in the Mathematical and Computer Sciences at the Colorado School of Mines. Her research interests include student assessment, K-12 outreach and equity issues. In 2000, she received a New Faculty Fellowship at the Frontiers in Education Conference and in 2006, she received the William Elgin Wickenden Award with her colleagues, Barbara Olds and Ronald Miller.

Catherine K. Skokan is Associate Professor in the Division of Engineering at the Colorado School of Mines. She received her Ph.D. in Geophysical Engineering with a minor in Geology and her MSc in Geophysical Engineering from the Colorado School of Mines. Her research interests include near surface geophysical measurements especially in the area of groundwater mapping, humanitarian engineering, and educational outreach. She has taught Electrical Geophysical Exploration classes, circuits, digital data analysis, linear systems, and Senior Design.

David R. Muñoz is an Associate Professor in the Engineering Division at the Colorado School of Mines. He earned his Ph.D. and MS Mechanical Engineering degrees from Purdue University, and his BS in Mechanical Engineering from the University of New Mexico. He spent a sabbatical year as a Visiting Professor to Monterrey Tech. in Monterrey, Mexico. Dr. Muñoz has taught several thermo-fluid science and design courses. He served as Interim Director of the Engineering Division, 2003–2006, and is currently directing the Humanitarian Engineering minor program at CSM.

Joan Gosink is an Emerita Professor and former Director of the Engineering Division at the Colorado School of Mines. Under her direction, the Division received various accolades, including designation as a Program of Excellence from the Colorado Commission on Higher Education. The program also expanded to include Masters and Doctorate degrees and an undergraduate specialty in environmental engineering. Dr. Gosink twice served as a Program Director at NSF.