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ORIGINAL PAPER

Educating the Humanitarian Engineer

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Abstract The creation of new technologies that serve humanity holds the potential to help end global poverty. Unfortunately, relatively little is done in engineering education to support engineers' humanitarian efforts. Here, various strategies are introduced to augment the teaching of engineering ethics with the goal of encouraging engineers to serve as effective volunteers for community service. First, codes of ethics, moral frameworks, and comparative analysis of professional service standards lay the foundation for expectations for voluntary service in the engineering profession. Second, standard coverage of global issues in engineering ethics educates humanitarian engineers about aspects of the community that influence technical design constraints encountered in practice. Sample assignments on volunteerism are provided, including a prototypical design problem that integrates community constraints into a technical design problem in a novel way. Third, it is shown how extracurricular engineering organizations can provide a theory-practice approach to education in volunteerism. Sample completed projects are described for both undergraduates and graduate students. The student organization approach is contrasted with the service-learning approach. Finally, long-term goals for establishing better infrastructure are identified for educating the humanitarian engineer in the university, and supporting life-long activities of humanitarian engineers.

Keywords Engineering ethics education · Volunteerism · Humanitarian · Service-learning · Community design projects

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Introduction

Professionalism and service are intimately coupled. It is impossible to be a true professional without service. Definitions of a "professional" typically include a requirement for "public service," as do many codes of ethics (Martin and Schinzinger 2005b). Professions such as law and medicine require or encourage "*pro bono*" (unpaid, voluntary) public service as part of the conduct of professional duties, and this service is often partially supported by law firms or hospitals. Although exposure to service initiatives often starts during medical or law school, there are few comparable university educational experiences in engineering, as well as a *perceived* lack of a pervasive voluntary service spirit in the engineering profession, and insufficient infrastructure to support engineering volunteerism.

To address this problem, it is first proposed that aspects of existing engineering ethics and professionalism education be augmented to include education that will increase volunteerism among engineers. Second, it is proposed that a student organization focusing on engineering volunteerism can provide hands-on opportunities for *pro bono* work (perhaps via consolidating or augmenting existing volunteer projects in other engineering student organizations). Experience shows that these activities provide significant motivation, know-how built on idealism, and a strengthened spirit of volunteerism in new engineering graduates.

In "Expanding ethics and professionalism to provide educational foundations for volunteerism" section it is explained how to expand a variety of topics in ethics and professionalism beyond the treatment in standard texts (Bowyer 2001; Forester and Morrison 1992; Harris et al. 2005; Johnson 1991; Martin and Schinzinger 2005; Quinn 2004; Unger 1994; Vesilind and Gunn 1998) to support engineering volunteerism. Sample homework assignments are provided. In "Hands-on volunteerism via a student organization" section the idea of conducting hands-on volunteerism projects through a student organization is discussed. Taken together with "Expanding ethics and professionalism to provide educational foundations for volunteerism" section, a "theory-practice" approach is advocated for educating an engineer in volunteerism and project ideas and examples are provided. This approach is critiqued and compared to the service-learning approach with "for credit" (strictly speaking, non-volunteerism) community-oriented design projects (Oakes 2004; Tsang 2000). In "Engineering volunteerism infrastructure" section a vision for a comprehensive educational program on engineering volunteerism is provided, and needs for infrastructure to support university-based and career-long engineering volunteerism are highlighted.

Similar work by Michael Pritchard highlights the relationship between ethics, service-learning, and aspects of volunteerism (Pritchard 2000). The present work provides specific educational strategies and examples to support Pritchard's ideas, along with a broad vision for education and support for the engineer engaging in volunteerism. This paper is also consistent with Pritchard's view that it is important to focus on "good behavior," character, and imagination in teaching ethics (e.g., examples of exemplary behavior of individuals) (Pritchard 1998, 2001).

Teaching volunteerism in the university is facilitated by the ease with which students can be engaged in its ideals and objectives. The rationale for providing volunteerism within existing ethics and professionalism courses is two fold: the close parallel to the topics being taught in these courses as part of the Accreditation Board for Engineering and Technology (aka ABET, Inc) requirements, and the desire to avoid the introduction of an additional course in a generally over-stuffed curriculum. In some universities, other courses may provide a basis for engineering volunteerism (e.g., courses on science, technology, and society), but these are most often not required, and hence do not form a broadly consistent basis for wide-spread teaching strategies for engineering volunteerism.

It is hoped that encouraging *pro bono* practice as part of engineering education will open another direct path for engineers to positively affect or have a positive impact on the welfare of the public (e.g., augment or highlight a path currently taken by many engineers in providing community service in the form of tutoring, speaking in high schools, etc.). It should be possible to produce more volunteers, more effective volunteers, improved benefits to communities, more and improved corporate citizenship programs, other volunteerism infrastructure developments to facilitate voluntary provision of services, and more engineers speaking out on technological policy issues that have an impact on society. The combination of such benefits will ultimately lead to advancement in the level of professionalism in engineering, improvement in the public image of engineers, and a corresponding projected benefit of attracting talented people to our field who want to directly help others.

Expanding Ethics and Professionalism to Provide Educational Foundations for Volunteerism

The main theoretical support for engineering volunteerism is found in the call for ethical and professional responsibility of engineers. There are excellent textbooks on these topics (see, e.g., Martin and Schinzinger 2005; Harris et al. 2005; Unger 1994; Johnson 1991; for a computer ethics focus see Forester and Morrison (1992), Bowyer (2001), Quinn (2004); and for an environmental focus see Vesilind and Gunn (1998)). Here, it is explained how to augment this material to provide foundations for engineering volunteerism. Each proposed approach or activity below is fully consistent with the ABET 2004 criteria for what engineers should know. Particularly relevant to this paper are some elements of Criterion 3, Program Outcomes and Assessment ("an understanding of professional and ethical responsibility, the broad education necessary to understand the impact of engineering solutions in a global and societal context, and a knowledge of contemporary issues") and Criterion 4, Professional Component ("[d]esign experience to include most of the following: economic; environmental; sustainability; manufacturability; ethical; health and safety; social; and political").

These criteria have led engineering programs to incorporate design experiences, along with ethics and professionalism, into their curricula in a number of ways (e.g., spread across the curriculum or concentrated in a course or course sequence). The educational strategies in this paper that encourage volunteerism provide further support for achievement of each of these ABET criteria.

Professionalism and Public Service

Webster's Third New International Dictionary (Merriam Co., 1966) defines a "profession" as: "A calling requiring specialized knowledge and often long and intensive preparation including instruction in skills and methods as well as in the scientific, historical, or scholarly principles underlying such skills and methods, maintaining by force of organization or concerted opinion high standards of achievement and conduct, and committing its members to continued study and to *a kind of work which has for its prime purpose the rendering of a public service*" [italics added]. The American Society of Civil Engineers (ASCE) says that "A profession is the pursuit of a learned art *in the spirit of public service*" [italics added] (ASCE 2009a). The Engineer's Council for Professional Development (ECPD) says of one who practices a profession:

> (i) They must have a service motive, sharing their advances in knowledge, guarding their professional integrity and ideals, and *rendering gratuitous public service in addition to that engaged by clients.* (ii) They must recognize their obligations to society and to other practitioners by living up to established and accepted codes of conduct. (iii) They must assume relations of confidence and accept individual responsibility. (iv) They should be members of professional groups and they should carry their part of the responsibility of advancing professional knowledge, ideals, and practice. (ECPD 1948) [italics added]

Reconsidering the above italicized statements one might wonder about the meaning of the term "public service". Broadly speaking, there are *two* routes to public service for engineers. The first is service via employment and to the professions. In this case, engineers employed at corporations, universities, small companies, or in consulting must, according to ABET, "hold paramount the safety, health, and welfare of the public in performance of their professional duties" (ABET 2009). From this, it is implied that with the knowledge of how to develop technologies, comes the responsibility to protect the public from dangers associated with technology and in this sense they provide the public an important service. Of course, some activities could be above and beyond the call of duty to the employer, fall in the category of "generous" professional behavior (Martin and Schinzinger 2005, p. 67), or "good works" (Harris et al. 2005; Pritchard 1998), and hence constitute an especially admirable form of public service. Service to engineering professional societies and the professions in general constitutes another type of important service, even though in some cases it may have a less direct impact on the public.

The second form of engineering service is voluntary community service. In this case, engineers can provide voluntary professional services for their local community and beyond. These are "good works" (Harris et al. 2005; Pritchard 1998) that are unpaid, and typically "generous" professional service (see Martin and Schinzinger 2005, p. 67; Harris et al. 2005). As technology grows in importance and is further integrated into every aspect of our lives, it becomes increasingly common for communities to require engineers' skills to meet their needs. Moreover, there is likely to be an increased need for engineers to voluntarily speak out on complex technological matters that affect the health and welfare of the public.

Both routes to public service can be supported by companies via responsible technology development, support for the engineering professional societies, and corporate citizenship programs (see "Concluding remarks" section).

Codes of Ethics, Comparative Professionalism, and Volunteer Service

Each major engineering organization has a code of ethics. The critique of such codes is a useful educational exercise in teaching engineering professionalism. The codes differ with respect to the strength of statements on voluntary public service, and several have no such statement. Five forms of classroom discussion on how codes and professionalism relate to volunteer service are quite useful in a course on engineering ethics.

First, it is important to clarify the role of the codes. Codes of ethics seek to serve and protect the public, support engineers' good conduct, and inspire the engineer, among other objectives (see Martin and Schinzinger 2005, pp. 44–51; Unger 1994). Moreover, they can have an impact on a profession's image. The codes are, however, limited; they cannot be so detailed that they can cover every eventuality, which leaves them somewhat vague and hence not always useful in every-day ethical decision making.

Second, the role of service in the codes should be identified. Does the code of a particular profession address both routes to public service discussed above? If so, then discuss why it is good that both are addressed using the arguments given below. If not, then it is helpful to conduct a discussion on why voluntary public service, for example, should be explicit in the code. In this respect, the following points could be addressed: (1) what the standards should be for the professional engineer. (2) The code of the National Society of Professional Engineers (NSPE), states "Professional Obligations, "Engineers shall seek opportunities to participate in civic affairs; career guidance for youths; and work for the advancement of the safety, health, and well-being of their community" (NSPE 2010; Martin and Schinzinger 2005, pp. 300–306). In a sense, this is *the* governing code for all professional engineers, and its authority certainly has significance for every engineer. Since it is natural for engineers to pay attention to the code of their subfield, it is good to compare and contrast such codes with the NSPE code. For instance, it is useful to consider other codes such as that of the ASCE that fully integrate the encouragement of voluntary public service. The American Society of Civil Engineers, under Canon 1(e) of the ASCE code states "Engineers should seek opportunities to be of constructive service in civic affairs and work for the advancement of the safety, health and well-being of their communities, …" (see ASCE 2009b; Martin and Schinzinger 2005, pp. 318–325). The Software Engineering Code of Ethics and Professional Practice (Association. for Computing Machinery (ACM) and Institute of Electrical and Electronics Engineers (IEEE) Computer Society) states under "Principle 1: Public" that "… software engineers shall as appropriate:" "…1.08. Be encouraged to volunteer professional skills to good causes and contribute to public education concerning the discipline" (IEEE/ACM 2009). It can also be useful to consider codes that do not have a clear statement encouraging voluntary public service, or no statement at all (e.g., the current IEEE, American Society of Mechanical Engineers (ASME), or American Inst. Of Chemical Engineers (AIChE) codes, as seen in Martin and Schinzinger (2005, pp. 300–325)).

Third, it is worthwhile and valuable to engage in a discussion of comparative professionalism. For this topic it is effective to discuss (i) the public's perception of the level of professionalism for different occupations; (ii) the impact of events on that perception (Martin and Schinzinger 2005; Harris et al. 2005); (iii) cultural differences in such perceptions (e.g., increased relative respect for engineers in some other countries) (Christiansen 1987); and (iv) for the U.S. it is particularly helpful to compare the public's perceptions of the level of engineering professionalism to that of lawyers and medical doctors. In this respect, a key point is that these professions have a long tradition of voluntary public service. For medical doctors, the American Medical Association (AMA) document on Principles of Medical Ethics (June 2001 version) states in Section VII "A physician shall recognize a responsibility to participate in activities contributing to the improvement of the community and the betterment of public health" (AMA 2001). These ideals are implemented by many organizations (e.g., "Doctors Without Borders"). For lawyers, the American Bar Association (ABA) document on Model Rules of Professional Conduct (2003 version) states in Rule 6.1: Voluntary Pro Bono Publico Service that "… Every lawyer has a professional responsibility to provide legal services to those unable to pay. A lawyer should aspire to render at least (50) hours of pro bono publico legal services per year" (ABA 2002). Following the comparative analysis of professionalism and volunteerism for doctors and lawyers it is useful to (i) ask students if they think that perceptions of these professions are influenced by doctors' and lawyers' commitment to voluntary public service; (ii) discuss public perceptions of doctors and lawyers and how public service has an impact on these perceptions; (iii) discuss whether the public's view of engineers would improve if the engineering profession had a similar spirit of voluntary engineering service. To make such a discussion more concrete it can be pointed out that it is the "direct contact" (i.e., professionals and clients meeting face to face) nature of medicine and law that leads to respect (or disrespect) for those professions. Then, the students can be asked to consider whether engineering is slowly becoming a direct contact profession. Compelling examples of how engineers can make significant and direct impact via volunteer activities include the importance of access to and understanding of digital technology (a key determinant of wealth and opportunity), and water quality (a key determinant of health).

Fourth, there should be a discussion of the roles of codes in the development of the profession and volunteerism. Taking into consideration the limitations of the codes, many still feel strongly that the ideals of a profession must be prominently stated. Service ideals can inspire engineers and companies in their pursuits of volunteerism for community service. Ultimately, a true spirit of volunteerism will certainly lead to the development of the profession, and it is largely the responsibility of the university to lead the development of the profession via education of engineers (Lynch 2003a, b).

Fifth, in order to promote critical thinking about the profession and the directions in which it will develop, it may be useful to encourage students to think about whether to propose changes to the code of ethics of their profession. For example, a recent proposal was made to the IEEE that they update their Code of Ethics to include a clear statement that "encourages" voluntary community service since they have no such statement in the most recent revision of their code. Experience shows that a classroom discussion on such a proposal is lively, helps students feel invested in the future of their profession, and helps raise awareness about what it means to gain the personal responsibilities of becoming a professional (i.e., moral autonomy).

Moral Frameworks for Support of Volunteerism

Utilitarianism, rights ethics, duty ethics, and virtue ethics form the foundation for codes of ethics and standards of conduct for engineering professionals (Martin and Schinzinger 2005). To a certain extent, such moral frameworks support engineering volunteerism in the sense that they support public service and activities promoting the common good in the broadest terms (Schlossberger 1997), hence the two routes to engineering public service outlined above. Specifically, utilitarianism supports engineers' development of technologies to improve the general safety, health, and welfare of the public. Rights, and corresponding duties, such as those defined in the United Nations Universal Declaration on Human Rights or elsewhere (Martin and Schinzinger 2005, pp. 249–251), state that engineers have the duty to help support the rights of individuals to technologies insofar as they help meet basic needs. Virtue ethics focuses on competence, honesty, loyalty, etc., and has had a tangible impact on existing engineering codes of ethics. In the virtue ethics moral framework, and under public-spirited virtues, the "generosity" ideal specifically encourages service to the community (Martin and Schinzinger 2005).

The most firm support, however, for engineering volunteerism seems to come from the community-oriented version of self-realization ethics (Martin and Schinzinger 2005) that promotes the achievement of professional behavior via a combination of workplace and community service activities. This view does not *require* a continual, life-long, and significant time commitment to community service. Indeed, an engineer's commitment to the community certainly should not adversely impact workplace responsibilities. Self-realization could be achieved with a firm commitment to the development of competence, loyalty, professionalism in the workplace, and occasional community service *if* it is possible (e.g., considering personal health and personal commitments to family). Community-oriented self-realization does, however, affirm the value of encouraging the integration of an engineer's personal and business life. It recognizes inherent human self-interest tendencies, but also acknowledges that there is often a desire by individual engineers to "give back" to the community. This desire can be especially strong among some students who seek out ways to use their new-found engineering skills in community service. There are also many established practicing engineers who feel a similar desire, and feel that acting on these desires will lead to an integration of their personal convictions and their professional life. Such persons who achieve an integration of their personal and professional lives often increase their personal commitment to their employer, particularly if that employer supports their activities formally via a corporate citizenship program, or informally, with a "pat on the back." An engineer who engages in voluntarism is encouraged to behave with integrity and this typically affects professional behavior and loyalty in the workplace, which can, in turn, increase company profits (e.g., these engineers may make extra effort for the company). Often, if the company supports an engineer's deepest commitments in life, the engineer will develop a pattern of life-long professionalism that will have a positive impact on the company in many ways. Engineering education should show students and corporations all possible paths to professionalism, and how these paths can be simultaneously profitable for companies and communities.

Global Issues for Humanitarian Engineers

Technological problems of communities around the world present a number of design constraints, ones that are not typically encountered in university laboratory projects, and that require attention to a number of aspects of ethics and professionalism that are typically grouped under "global issues" (Martin and Schinzinger 2005; Harris et al. 2005). It is important that students of volunteerism have a theoretical background to conceptualize these constraints so that they can be effectively recognized and accommodated in their technical design process. Just like engineering ethical dilemmas have been profitably viewed as design problems (Martin and Schinzinger 2005, pp. 41–43; Whitbeck 1998), here community needs and constraints can be viewed as design challenges. Not only are such constraints discussed in ethics and professionalism (Martin and Schinzinger 2005; Harris et al. 2005), but also in service-learning for community-oriented design projects (Oakes 2004; Tsang 2000).

A key challenge for an engineer who engages in voluntarism is the development of appropriate technology and technology transfer (Martin and Schinzinger 2005, pp. 244–249). Transfer of a technology to a community is a complicated process. There is a range of questions under the topic of community needs: What are the most pressing technological needs? Do resources and skills allow the team to meet these needs? Does the community really want the technology? What is the priority of deploying the new technology? Is a new technology needed, or is it more important and appropriate to educate the community on how to use existing technology (e.g., computer software)? In addition, there are several questions about the range and types of impact: What is the impact of the technology on the community? Will it improve the overall economic situation? Who will win and who will lose due to the addition of the technology? Will it support undesirable power relationships in the community? Will it encourage dependency, or empower individuals to advance themselves? There are also issues related to technology maintenance and improvement: Is the technological advancement too large? Is the community able to use the envisioned technology or is it too advanced for some (or all) members of the community? Does there need to be an associated technology education program? Would a modest advancement be more appropriate, followed later by a more aggressive improvement? Can the local community independently maintain and periodically improve the technology so that long-term goals can be realized? Can the community take on responsibility for its own technological education needs? Given that students graduate and continuity of service can be difficult, can a good “exit strategy” be designed so that continual community service is not needed and the community develops autonomously? There can be several questions related to human safety and the environment: Are there safety concerns for the deployed technology? How are these communicated to the community? Will they understand and adhere to safety procedures? What is the impact of the technology on the environment? Will the community be concerned about environmental impact? Can environmental standards be respected and maintained? Are the technological experts present in the community capable of recognizing new safety or environmental problems that may arise long after deployment? Is there a long-term organizational structure in place to address these concerns? Finally, there are issues associated with the challenges of delivering useful technology at low cost: Is the cost of the technology in line with what is achievable by a broad range of persons in the community? What is the cost of maintenance? Of technological improvements? Of attention to safety and the environment? How are these costs balanced against competing needs? Such challenges are faced by most engineers in their normal duties; they are clearly also important for the humanitarian engineer.

Next, in a broader context, an overarching challenge to all engineers (not just the humanitarian engineer) is learning about cultural differences and the effects of globalization. There is typically a cultural and socioeconomic gap between the engineer and the community that is served. It is important for the student to recognize the existence of such gaps, and try to understand how they impact a technological design. This leads to a better understanding of the process of economic and technological globalization and its impact on the profession of engineering, a critical contemporary issue for engineers.

Language and cultural divides can create problems and significant design challenges for the engineer (e.g., for education and cooperative technology development). Other cultures often have very different views of technology and the value of technological advancement. For example, technology might not be highly-valued because technological training and expertise may entice individuals in one community to pursue employment in other cities or countries rather than their own community, thereby leading to “brain-drain”. Technology can potentially adversely impact culture. Further, companies, especially large multinational corporations who are often the creators and manufacturers of high technology, may be demonized or idealized inappropriately, that is, they may be viewed as “exploiters”, “saviors”, or “good citizens”. For this reason it is important to ask: What are the dominant views? With what will the local people associate the engineering/volunteer team in performing community service?

Not surprisingly, there is also a significant difference in priorities between the engineer who is volunteering and the local individuals being served, who sometimes work hand-in-hand with the volunteer. In the U.S. there is typically a practical focus on completing projects efficiently. This can seem very insensitive in some international communities because some cultures place a higher value on developing interpersonal relationships and focus on the process of completing technological projects, rather than focusing too strongly or entirely on project completion. Such relationships build trust, and sometimes are the key to long-term success of a community service project (e.g., to get the community to "buy into the project").

Finally, for an engineer to be an effective volunteer, local talent must be recognized and used. In fact, if it is at all possible, it is very important to involve local people from the community in the service project. For an international project, it may be natural to get local engineers involved, or a local engineering university. Completion of a project with engineers (or students) from the local community is a valuable experience for U.S. engineering students as it helps to develop respect for other cultures, to highlight international competition in the development and deployment of technology, and to raise awareness of the impact of globalization both on technology and on engineers.

Sample Assignments on Volunteerism for an Ethics and Professionalism Class

As part of the regular treatment of engineering ethics and professionalism it is important to give assignments that consider, examine, explore, and promote engineering volunteerism, even if such assignments are entirely "paper studies." A valuable educational experience can be obtained through the study of cases of engineering volunteerism in action such as those described at the web sites of volunteer student organizations in "Hands-on volunteerism via a student organization" section below, or cases in the textbook *Engineering Ethics: Concepts and Cases* by Harris et al. (2005—see especially Cases 6, 11, 42, and 49; see also Pritchard 1998). Appendix A provides a sample design project "proposal" that is suitable for an ethics and professionalism course as a "paper-only" project. Two similar sample assignments are available for a course entitled "Professional Aspects of Electrical and Computer Engineering" (ECE 481) (see http://www.ece.osu.edu/~passino/ee481.html).

A number of research papers could be assigned in a course on engineering ethics and professionalism with a view toward supporting engineering volunteerism. First, the students can be asked to assess the quality of existing corporate citizenship programs, listing the characteristics of the programs and evaluating their effectiveness with regard to (i) reach (e.g., number of persons affected/influenced), (ii) type of impact (e.g., on the economy or health of communities), (iii) level of involvement of engineers and others at the company, and (iv) the extent to which the existence of a corporate citizenship program supports the business objectives of the company (including profits). Examples of companies that students could consider include, among others, Texas Instruments, Hewlett-Packard, General Motors, Exxon-Mobile, and Microsoft. Students could be asked to design what they consider to be a "model" corporate citizenship program by integrating the best practices of many companies. They could be challenged to design such programs for small, medium, and large companies.

In a second research paper, students could be asked to research and then provide a survey of current volunteerism projects that clearly require engineering skills. This should include a survey of activities by national organizations like the Peace Corps and Habitat for Humanity, as well as student organizations like Engineers Without Borders, Engineers for a Sustainable World, Engineering Projects in Community Service, and Engineering World Health (Engineers for Community Service (ECOS), a student organization at the College of Engineering at Ohio State University, can provide detailed information on projects, participants, and related activities as well as links to web sites for all these organizations. See: http://ecos.osu.edu/). Students should be asked to assess the level of engineering skills needed for each project, and to highlight projects that clearly demand new technology and advanced research and development.

For a third research paper, the students could be asked to more fully develop the analysis and critique of codes of ethics of a wide array of professions and develop recommendations for how community service should be included. Should community service be required or only encouraged? How many hours? Have the students consider law, medicine, nursing, psychology, business, engineering, science, and others. Students could be required to develop and conduct a survey of other engineering students regarding the level of acceptance of strong statements that require volunteerism versus weak statements that only encourage volunteerism, or no statements at all.

Other similar projects or papers can be designed. For instance, projects could be designed to focus on the impact of technology on society (Hickman 1990) or cultural differences in engineering practice (Christiansen 1987), as they relate to volunteerism.

Hands-on Volunteerism via a Student Organization

However beneficial, paper-only assignments fall short of providing hands-on experiences in engineering volunteerism. Although team technology projects in the university provide opportunities for leadership and management experience, most often there is no clear customer (other than, perhaps, the professor) or team of customers that will help with a project and maintain the technology. Moreover, in a university it is rarely possible to provide tangible experiences to teach about technology transfer, appropriate technology, cultural interchange, globalization's impact on engineering, and other community design constraints (see "Global issues for humanitarian engineers" section). However student organizations offer/can provide tangible educational experiences in engineering volunteerism.

Student Organization: Engineers for Community Service

In Autumn 2003, two meetings between myself and a group of students following an Ohio State University engineering course, "Professional Aspects of Electrical and Computer Engineering" (see http://www.ece.osu.edu/~passino/ee481.html) resulted in formation of a student organization with a community service focus. The group initially investigated whether to become a student chapter of one of two organizations already in existence, Engineers Without Borders (EWB): http://www.ewb-usa.org/ or Engineers for a Sustainable World (ESW): http://www.esustainableworld.org/. At the time of the evaluation these were both found to be highly focused on civil engineering projects, with little attention to, for example, electrical and computer engineering. To ensure inclusiveness across engineering disciplines, a separate organization was created, called "Engineers for Community Service" (ECOS). It was a college-wide effort with a range of projects that could reach out to all types of engineers. The possibility was left open for subgroups within ECOS to team with other organizations.[1]

In addition, ECOS officially became an OSU student organization with a faculty advisor (the author) and a faculty and staff advisory board, and adopted the following mission statement:

> Mission Statement: Engineers for Community Service (ECOS), a student organization at The Ohio State University, promotes life-long professionalism via educational experiences in the uses of engineering skills for local and international community service projects.

Students established a web page (see: http://ecos.osu.edu/) where students can sign up and a number of projects already in place across the college were integrated into and enhanced under ECOS. ECOS also started other projects and a seminar series was started, with an emphasis on speakers with service projects that they had completed, or with which they wanted help.

ECOS is a vibrant and active group with local, domestic, and international projects completed and in progress. Projects are led by students or members of the advisory board (see the ECOS web page for details: http://ecos.osu.edu/).

Volunteerism Design Project Ideas

Design projects that have technical challenges, but are also useful for at least some types of disadvantaged communities make good projects for volunteers. Some examples include drinking water filtration, waste treatment (that is low cost and effective yet without adverse environmental impact), irrigation and other agriculture needs (to improve yield), low-cost housing (that uses local materials and is portable for refugees), electricity generation (from renewable energy sources that provide low-cost solutions to basic needs, often "personal" systems such as seen in Appendix A), wind and solar power, solar cookers, low-cost lighting, computer technology (for education support and career-development), communications technology (to promote democracy and provide market price information), and medical technology and telemedicine (to promote healthcare access and quality).

[1] For example, team with others, e.g., EWB, ESW, Engineering World Health (EWH) at Duke University, Project Hope, the Engineering Projects in Community Service (EPICS) program at Purdue University and this could still be done if OSU moves toward more service-learning initiatives (see "Engineering volunteerism infrastructure" section). An organization similar to ECOS, at the University of Dayton, is called "Engineers in Technical, Humanitarian Opportunities of Service Learning" (ETHOS). Case Western Reserve University has the "Case Engineering Service Group."

Sample Engineering Volunteerism Projects

Major thrusts for ECOS projects include the digital divide and sustainability. Some sample projects are described below.

In Summer 2004 ECOS carried out its first international project at Casa de Maria y El Niño Orphanage in Medellín, Colombia. Two Ohio State University graduate students and the author brought and set up four computers, a printer, and software and taught the children and staff of Casa de Maria how to use them. Local university students and faculty (from Universidad Pontificia Bolivariana) assisted in the project, and offered to help maintain the computers after the U.S. volunteers left. Figure 1 shows a picture of the children with the computers. A project report is at ECOS website (see: http://ecos.osu.edu/).

A second project was carried out in 2005 and 2006 at Montaña de Luz Orphanage for Children with HIV/AIDS in the Honduras. For Spring Break 2005 a group of Ohio State students, faculty, and staff traveled to the site to: (i) improve the electrical wiring and assess power leak problems; (ii) deliver and set up computers for the children and administration; (iii) educate the children on computer use; (iv) assess the potential to solve communication problems (e.g., obtain an internet connection for the computers and voice-over-IP for telephone service via satellite); and (v) assess the need for drinking water filtration (see: http://ecos.osu.edu/).

These projects provided the engineering students with invaluable experience in teamwork and project management, financial challenges, and opportunities for cultural interchange. They also offered tangible experience in technology transfer and in the assessment of appropriate technology as well as demonstrated the difficulty in working within severe cost constraints. It also became apparent that there was a need for a strategy to provide maintenance in order to assure long-term benefits. As a result, local talent had to be developed or recruited. While there were some interesting technical challenges for these projects (e.g., power leakage, and

Fig. 1 Children at Casa de Maria working with ECOS computers

budget assessment, drinking water assessment, and computer software set up), the group viewed this as a long-term project where technical challenges will be addressed step-by-step. A key challenge was and continues to be fund-raising.

A second type of project that focused on low-cost educational laboratory design for development of higher-education is described in Appendix B. It is worthwhile to note that many ideas in Appendix B could be used for design projects that have a clear service motive, for example, as in this case, the professional education of colleagues in other countries. Such projects could be implemented via either a service-learning or volunteerism approach. Moreover, the higher education project provides opportunities to involve graduate students in volunteerism projects where many of their intellectual abilities are fully challenged. For instance, for PhD students, the project provided the benefit of practical experience in developing and delivering a course, and participation in laboratory development.

Relationship to Service-Learning

Required design projects can be made "community-oriented" and coupled to service through a service-learning approach (Oakes 2004; Tsang 2000). However, service-learning "is never conceived purely as a service activity" (Oakes 2004, p. 9) since the main goal is the education of the engineer. Such design projects are "for credit" courses, and hence not *true* volunteerism projects. Clearly, however, students can go above and beyond the requirements for their class and then provide true voluntary service. Moreover, a strong service-learning program can help educate the engineer and encourage volunteerism since it introduces community design constraints like those described in "Global issues for humanitarian engineers" section and provides hands-on community experience.

A university with a strong engineering service-learning program can profitably exploit the strategies described here since such programs do not necessarily have the goal or means of instilling a voluntary spirit into the profession. To augment an existing service-learning program, the ideas in "Expanding ethics and professionalism to provide educational foundations for volunteerism" section about volunteerism being rooted in ethics and professionalism is especially useful, along with a stated ideal that students should, when possible, go above and beyond the basic course requirements in their project.

The student organization approach should be considered in the context of a service-learning perspective. The advantages of the student organization approach include that it: (i) engages the truly enthusiastic students, faculty, and staff; (ii) provides opportunities for hands-on learning about key aspects of the ABET requirements; (iii) makes it easier to bridge curricular barriers and get a range of engineering majors involved when course credit is not an issue; (iv) generates an environment conducive to learning where students do not worry about grades, homework, and exams and simply enjoy the educational experience; (v) encourages a spirit of independence in students who come to meetings and seminars by choice and are truly interested; (vi) engages students in productive extracurricular activities, possibly even over Spring Break when less-than-productive activities sometime take place; and (vii) provides opportunities for students to meet likeminded individuals and witness engineers using technical skills to serve a community.

The disadvantages of the student organization approach include that it: (i) only reaches out to a limited number of students and faculty whereas a strong service-learning program could engage more students, though typically not all (Oakes 2004); (ii) is not a formal program like a service-learning approach so it is difficult to measure outcomes for students that are not in a major project; and (iii) it has no grading on volunteerism projects so there is no formal record of their accomplishments. Problems in items (ii) and (iii) could be solved by introducing a service-learning course; however, there is *some* hesitation to do this since it destroys the spirit of volunteerism for some people.

Engineering Volunteerism Infrastructure

University Education

It is not possible to run a comprehensive educational program on engineering volunteerism based solely in classroom instruction on background theory, research papers, and design projects confined to the university, even if these activities are all enhanced through a student organization focused on community service. A comprehensive program must have three key components.

First, there must be curriculum modifications. There is a need for (i) enhancements to the college-wide teaching of ethics and professionalism (e.g., training programs for interested faculty and graduate level courses to train future educators on these topics); (ii) more required or elective courses to support the background theory outlined in "Expanding ethics and professionalism to provide educational foundations for volunteerism" section (e.g., courses on technology transfer, appropriate technology, sustainable development, the environment, culture, impact of technology on society, etc.); (iii) design courses that include items like those discussed above on community design constraints (e.g., via a service-learning program); and (iv) courses on leadership, out-reach, and service (perhaps via electives). At least some exposure to the ideals of professionalism must be required for graduation. Perhaps, some would support an "engineering volunteerism" minor or major, a special designation on a diploma to recognize voluntary service, or a college-level award. Consideration could be given to allowing students to independently (i.e., outside a formal classroom setting) choose their own service projects (outside of a class structure), do reports, and get graded on these to meet requirements. There typically needs to be a set of available courses on design projects for the community to make sure that a department is widely engaged in service (i.e., so a service "tone" is set).

Second, faculty attitudes drive the success of an educational program on engineering volunteerism. For this reason, faculty need to be fully integrated into engineering volunteerism programs. This is challenging because faculty are busy with many other demands, and adding more requirements is not likely to be met with enthusiasm. Faculty concerns can, however, be addressed if proper support is given to curriculum development, course development, and assistance is provided for setting up and conducting service projects.

Third, in order to run a comprehensive program and address faculty concerns, there should be an "Office of Community Service" at the College of Engineering level to support service-learning and volunteerism for engineers. Its main focus should be education *and* community service (typically, via capstone design projects). There should be at least one full-time staff engineer who serves as the director of this office, and perhaps some additional support staff. The director should be in charge of establishing new programs, organizing students to solve problems, and teaching students to run effective community service programs. The director must be an engineer so that projects have a firm focus on how to best recruit and make use of engineering talent in providing community service. The director should have secretarial or administrative support (e.g., to assist in promotion of programs). The director must dedicate significant time to fund-raising to support the projects, and must maintain good relations with companies in order to try to establish corporate citizenship programs (which could be an excellent source of financial support). The Office of Community Service must coordinate faculty involvement, because it is important to keep faculty in charge of constructing pedagogically sound engineering design projects, and to be mentors for students. Faculty must be properly compensated for their time (e.g., by having a service project count as teaching a class or two, and financial assistance must be provided for travel). An Office of Community Service could work with executive programs at a business school to train executives on best practices for creating engineering corporate citizenship programs.

Professions, Government, and Industry

Engineers are at a significant disadvantage relative to doctors and lawyers regarding opportunities for getting involved in delivering voluntary services (Baum 1985). There is little available "infrastructure" to support engineers who want to provide volunteer services. First, doctors and lawyers are encouraged by the stated ideals of their professions to provide pro bono services, whereas engineers often are not (see "Codes of ethics, comparative professionalism, and volunteer service" section). Hence, engineers even lack the support of their colleagues' professional ideals. Second, doctors can join free clinics to volunteer time. Lawyers can join existing groups that provide free legal services. Both typically have established buildings, equipment, and support personnel. There seem to be relatively few such outlets for voluntary engineering services. Establishing such outlets would make it easier for many engineers who want to provide services, but do not have ideas for how to match their skills with needs in the community. Moreover, traditions have developed in law and medicine where the government now relies on such services to a certain extent. For instance, judges send poor clients to groups of lawyers who provide pro bono services. Or, clinics are supported by government funds, and charities rely on doctors' free services to make delivery of health care feasible. There is relatively little similar government support or encouragement for the engineer who wishes to volunteer.

Infrastructure is also lacking in industry for support of engineering voluntarism. Strong corporate citizenship programs with good administration and financial support can have a significant community impact. Such programs are part of what is called the "social responsibility movement" where engineering companies try to be good neighbors by supporting schools, non-profit organizations, and charities (Martin and Schinzinger 2005, pp. 23–25). There is a need for more programs, for stronger programs, and for such programs to reach out and involve universities. The ultimate effect on communities from concerted efforts of the entire engineering profession via such programs has the potential to be profound (Lynch 2003b).

Concluding Remarks

There are several key conclusions that can be reached. First, it is possible to augment the standard topics in ethics and professionalism to provide an educational foundation and motivation for student engineers interested in volunteering. Second, there are effective strategies for enhancing classroom learning with hands-on volunteerism via a student organization. Third, there is a need to develop the infrastructure to support life-long engineering volunteerism. Future work to advance the ideas presented in this paper include the design and conduct of studies to assess the outcomes and effectiveness of the pedagogical strategies for teaching and promoting volunteerism presented here.

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Appendix A: Sample Engineering Volunteerism Design Project—Classroom Version

The personal electricity generation system described below is meant only to be a classroom project, with no laboratory work. However, it will be clear how a laboratory implementation component could be added onto make it a capstone design project. The student is asked to create a design proposal given a number of the design constraints encountered in the community (see "Moral frameworks for support of volunteerism" and "Global issues for humanitarian engineers" sections). With appropriate modifications, it is not difficult to change the objective from the design of an electricity generation system to: (i) a personal drinking water filtration system, (ii) a personal solar cooker, or (iii) low-cost housing. More extensive revisions would be needed for the other project ideas in "Student organization: engineers for community service" section. A very similar project was tested with good results in a course entitled "Professional Aspects of Electrical and Computer Engineering" (ECE 481), and in fact a closely-related international service project is in progress as reported in an article by Fairley (2004).

Engineering Volunteerism Design Project: Design Proposal for a Personal Electricity Generation System

Your company designs, manufactures, and distributes electricity generation systems. It has a world-wide market. It has a strong corporate citizenship program that has identified a need for a low-cost "personal" electricity generation system for persons in under-developed countries. Your company did some preliminary investigations and compiled the information below. This information is not complete, but since you are part of the corporate citizenship program, the company wants you to conduct a design feasibility study and a preliminary design. The general objective is not to make money on the end design, but it is also not possible for the company to give away the end product to millions of people who would want it. They are, however, willing to pay for engineering development, and sales "at cost", or a bit below cost. It is their hope that this will be truly helpful to developing communities, and also lead to an expansion of the market for the products of the company, and good company image.

Regional constraints: It has been found that the following constraints must be met for the villages and people who would be interested in purchasing such personal electricity generation systems:

- There are no nearby electricity sources.
- There is no nearby phone.
- There is no nearby potable water source.
- There is a stream near many of the village locations; however, its water flow is uneven. During the rainy season, there is a good current, but during the rest of the year it only has enough flow to meet drinking water needs of the village (after purification).
- Living quarters are of the "hut" type (e.g., tree branches with a piece of plastic for a roof). None are wired for electricity. Many of the huts in the "village" are at distances of 1 km from each other (since they are surrounded by either their crops or there are mountains in the way).
- Most of the villages are remote, and reaching them will take almost a day of driving, plus a 5–6 h walk in mountainous terrain.

- Diesel fuel or gasoline is prohibitively expensive in most areas (partly due to transportation problems).
- During the rainy season there is often no sun during the day, or at most 2 h of sun. During the dry season it is sunny almost every day and it is quite hot. At night it is cool in most locations since most of the villages are up in the mountains.
- In some locations, there is a relatively constant source of wind, although it is above the forest canopy in many cases. The company has not done the very expensive survey that would be required to determine the wind characteristics in the many remote locations.

Electricity needs: The need for electricity are prioritized in the following order:

1. *Light*: Currently, after nightfall, not much can be done. Children go to school in the morning, and then work in the fields in the afternoon until nightfall. It would be quite useful to have at least an hour of lighting at night for the children to read and study. Moreover, the parents would find lighting useful for crafts-making at night since then they could increase their return from sales at the market (that is around 20 km away).
2. *Heat*: Heating water for the purpose of water filtration would help avoid the problems of collecting firewood for that purpose. Heat for cooking would be useful for the same reason. Heating the hut is probably not feasible (e.g., due to leaks), even though it would be useful because in the mountains, it gets quite cold at night.
3. *Radio*: While a battery-operated radio is cheap, it would be better to have one that could be plugged in. The radio can be used for finding out market prices for crops. It would also provide news from the capital, and music.
4. *Pump*: Right now the primary water source is a mountain stream and it is contaminated. A chlorination system could take care of the problem, but that is expensive. It is known that if water were pumped from more than 200 ft deep in the ground, fresh potable water would be available. The community could, perhaps, get the resources from either the government or other sources to get the well dug within about 5 years (hopefully); however, there is the problem of an electricity source for the pump. This is a low priority item at this point, but it is on the "wish list."

There is no hope that the government or anyone else will run electrical lines or a water supply to the village in the next 20–30 years. Some locals say that would "never happen."

Conditions of operation: Most of the huts leak, and there is a long rainy season. There are long periods of high humidity. Most of the huts have a dirt floor. Temperatures in the area range from 40 to 110°F. In the dry season it will be over 100°F every day.

Operators: It must be possible for young children and adults to easily operate the device. It must be safe. The company is quite concerned about safety and liabilities.

Cost: Nearly everyone could not sacrifice more than 1–2 weeks of income for the purchase of an electric generator. This must be translated into a dollar amount that would be allowed for the project. Customer expectations are that the product would operate failure-free for at least 2-years of continuous operation. It must last at least 10 years in total.

Service and repair plan: Discuss a plan for service and repair that is consistent with the above constraints. What type of warranty can the company offer? What is your return policy? What qualifies as a valid return (if the device was left out in the rain for a month and now does not work, does it qualify for a full-refund, or at least a pro-rated one, or for some credit toward a new device)? What is the outlet for servicing these returns? Keep in mind that there is no person in this type of village with knowledge of electrical technology, nor is there anyone nearby with such knowledge.

Competition: Identify any competitors. For this you should provide: (i) a description of their products and their functionality (specification sheets can be put in an appendix; include URLs); (ii) their cost; (iii) their warranty and support services; and (iv) their market penetration (what countries, how many devices in service).

Company image: The company is quite concerned about its image; it does not want to be perceived as a multinational corporation trying to exploit under-advantaged people. This affects/determines cost, safety/liability, and service plans. Someone has suggested a survey of some of the local communities (the above information was gathered by an executive's visit to one country that s/he thought would be "typical") but there is a clear need for more information on community needs and priorities (they must be an active player in the process); you must specify in the plan how this survey should be conducted (e.g., what should be studied, what questions should be asked, and whether local engineering services in target countries should be sought).

Assignment: Given the above constraints, solve the following problems.

Design feasibility/competitiveness study:

1. Assess the competition as discussed above. Provide information to support your assessment.
2. Develop a strategy to gather more information to support the next stage of the design process (see comments under "company image" above).

Preliminary design:

1. Provide a preliminary design that best fits the above constraints. Explain how it meets those constraints. Provide a clear explanation of costs relative to customer's financial condition.
2. Defend your choices against competing technologies.
3. Explain your service and repair plan.

Questions:

1. Explain how the concept of "sustainable development" applies to your design. Discuss a plan for "design for environment" (see Martin and Schinzinger (2005), Vesilind and Gunn (1998) for an example).

2. Explain how the ideas of technology transfer and "appropriate technology" (Martin and Schinzinger 2005) apply to your design.

Design team: You must form a team to complete the project (envision your team as an enthusiastic group that is given the privilege of volunteering to work under the corporate citizenship program for a year to complete the project). Your team must have between two and four persons on it. All must contribute to the assignment. List on the cover of the final report the title of the report the persons on the team and the percentage contribution of each individual.

Solutions: Several student solutions are provided at the course website (see http://www.ece.osu.edu/~passino/ee481.html).

Appendix B: International Higher Education Development Project—Low-Cost Laboratories

Well before ECOS was formed, the author and his graduate students, along with a number of undergraduate project teams, developed a program/project designed to provide low-cost engineering laboratory experiments and exercises that do not compromise the pedagogical quality of a laboratory experience. This idea emerged through visits to a number of universities at sites around the world, and via conversations with graduate students about development needs at the universities where they completed their undergraduate degrees. International development of higher education is clearly very important, yet challenging since often political and economic conditions are the cause of underdevelopment. Yet, the needs cannot be ignored. In a number of cases, it would be helpful to have free or low-cost laboratory experiments available, freeing up scarce resources for other educational needs.

There are a number of features of the program that make it especially suitable for an engineering volunteerism project. First, it is collaborative in the sense that many universities around the world can construct low-cost experiments and share the complete details of the designs via web sites. In this way, everyone can build on each other's progress, and ultimately end up with a wide range of solutions that are more likely to fit into the constraints of each university.

In Summer 2004 N. Quijano, J. Finke, and K. Passino went to Colombia, gave some short courses, and presented this project at Pontificia Universidad Javeriana de Cali (with professors and students from Universidad del Valle present) and Universidad Pontificia Bolivariana. Later, N. Quijano and J. Finke presented the project at some other universities in Latin America.

Second, experiments are needed across the entire engineering curriculum, so there are many potential design projects. The projects challenge students to think about how to teach other students key theoretical concepts from the curriculum and thereby they have to think carefully about the best ways to illustrate these ideas via a laboratory experience. In other words, they can be excellent engineering design projects.

Third, the projects encourage good engineering practice in that they focus on the delivery of a product that is low-cost, yet meets the customer's objectives. Students are also motivated to do a project that they feel will be useful to someone else, beyond just being an educational experience for themselves and their team.

Fourth, while the main focus can be on producing experiments to be used in laboratories associated with classes in the regular curriculum, in some cases it is also possible to design experiments that can simultaneously be used in graduate-level research. Fifth, whenever possible, students will travel to other universities in other countries to work with local design teams. A number of benefits will be realized: (i) recognition of local talent, (ii) realization of the significant challenges that globalization will have on engineering (job competition), (iii) cultural interchange, and (iv) recognition of local constraints at some international universities.

The following is a concrete example of how such projects can be conducted. Due to team expertise, the focus has been on development of low-cost experiments to teach the concepts of feedback, disturbance rejection, robustness, nonlinear control, and distributed control. A number of very low-cost control system experiments have been designed (see http://www.ece.osu.edu/~passino/labdevelopment.html), and one temperature control experiment is shown in Fig. 2 (this experiment was designed and constructed by N. Quijano and more details can be found in Quijano et al. (2005)). In this experimental layout there are 16 zones, where the black objects are temperature sensors and lamps are used as heaters. The objective is to maintain a constant temperature across the grid. There are applications for this type of uniform temperature control in semiconductor manufacturing and computer temperature regulation. The experiment as shown costs less than $5 US per zone. It creates a multivariable control problem, with significant disturbances such as inter-zone temperature effects and ambient temperature effects. The experiment is particularly interesting if in the computer one simulates a distributed network of individual controllers, each of which controls a single zone. An interesting challenge is created when the amount of current that can be used for the lamps is constrained, or the number of lights that can be on at one time is limited. In these cases one must try to design strategies to obtain a maximally elevated but uniform

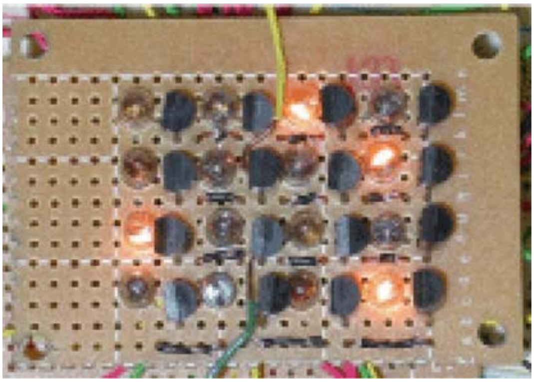

Fig. 2 Low-cost multizone temperature control experiment

temperature across the grid. Such challenges require the use of distributed resource allocation strategies that exploit feedback information.

Several other projects are fully described at http://www.ece.osu.edu/~passino/labdevelopment.html. At this site there are also a number of other ideas for projects. It is hoped that involvement of additional professors and students will make it possible to expand the number and types of projects.

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