Long-distance collaboration, international perspective, and social responsibility through a shared interdisciplinary engineering design course

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Abstract

Today's societal characteristics are compelling engineering graduates to have a broader range of skills rather than the highly focused technical repertoire demanded of engineers in the past, including teamwork and communication skills[1], as well as an awareness of the effects of technologies on cultures, societies, and economies[2]. In order to meet these needs, an undergraduate engineering design course has been developed as a collaborative effort between faculty members at two small liberal arts institutions separated by more than 800 miles. Each institution offers an ABET accredited engineering degree (Engineering Science and Industrial Engineering) and graduates ~7-12 engineers per year. In the shared course, engineering student virtual teams design and implement assistive technologies for persons with disabilities and underprivileged individuals for both local and global clients. The course is required for engineering majors from both institutions and is usually taken in the sophomore or junior year as a pre-capstone experience. Sharing expertise, capabilities, and faculty time are important considerations in developing the course because of the very small size of each school's departments.

Overcoming the challenges of communicating long-distance with teammates as well as project collaboration at a distance are important aspects of the course. Long-distance collaboration is particularly important today as many engineers in industry now work at a distance with colleagues. In this paper, we will describe our course and describe a variety of lessons learned about this type of course and collaboration. A comparison of the course with and without the use of virtual teams suggests that students rate their multidisciplinary teamwork skills as being much more developed in the version of the course with virtual teams as compared to when team members are all at one campus.

Introduction

Corporations and national leaders have expressed disappointment in engineering graduates' abilities to fulfill the needs of the workplace, emphasizing their low levels of communication and teamwork skills[2, 3], as well as a deficiency in social skills[4]. Characteristics of today's society include multidisciplinary technological advancements, globalized markets, and emerging social responsibility[2]. These societal characteristics are compelling engineering graduates to have a broader range of skills rather than the highly focused technical repertoire demanded of engineers in the past[1], as well as an awareness of the effects of technologies on cultures, societies, and economies[2]. Our approach is to provide students an opportunity to improve in a variety of areas, including multidisciplinary teamwork, communication and global perspective, by working on virtual teams to design assistive technology for disabled clients in a pre-capstone experience. We believe our approach is different when compared to other design programs for underprivileged clients because of our use of virtual teams and our collaboration between two small engineering programs at liberal arts institutions.

Engineers in industry routinely work on teams where members are at different geographic locations that meet and collaborate electronically. These virtual team members may have never met in person. In order for these virtual teams to be successful, engineers need both strong communication skills and teamwork skills. Even with video communication, engineers working at different locations completing complex tasks can experience problems with communication and teamwork. These issues can be made more difficult because of the potential lack of rapport within virtual teams[5; 6]. While industry makes use of virtual teams, it is not yet common for engineering programs to give students opportunity to work in this setting.

The Program for Assistive Technologies for Underprivileged (PATU) was developed as a collaborative effort between faculty at two small liberal arts institutions separated by more than 800 miles. Each institution offers an ABET accredited engineering degree (Engineering Science and Industrial Engineering) and each graduates ~7-12 engineers per year. Sharing expertise, capabilities, and faculty time are important considerations in developing the program because of the very small size of each school's departments.

The mission of the program is to allow students to practice engineering skills while they develop strong communication and teamwork skills, gain global perspective, and learn social responsibility through projects for persons with disabilities that otherwise could not afford assistance, both locally and globally. At each institution the program is incorporated into required sophomore and junior-level design-intensive courses. The course is offered every-other year at one institution, enrolling 20-25 students in the course, and every year at the other institution with 10-15 students. It has been suggested that early incorporation of multidisciplinary teamwork into the curriculum is a more effective strategy than waiting for senior design[7], supporting the effectiveness of our inclusion of PATU into sophomore and junior-level courses. In addition, the integration of engineering and non-engineering students in collaborative virtual teams has proven to be an effective learning strategy in multidisciplinary teamwork[8]. These projects provide students practice in the engineering design process and with communication techniques.

One of the key components of the program, and one reason the co-institutional collaboration is critical, is that it allows for the development of multidisciplinary teamwork. Because each institution is small and offers only one or two programs in engineering, working across different engineering disciplines is difficult or impossible without this collaboration. Design course teams include Industrial Engineering (IE) and Mechanical Engineering (ME) students from one institution, and Engineering Science (ES) and liberal arts students from another. Masters-level occupational therapy students and faculty also collaborate on functionality of resultant designs. Collaboration between health sciences, liberal arts, and engineering students during the design and implementation process through cross-discipline virtual teams enhances students' communication skills and is important for the development of a quality end-product. While completing projects for persons with disabilities or the underprivileged is not unique to our program, it is a critical component to the success of our virtual teams because it appeals to the students' desire to complete the design successfully and motivates them to work through any difficulties encountered with team dynamics.

Program planning and management

Prior to the start of the semester, faculty from each institution carefully organize and discuss the course organization, delivery, and management (Figure 1). Two main faculty, one at each institution, have been involved each year to date, with an additional faculty at each institution playing a smaller supporting role. Responsibilities of each faculty are negotiated, including delivery of each lecture, development of assessments, grading, expectations of students and timeline of deliverables. Courses at each institution meet at the same time, allowing materials to be delivered synchronously to both student groups through the online course delivery systems Elluminate and Blackboard. Although the majority of the effort by faculty is in the planning immediately prior to the course implementation, work for the program is completed year-round.

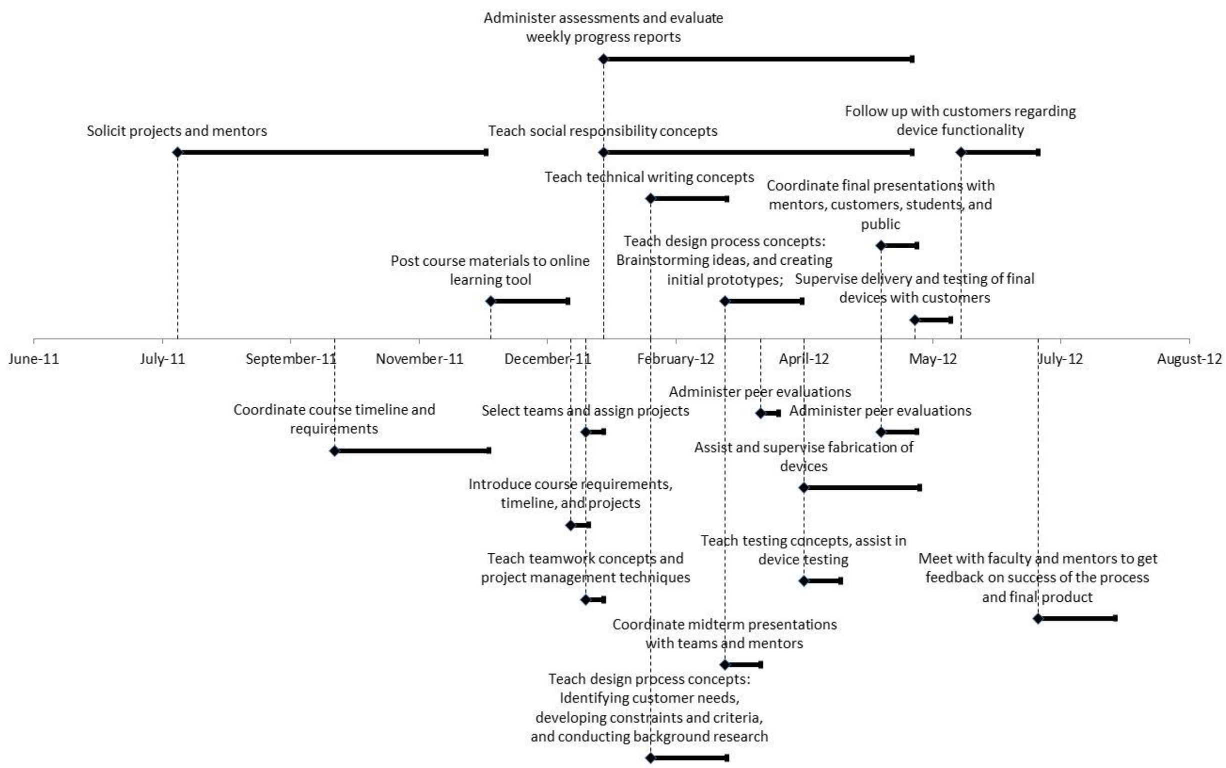

Figure 1: Annual program implementation timeline. Detailed timeline of tasks completed by faculty at both institutions for one year (July to June) to implement PATU. Length of bar under each task denotes approximate length of time spent on the task. Timeline assumes implementation of course in spring semester only.

Project ideas are collected throughout the year from several organizations near each institution and clinics in Itabuna, BA, Brazil. Faculty select projects based on feasibility, student interests and capabilities, as well as level of meaning and experience the project will provide for the student and client. While each project represents a critical need for an individual client, many projects may require more than a single semester or design iteration.

After being introduced to the projects and the students from the opposite institution, each student ranks the projects in order of his or her preferences and lists two students with whom they would prefer to work. Allowing students to choose at least one team member reduces the stress that occurs when working with virtual teams. Course instructors from each institution, after extensive discussion, assign teams and projects based on preferences, abilities, and learning styles, to create teams that will work synergistically[7]. Because each program is small, instructors are highly familiar with each student's abilities and personalities, allowing for the construction of teams designed for optimal performance[7]. As in many engineering design courses, a section early in the semester is devoted to teamwork and collaboration skills. We know this is particularly important because of the team dynamics as projects become more challenging and because of our use of virtual teams. Difficulties experienced with virtual teamwork are particularly stressed. For example, it is emphasized that tone can be difficult to assess through email and placing blame for difficulties on team members from the opposite institution should be avoided.

Project teams include 2-3 students from each school, bringing complimentary abilities to the group. Key knowledge and skills needed for successful device design are an understanding of how devices affect the human body, effective manufacturing practices for both the individual device and for future sustainable production, as well as technical skills in mechanical and electrical design and computer programming. IE students have expertise in human factors and manufacturing techniques and capabilities, ME and ES students bring skills in mechanical and electrical device design, while all students have experience with problem solving and computer programming. Students meet (virtually or in person) with a collaborator from occupational therapy at least once a month to ensure that their devices properly satisfy the therapeutic needs of the patient for whom it is being designed. Liberal arts students round out the multidisciplinary teams by bringing a unique perspective to the project and its effects on the persons and societies involved. The vast needs of these projects require a truly multidisciplinary team that is enriched by this co-institutional collaboration.

Each student group determines the best modes and schedules of communication for the group and delegates responsibilities for the completion of deliverables. A different team member leads the composition of each of the design reports. The exercise of making such decisions is an important educational experience. Faculty members provide guidance and assistance as necessary to ensure smooth operation of the collaborative groups while remaining flexible in the methodologies utilized by each group. Students most often communicate by email, phone, text, and Skype, and share documentation through GoogleDocs and other file sharing sites. Constant communication between faculty leaders is critical, especially during "storming" stages of team development.

Product design and development

The course in which this program is implemented is typically the first time students experience the engineering design process in great depth and work for a real client. Students are guided through the steps of the design process by course instructors through course materials, discussions, and the expectation that groups achieve certain milestones in a timely manner. The course is co-taught as one cohesive course across the universities, with typical course responsibilities shared among the faculty from each institution so that all students receive the same instruction and grading. Once teams and projects are assigned, groups work to produce specific goals the product must accomplish. In order to properly define these goals, teams are expected to conduct interviews with the participants and extensive research into their living or work conditions and maintain regular communications with support personnel at participating organizations. For clients in Brazil, students communicate with therapists in the clinics through email and other web-based video and voice conferencing systems.

Once customer needs are fully defined, students brainstorm ideas and produce prototypes of their design. They are expected to complete several iterations of device fabrication until they create a product suitable for delivery to the customer. Each institution has different fabrication facilities and skill, and the sharing of fabrication resources between institutions is a critical aspect to the collaboration. Students are given time during class to manufacture the projects but are expected to work outside of class as well to complete their device. Each group decides which institution's facilities best fulfill their manufacturing needs. Different components of each project may be manufactured at each institution, requiring students to send components between schools for final assembly. Each group is given a budget of $500 to manage for supplies and other costs to fabricate their devices. Currently, support for the projects comes directly from the operating budget of each department (split evenly). Few projects have used the entire allotted budget.

Students gain global perspective and social responsibility through the integration of reading and writing assignments throughout the course that explore the effects of technology on society as well as Brazilian culture. Every other year, an optional short-term study abroad trip is offered. While in Brazil, students experience area clinics, examine typical living conditions, meet with clients and their families, and tour various manufacturing facilities. Information gathered is then available to the next group of students completing projects for Brazilian patients. Students and faculty from both institutions participate in the study-abroad program. Without this co-institutional collaboration the cost of this program would be prohibitive.

Projects

More than ten projects have been completed through PATU over the course of two different semesters, including projects that have required several iterations, projects that were completed and delivered in one semester, and projects that require additional work before they can be delivered. Examples of projects include a compression vest for a boy with sensory-seeking behavior (Figure 2A), a blink-controlled communication board and power supply for a girl with cerebral palsy (Figure 2B), a detachable desktop with communication icons for a boy with muscular dystrophy (Figure 2C), and a volume feedback device for a girl with hearing impairment. Projects have been completed for more than five different collaborating organizations in two states and two countries.

Figure 2: Project examples. Photographs of projects completed for persons with disabilities. A) Compression vest for Max, who has sensory-seeking behavior. B) Communication board for Emanuelle, who has cerebral palsy. C) Wheelchair desktop with communication icons for Manuel, who has muscular dystrophy.

Assessment of student learning

Despite additional challenges associated with virtual teams, quality of final devices produced for terms with and without virtual teams were similar based on qualitative observation from faculty.

Both institutions have ABET accredited programs and, therefore, implement assessments annually of the student outcomes (a-k). After completion of the course, students were asked to complete an anonymous survey indicating their perception of their level of ability for each outcome (a-k) by circling the appropriate number using the following scale:

5 = High level of competence - extensive ability
4 = Moderately high level of competence - good ability
3 = Average level of competence – some ability
2 = Low level of competence – little ability
1 = No level of competence – no ability

The course is offered at one institution every-other year and at the other institution every year. Therefore, students participate in virtual teams only in alternating years. While unfortunate, the situation allows for comparison of assessments. Student responses from this institution were analyzed and one term when long-distance collaborations were completed (2013) were compared with one term (2012) where long-distance collaboration was not available but similar projects were undertaken. There were 11 student responses in 2012 and 10 in 2013.

Several observations can be made from the assessment results that support the advantages of this long-distance collaboration between engineering programs at small liberal arts institutions. Design (student outcome c) and utilization of engineering techniques (student outcome e) are outcomes covered thoroughly throughout typical engineering curricula through highly technical courses. While these outcomes are claimed to be important in this program, they did not improve or improved very little in student ratings during the long-distance collaboration term (Figure 3 A, J). This is not unexpected, as these concepts are easily covered in the course with or without the collaboration. It is interesting to note that the use of virtual teams does not generally reduce students' sense of their design skills. However, the students' perception of their ability to solve engineering problems (student outcome e) was lower during the year of collaboration (Figure 3C), perhaps because of the challenge of dealing with long-distance collaboration.

There are improvements in other student outcomes that can be observed when comparing the term with virtual teams to the term without. The most notable differences occur in the outcomes that address the softer skills in engineering, which are the key focus of this collaborative program. The goal, "an ability to function on multidisciplinary teams" was rated at a level 5 by 63% more students during the long-distance collaboration term than the non-collaboration term (Figure 3B). The outcome assessing understanding of the impact of engineering on society was also greatly improved, rated at a level 5 by 60% of students during the collaboration term compared to 18% without collaboration (Figure 3F). These results are supportive of our efforts to enhance graduates' skills in communication, multidisciplinary teamwork, lifelong learning, and awareness of social and ethical considerations in addition to a firm grasp of science, mathematics, and engineering fundamentals.

Future directions may include comparison of student performance in Senior Capstone experiences with or without participating in this model of long-distance collaboration.

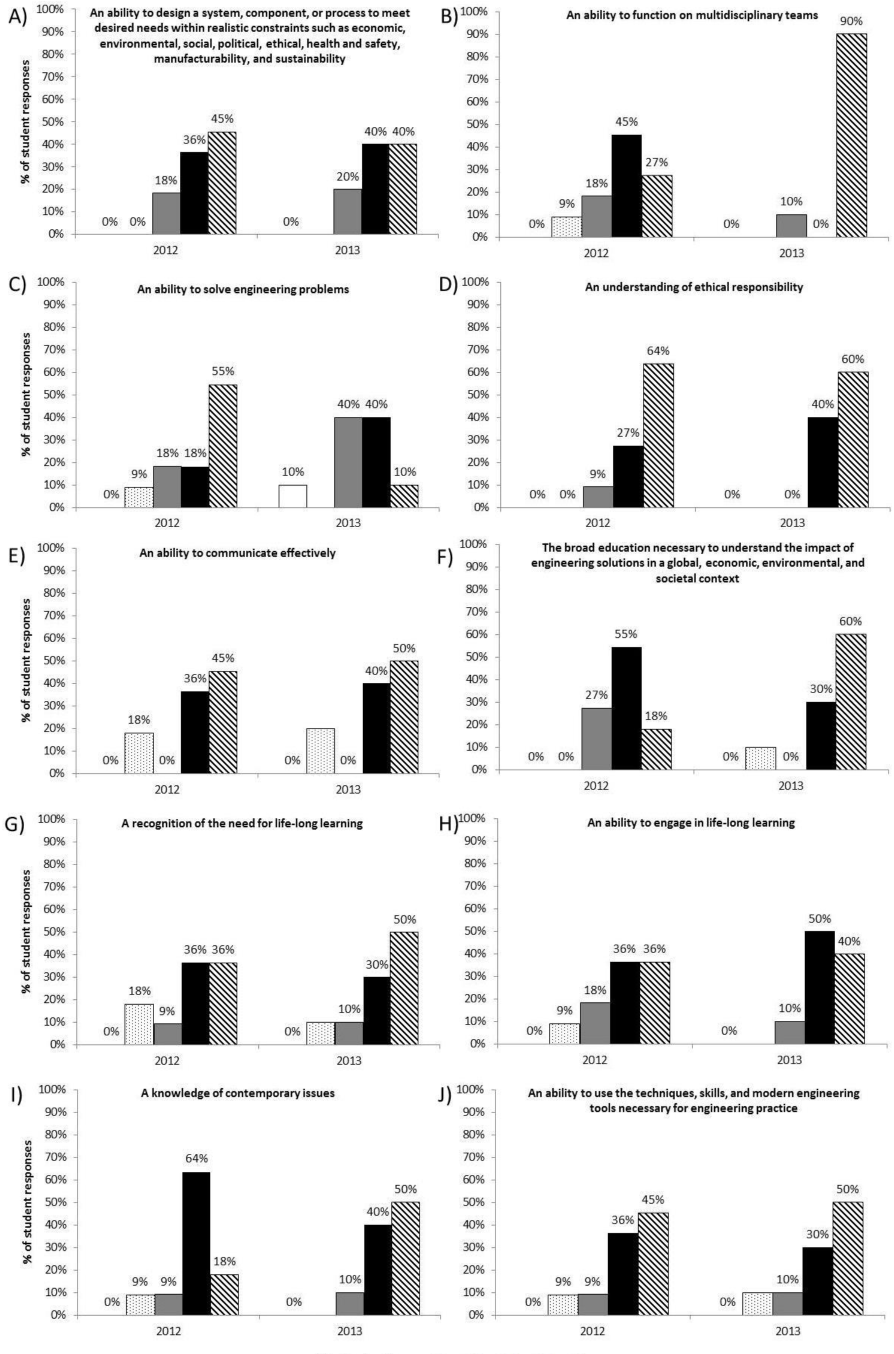

Figure 3: Student outcome assessment results. Percentage of students rating their perception of their ability for each outcome for one year without collaboration (2012) and one year with collaboration (2013). Each graph is one ABET Student Outcome or component of one ABET Student Outcome assessed for the course. Eleven students were assessed in 2012 and ten in 2013.

Lessons learned about collaboration and virtual teams

The work required of faculty to coordinate this program is intense and critical to the success of PATU. Faculty recruit projects and mentors, coordinate delivery of course material, manage teams and project progress, and coordinate the short-term study abroad program (Figure 1). The key to successfully completing the required work is regular and open communication. Faculty at each institution communicate daily through email, online chat, and telephone. In addition, faculty meet face-to-face at least once each year, which is critical for morale and understanding between faculty at each institution. While today's technology allows for clear visual communication through the internet, there is something to be said for a good hand shake and sitting next to a person for a serious discussion about lessons learned and future work that needs to be completed.

A key lesson learned during implementation of this program is the critical need for appropriate video conferencing technology; a dedicated distance-learning classroom would be ideal. During the program, classes at each institution meet at the same time and a faculty member lead both groups of students via video through Elluminate and Blackboard. Elluminate is a video communication module within Blackboard and allows for video communication while also showing PowerPoint slides (or other type of writing/sketches). This was done to manage faculty time as well as to give students from each school a different teaching perspective and experience with telecommunication. We found that the technology for video conferencing (single camera at each site with single microphones) that we used made teaching difficult. For example, without multiple microphones, cameras, and a technician, engaging all students from both institutions in conversation about a topic was quite difficult and often frustrating for both faculty and students. Alternatively, the technology used by students for team collaboration (typically Skype and simple integrated webcams) works very well because of the comparatively smaller number of individuals utilizing the technology at a given time.

One of the greatest advantages for students at small liberal arts institutions is the relationship developed with faculty. Students have faculty as an instructor for several courses throughout their undergraduate careers and interact with them at many different levels (e.g. advising, tutoring, and club mentoring). A lack of this history with collaborating faculty has, in the past, caused some stress in students and impeded progress on design teams. We would like to find a way to make it possible for each faculty to spend a few days at the beginning of each semester at the collaborating school to enhance the understanding the students have of each of the faculty involved in the program and their intentions.

In addition to strong relationships with faculty, students in small programs such as ours also develop distinct relationships within their cohort. However, many of the usual challenges of teamwork can be amplified in virtual teams. It is critical that faculty appeal to the goal of the project (producing a life-changing device for a customer with a disability) and use difficulties as an opportunity to talk about team dynamics. It is also essential to have at least two students from each school on each team so that it is difficult for a single student to be marginalized. We also found that categorizing projects and making final deliverable expectations clear helped to reduce the level of anxiety that can occur with unrealistic expectations while providing a challenging project with tangible results.

Finally, in the past faculty allowed teams to decide which campus would build their prototypes and final devices. This meant that the non-building campus did not get the opportunity to take part in that phase of the project where many times new challenges are faced. While the choice of building seemed reasonable, especially given limited resources, in the future, we plan to have both campuses work to build prototypes if at all possible. Final devices may still only be fabricated at one location.

The study abroad trip was first piloted in Summer 2011. Students and faculty both felt the trip was a unique and life-changing experience. The reaction of patients to the devices that we delivered was also unforgettable. Emotions were high as they expressed their appreciation for our projects, explaining how they never dreamed such assistance was even possible for them. Our patients' love for life, determination to find a way to improve their conditions, and sincere appreciation of our work, sparked in us (both faculty and students) admiration and desire to continue our projects for as many underprivileged persons with disabilities as possible.

This unique pre-capstone experience has helped shape the way we teach engineering design, allowing us to observe students as they complete the entire design process, utilizing the classical tools often published in engineering design process textbooks. By implementing the process early, we see the advantages and disadvantages to the structured design process and the various tools available to make design choices, and can make changes to those tools and processes we use in later courses. Overall, this program and collaboration has improved our students' learning, especially of the "softer skills" required of today's engineering graduates, including multidisciplinary teamwork, communication, social responsibility and global awareness (Figure 3). While these lessons are especially applicable to small liberal arts institutions with limited resources, the improvement of critical skill such as communication and the ability to work on interdisciplinary teams suggests that this pedagogy could also enhance these attributes in students at large institutions. Collaborations between smaller and larger engineering programs could provide benefits for both institutions. We know that the details of implementing this program will continuously evolve, but will always remain rooted in the importance of collaboration.

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