Role of the Community in Teaching Undergraduate Engineering Design

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Abstract: The local communities surrounding universities provide a wealth of opportunities for engineering students to practice engineering design while making real contributions that affect people's lives. Such design projects also directly address ABET EC2000 criteria that students should understand the impact of engineering in a societal context. This article identifies several sources within the community that supply engineering problems suited for independent study and senior design projects, and discusses the practical development, execution, and outcome of two specific projects worked in collaboration with a museum of science and the Department of Electrical Engineering at the Virginia Military Institute (VMI).

I. Introduction

What are community-based projects?

Until the mid 1850's, engineering was a craft taught only in a mentor/apprenticeship relationship, and focused entirely on the needs of the immediate community. With the adoption of the classroom as the primary teaching model at the turn of the century, the engineering curriculum became standardized and more suited to its increasingly technical nature, at the cost of loss of satisfaction and relevancy that comes with learning though helping others. By the late 1920's, Alfred North Whitehead wrote in his classic *Aims of Education* [1] that most of what is taught is "…no longer about life as it is known in the midst of living it," and suggested that efficiency in teaching through subject compartmentalization is achieved at the cost of reducing its ties to the society it purports to aid.

Community-based projects (CBPs) attempt to restore this link between the undergraduate engineering experience and society by allowing students to learn while creating devices that help people or organizations within their immediate community. The projects may be implemented at any level from introductory (such as preparation of a laboratory for local high school seniors learning Ohm's Law) through senior capstone design (creating a radio-monitored remote weather station for a neighborhood airport).

Why community-based projects?

Integrating CBPs into the undergraduate engineering curriculum provides several advantages to the students, advisors, and university. Similar to good open-ended design problems, CBPs motivate students to self-teach and establish material relevance, answering the silent question "why do I have to know this" with the realization "I can use my skills to make a real contribution to my community." The advantages of active learning are well-known [2,3,4] and are intensified by seeing the results of personally contributing to a person or organization outside of the university setting (e.g. [5,6]). This basic objective is easily lost in the traditional curriculum, even ones that integrate design problems. Discussion of key concepts from particularly successful projects can be introduced in lower classes, and can thus motivate students not directly involved. The value of the publicity surrounding a successful project should not be underestimated, especially in this era of generally declining enrollment in US engineering programs.

Like good design projects, CBPs can be used to teach practical engineering skills, both specific such as soldering and enclosure-building ability, and general such as project management, alternate solution synthesis, economic analysis, and teamwork [7,8]. They can also perforce introduce other important topics not commonly considered in design courses such as reliability, maintainability, safety, user-friendliness, and end-user documentation. From a laboratory skill perspective, this expansiveness provides a good balance to the topic focus that can be achieved with increasingly popular virtualized laboratories.

CBPs address several of the ABET2000 Engineering Criteria, including awareness of engineering solutions in a societal context, recognizing the need to engage in lifelong learning, professional ethics and responsibility, and effective communication. Since CBPs may contain design projects at their core, they further help fulfill the ABET mandate to have a design-oriented curriculum, an often-noted deficiency [9].

Perhaps most directly, CBPs directly address the responsibility of universities to provide opportunities that allow young adults to mature in their sense of compassion and responsibility toward society at large. Research shows a continuing decline in civic engagement of college graduates during the last four decades, despite a paradoxically heightened graduate awareness of the need to do so [10].

What schools actively engage in CBPs?

It is not uncommon for engineering universities to supervise community-based projects as part of a design capstone program; for example, MIT students build ophthalmologic devices for patients through Project Orbis, and appliances built by cadets at the US Military Academy have helped cerebral-palsy victims [5]. Although CBPs do afford excellent capstone design experiences, we have discovered they can also provide meaningful independent study projects to lower-level students if the advisor provides a well-defined problem. Indeed, the concept of CBPs has been shown to produce remarkable results when integrated into a freshman introductory engineering program (such as in Case Western Reserve's Engineering 101), and at the high school and elementary levels as well, with a proportionally larger degree of teacher involvement [11].

II. Identification and Selection of CBPs

What makes a good project?

In order to gain student ownership, a CBP must fulfill a real need not directly addressed with off-the-shelf technology; the more compelling the need, the more student ownership. The construction of an interface between a doorbell and a commercially-available power controller switchbox to flash lights around a two-story home for a partially deaf person generates significantly more student interest than simply reinventing the power controller switchbox alone. An exception: when teaching specific technical skills, such as peer-to-peer networking, it may be appropriate to gain some hands-on experience working entirely with off-the-shelf equipment alone, such as installing network cards and a proxy server to allow a senior citizen's computer center internet access. Similarly, the project is more likely to be effective and have more meaning to the students involved if the beneficiary or receiving organization is local enough to permit student interaction both in the early needs analysis stage, a midterm testing stage, and a final handoff stage. In competition with the desire to have a compelling project, the proposed CBP should not be selected if the need is immediate (under six-month), or be a show-stopper if not delivered on time. A device to aid an already-employed chronically-disabled person perform her job more effectively (e.g. [5]) makes a better CBP than a device needed by a newly-disabled person to perform basic life skills. Other equally important considerations are pedagogic goal (clearly illustrates a specific concept or requires synthesis of material from many courses), economic constraints, and time limitations.

Similar to design projects, the complexity of the CBP must be matched to the student academic year and ability [12]. For example, an independent study project for sophomores may require the professor to fully define the problem and broadly suggest approaches (e.g. "construct a three-zone speaker timing light for a library conference room"), whereas an open-ended project that requires more interaction with the beneficiary is very appropriate for a senior design (e.g. "build an exhibit for the newly-opened telecommunications wing of the local museum of science that illustrates communication via laser").

Final selection of a CBP must strike a balance between student input, faculty guidance, and community need. One method we have found works well for our senior capstone course is to have a project director identify many projects that address community needs (described in greater detail below), convene a meeting of the faculty project advisors to develop a short list of potential projects, and then distribute a student questionnaire at the end of the semester preceding the design course. Independent study projects can be identified through several brief meetings with interested students. Either method permits the undergraduates to leverage their particular interests and strengths; an artistically-talented student may prefer to develop a piece of electronic art for a Department of Motor Vehicle waiting area, and one entranced by physics a high school classroom demonstration.

Sources of projects

It is not difficult to identify sources of CBPs: religious centers, hospitals, museums, government offices, elementary and high schools, special education centers [13], local industries [14,15,16], senior centers, government offices [17], and public waiting areas team with opportunities. The difficulty is recognizing them. Suitable projects may be identified by faculty working alone ("this is a unique new sensor…what need can it fill?") or in concert with other community professionals ("we can analyze your clinic's energy usage and recommend changes"). Many national organizations such as The Jimmy Fund have public relations offices that direct offers of non-monetary assistance. Third parties outside the university setting are often eager to help identify humanitarian projects once educated about what types of projects are suitable; this can be accomplished via newsletters to alumni, talks at business community organizations such as the Rotary or Kiwanis Club, and informal networking in local professional organizations such as the Institute for Electrical and Electronic Engineers, the American Society for Mechanical Engineers, and the National Society for Professional Engineers. Students may also generate their own ideas as products of their experiences and families' careers.

Project pitfalls and solutions

These types of projects are rewarding for the students, professors, and administration but are inherently time-consuming, hard to teach, messy, and frequently expensive. These are common to all design problems; Emmanuel [7] offers an excellent discussion. The primary problem unique to CBPs is that non-delivery of a promised item reflects poorly on the students, advisor, and school, yet a good CBP is not a canned project by design. Students want the emotional satisfaction of building something entirely new to fulfill a real need, yet this often requires the professor advise a project whose pitfalls may not be fully apparent *a priori*. This issue is compounded by the tendency of students to envision grander-than-necessary-or-practical solutions when confronted by the humanitarian nature of CBPs. These projects require close supervision to ensure an on-time deliverable. It is difficult to supervise more than one project at once; for a senior design scenario multiple teams can compete for the best design without diluting the sense of contribution each student makes. Runner-up projects may be used as departmental demonstrations. Weekly status reports are essential, as are special meetings to discuss alternate strategies when timelines slip. The advisor should stress the importance of the project, and make clear what maximum grade will be awarded to an even superior design that is not completed on time. CBPs engender an impressive degree of student responsibility, although it is still wise to consider having the in-house demonstration of the final deliverable project two weeks before the device is due to the beneficiary. During the project's development it should be made clear to the beneficiary that the students will try their best but ultimately it is a learning experience so their product will be free with no guarantees.

Problems inherent in advising completely original projects may also be circumvented by developing a few reusable CBPs. Projects must fulfill real and current community needs or else are no different from any design project, however with this requirement satisfied we have found that student ownership is not reduced. For example, the experience gained while advising the construction of a museum of science display need not be lost. There are many museums of science in this country; some states have multiple, and many would welcome an offer for a low-cost, high-tech demonstration.

III. Typical experiences at VMI: Senior design and independent study

Projects chosen

Two projects completed by cadets (students) in the Department of Electrical Engineering at VMI were chosen to illustrate CBPs; to simplify comparisons both entailed creating demonstrations for the Virginia Museum of Science. The senior class designed a laser-based communications display involving eight visible lasers operating in parallel to digitally transmit music; museum guests can selectively block light streams and hear signal degradation. During the same semester a single cadet in a junior year independent study developed a device to intuitively show how multiple signals may be carried on a single channel by optically multiplexing and separating microprocessor-controlled red and blue lights transmitted over a thick acrylic light pipe.

Administration

The administration of a senior capstone design class and independent study was not largely altered by the inclusion of a CBP; [7] provides detailed advice which we followed. The senior design class was divided into teams of 6 or 7 cadets, each with a project manager who decided how to subdivide responsibilities. The project goals were introduced, and topics in project management were discussed in the first third of the semester, with the remaining classes scheduled as release time. Project managers were required to submit timelines and landmarks at the end of the second week, and submitted weekly status reports thereafter. Grading of the four-credit class was based on the effectiveness of the display, a final written report, and presentation to the department faculty. Details of the one credit-hour independent study project were developed over short daily meetings during the first week, and a timeline with landmarks was submitted during the second. Weekly one-hour meetings were held and both the advisor and student shared roles as project manager. Grading was based on the product effectiveness and on a final report.

Several aspects of administering a CPB differed from traditional courses. Initial project exploration required early interaction between the faculty advisor and external beneficiary. The museum of science projects were identified by a faculty member after reading a newsletter describing the opening of a new telecommunications wing. Three months of intermittent communication were required before both advisor and museum representative felt suitable CBPs were identified. During the execution phase cadets were encouraged to remain on task by frequent self-evaluations, accomplished by comprehensive written weekly status reports by the cadet project managers and oral reports by the independent study student. The display was planned to be delivered during a meeting with all project managers, independent study cadet, faculty advisors, and the Museum Gallery Programs Assistant Director two weeks following the oral presentations.

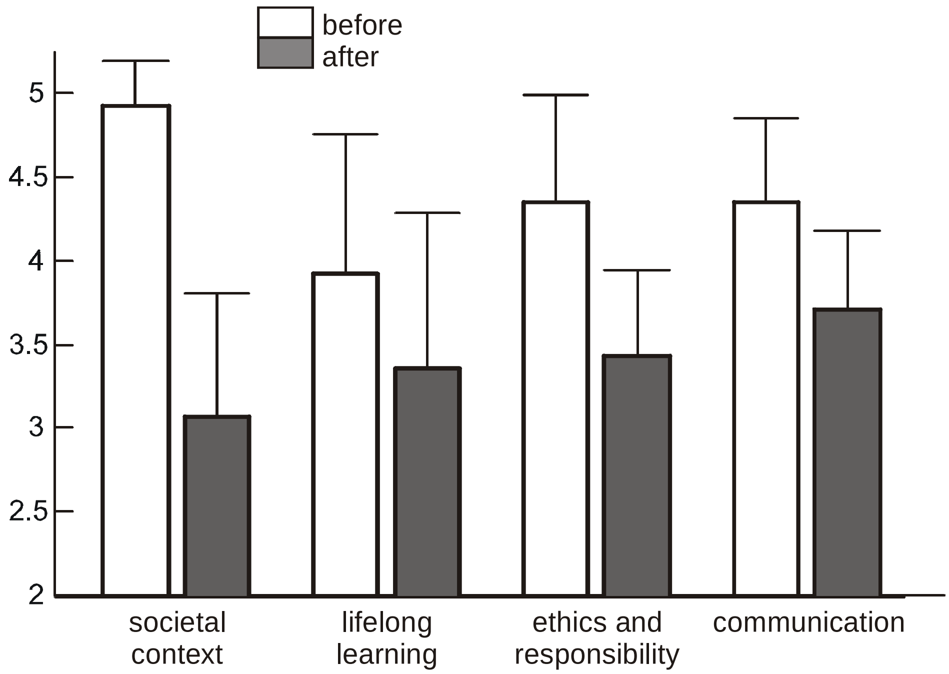

Figure 1: Student self-evaluations of four ABET 2000 criteria rated on a 0-5 scale before and after participating in a CBP. Error bars plot standard deviation, not standard errors, and show significant improvements in three categories.

Evaluation

All students completed self-evaluation surveys before and after their capstone/independent study experience. Figure 1 summarizes their responses to a subset of outcomes emphasized in ABET2000 criteria yet difficult to teach in traditional courses. Analysis of each set of lumped responses using a two-tailed Student t, unpaired (since surveys were anonymous) shows an increase in awareness of engineering solutions in a societal context, awareness of professional ethics and responsibility, and ability to effectively communicate (p values <0.001, 0.4, <0.001, 0.003, respectively). This suggests the course is meeting its intended goals, and that cadets were expanding their definitions of professional responsibility from punitive issues (safety/theft) to include civic duties. In write-in blocks, students reported "being useful", "being independent", and "being responsible", in marked similarity with findings by Catalano, although several members in the senior capstone class suggested too much time was spent covering project management skills which reduced the time available for "doing the project", and some felt grading criteria were unclear. We intend to emphasize in future classes the need for project managers to delegate design tasks immediately after they become apparent, without waiting for enough information to fully plan all project aspects.

IV. Summary

Engineering exists to serve societal needs, yet this is often largely disregarded in traditional undergraduate engineering curricula. Projects that allow students to design devices used in the community provide this focus, and rekindle the reason many students desire to become engineers: to help others. CBPs are accessible to both seniors as part of a capstone design experience and to lower students as independent study courses. These opportunities enhance the relevance of the engineering curriculum to students and forge a bond between the local community and university.

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