DESIGN COURSE PROJECTS THAT AID PERSONS WITH DISABILITIES

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Abstract – Several challenging issues must be addressed when developing class projects for introductory and intermediate design classes. The students have limited technical backgrounds. Large course enrollments conflict with the desire to have students work in small teams. Developing design course projects based upon devices to aid persons with disabilities can address many of these challenges. For the past 3 years we have implemented this approach in an introductory mechanical design course (50 students) and in an intermediate level course (20 students). Project topics are readily obtained from local and regional organizations that deliver services to persons with disabilities. Multiple appropriate level projects are simultaneously executed in the same class. Each project focuses on the design process and includes building and evaluating a prototype. Final oral and written reports are required. The nature of these projects also requires that the students address a variety of other issues including application of engineering within a societal context, ethics, confidentiality and professional behavior.

Index Terms – design projects, introductory design courses, assistive technology, persons with disabilities

INTRODUCTION

It is well recognized that a significant design experience is an essential component of an engineering education. The 2002-03 Criteria for Accrediting Engineering Programs [1] states that student preparation for engineering practice must culminate in a major design experience which is often referred to as the capstone design project. This capstone design experience should incorporate engineering standards and realistic constraints such as economic factors, environmental issues, sustainability, manufacturability, ethics, health and safety, social impact and political issues.

Capstone design projects that aid persons with disabilities are well established. The National Science Foundation (NSF) began the Bioengineering and Research to Aid the Disabled (BRAD) program in 1988. The goal of this program was to fund undergraduate design projects to develop custom devices to aid persons with disabilities [2]. This program is ongoing under the name of Research to Aid Persons with Disabilities (RAPD) [3]. Annual compilations of the senior design projects produced with program funding have been published under the auspices of NSF [4]-[5].

One goal of introductory and intermediate design courses is to develop skills, tools and experiences that will prepare students to engage in capstone design activities later in their academic careers. Teaching these courses can be a very challenging endeavor. These courses often have large enrollments and the students have limited technical backgrounds. The focus of these courses tends to be on the design process with emphasis on topics such as defining the problem, setting design criteria, developing multiple preliminary designs, selecting a final design, analysis of that design, and building and evaluating prototypes. It is difficult to focus upon the design process as an abstract issue in the absence of significant participation in solving a real design problem. It is also difficult to construct purely academic exercises that mimic the true design process. Thus there is a need to introduce real life project experiences into beginning and intermediate design courses. Student motivation is often improved when working on real problems rather than academically generated problems. Giving students some level of self-selection in choosing the project also aids in improving motivation. The lack of student background necessitates developing projects whose solutions are considerably more limited than those found in capstone design projects. The desire to have the students work in small teams can conflict with the relatively large class sizes, particularly in courses that emphasize oral presentations. In large classes, using a single or just a few projects that have a limited number of solutions results in presentations that are repetitious. Student groups working on the same project should present their findings in the same class period so as not to give students who present later an unfair advantage.

Thus the real challenge to reaping the benefits of having small groups of students work on projects in introductory and intermediate design courses is development of a sufficient number of appropriate quality projects and devising effective methods so that multiple class projects can be executed simultaneously. For the past 3 years we have successfully developed and implemented design projects that aid persons with disabilities in two courses; an introductory mechanical design course (ME 2300) and an intermediate level design course (ME3506).

BACKGROUND

Both Introduction to Engineering Design (ME 2300) and Rehabilitation Engineering (ME 3506) are process oriented.

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design courses. Both courses have several common features, the most notable of which is being organized around student design projects that are based upon aiding persons with disabilities. At our institution, courses meet in a 7 week format. Both design courses meet 5 times per week and the design projects are conducted over the final 4-5 weeks of the course. In each class, multiple projects are conducted simultaneously with 2-3 teams containing 3-5 students assigned to each project. The teams are expected to follow the design process [6] including problem definition, background research, developing design specifications, creating multiple preliminary designs, final design selection, analysis, prototype construction and evaluation. At the end of the project, each student group gives a formal oral presentation and submits a written report. Specific information about each of these courses follows.

Introduction to Engineering Design (ME 2300) is directed toward sophomore Mechanical Engineering students and is intended to be the first design course taken by these students. The course is offered each fall with a typical enrollment of 50 students. Most students will have a firm foundation in mathematics, physics and statics. Many have been introduced to computer aided design and manufacturing processes and most will be concurrently taking a course in stress analysis. The course objectives focus on the steps in the design process, how to work on a design team, structured design methods and the application of these methods to a design problem. Oral and written communication is emphasized. Course topics include the design process, project planning, searching product literature and patents, decision matrices, functional decomposition, customer assessment, benchmarking, brainstorming, concept generation and preliminary prototyping.

Rehabilitation Engineering (ME 3506) is an intermediate level design course directed towards junior and senior Mechanical and Biomedical Engineering students. The course is offered annually to about 20 students. Students are expected to have a firm background in statics, dynamics, stress analysis, and materials processing as well as an introductory course in design. Many students will have also completed courses in electric engineering, organic chemistry, thermodynamics and fluid mechanics. The course objectives focus on the design process and the application of fundamental engineering principles to the development of assistive technology devices. Course topics include an introduction to disabilities and assistive technology, anthropometrics and ergonomics, the user (human-machine) interface, and the design process for assistive devices. The course uses assistive technology as a vehicle to emphasize mechanical and electromechanical design. Students in this course are nearly evenly divided between those interested in rehabilitation engineering topics and those interested in taking an intermediate design course.

METHODS

Four to six weeks before the beginning of the class, projects are solicited by email from previously developed contacts at potential sponsoring agencies that provide services to persons with disabilities. The email solicitation describes the project schedule, the likely outcomes from a project, the sponsor commitments that are necessary to participate, instructions on how to submit a project proposal and a reference to a web address where past class projects have been highlighted. These contacts were originally developed through our Assistive Technology Resource Center (ATRC) [7]. While the ATRC structure has been used to facilitate soliciting class design projects, this process could easily be replicated using a much less formal structure. The important features that the ATRC provides are an email database of contacts in agencies that provide services to persons with disabilities, a means to efficiently submit proposed projects via either email or a web-based form and finally a web page where descriptions and results from past class projects can be viewed [8]. These same features could easily be set up on a university web page associated with an engineering department, an individual professor, a particular course or a group of courses.

The email solicitation for projects states that groups of 2-5 students work on a project suggested by a sponsoring agency for approximately 1 month. As a minimum, each group is expected to develop a crude prototype of their concept for solving the problem and a set of detailed drawings to enable construction/implementation of the final design. Since multiple groups work on the same problem, a wide variety of potential solutions are likely to be explored. The solicitation states that students are likely to be highly motivated since they are working on real problems. Finally, it is noted that the sponsor is invited to the final oral presentations and receives copies of the student reports.

Each sponsor must agree to appear in person or by videotape to introduce the project to the class. The sponsor must also agree to communicate with the project teams in a timely manner during the execution of the project. Most communication is by email and/or phone. Since both design courses meet daily, timely communication is defined as responding to student messages on a daily basis.

A 1-2 paragraph description of the potential project is requested. Almost all projects submitted by potential sponsors are associated with meeting the needs of a specific client or group of clients. The course instructor promptly reviews the proposals for appropriateness of the topic and for the technical level of the project. Design requirements for devices for persons with disabilities are usually highly individualized. Often the sponsor has conducted an unsuccessful search of commercially available products prior to proposing the project. If this has not occurred, the instructor will conduct a product search to minimize the possibility of a single commercial product satisfying all of
the design requirements. Since the courses emphasize mechanical and electromechanical design projects, submissions with a major emphasis on software development are not appropriate. It is common for the instructor to visit the prospective sponsor’s site to gain further information before making a final commitment to offer the project.

Almost all project sponsors choose to appear in class to present their project rather than appearing by videotape. The sponsors recognize that students have a choice in selecting their project and view the class appearance as an opportunity to market their project. There are considerable secondary benefits to these class visits. The project presenters are typically from professions such as occupational or physical therapy, special education or social services. Their view of technology and its applications in a societal context is generally quite different from that of the engineering students in the class. Each design project is usually associated with a specific client that the sponsor has identified and it is common for the sponsor to bring the client to meet the class. If the level of disability prevents the client from traveling to campus, the sponsor will arrange for the project groups to meet the client in the setting in which the device is to be used. Up to 8 distinct projects are usually developed for the introductory design course (50 students). One or two of the projects may be from sources other than those associated with persons with disabilities. In some cases, a more complex problem may be divided into components and presented as 2 distinct projects. Usually 3 projects are developed for the intermediate level design course (20 students).

After all potential projects have been introduced to the class, students are asked to list their project preferences. The instructor then creates 2-3 teams of 2-5 students each to work on each project. It is very rare that a student is not assigned to a project that was either his/her first or second choice. Team size varies according to the perceived complexity of the project. Team sizes in the introductory course usually have 4 students, while teams in the intermediate course most often have 2-3 students.

The project teams are expected to follow and document the design process throughout their project [6]. These steps generally include background research on the client’s disability, searching product literature and patents, development of a concise goal statement, development of task (i.e. design) specifications, creation of distinct preliminary designs, selection of a final design, analysis of the final design, development of a working prototype or in some cases a model, and evaluation of the prototype or model. Throughout the project, the student teams maintain contact with the sponsor, usually by email. Visits to the sponsor/client site are quite common. Oral and written progress reports are required at various project milestones. Depending upon the type of project, a modest university supported budget of $25-$75 may be available for prototype construction based upon a formal budget request.

Both oral and written reports are required at the end of the project. Oral reports for all teams working on the same project are scheduled for the same class period. The sponsor and client are invited to the final oral presentations. All past sponsors have attended the presentations and often become very involved in the discussion of the projects.

Written reports are expected to be of professional quality and document the development, testing and evaluation of the prototype. Detailed drawings of all components, and a bill of materials are required. After the course ends, copies of the student reports are forwarded to the sponsor. Student prototypes of sufficient quality are transferred to the sponsor. The sponsor is responsible for evaluating the prototype and deciding if the client should use the device. This step insures that the persons most knowledgeable about the client’s condition make the final decision about device usage.

RESULTS

This project approach has been successfully used in both courses for the past 3 years. Sponsoring agencies have included two state agencies, school systems, nursing homes, adult day care centers and nonprofit agencies serving persons with disabilities. The ages of the clients have ranged from 10 to 83. The clients’ disabilities have arisen from a wide range of causes including cerebral palsy, mental retardation, multiple sclerosis, spinal cord or other traumatic injury and aging.

Project topics have been widely distributed and have included devices to improve access to computers and environmental controls, adaptations of sports equipment, vocational aids, training and educational devices and even the redesign of the harness of an assistance dog. Most projects focus on designing a new device with the goal of delivering a crude working prototype and a set of detailed design drawings for the final device. Generally, others will construct the final device. Occasionally the prototype is of sufficient quality to be used directly. The goal of a few projects has been to develop plans for a system and illustrate those plans by construction of a working model. For example, the goal of one project was to design a system that would enable a fisherman with a significant mobility disability to enter and exit his boat from his dock. Student teams working on the same problem usually develop entirely different designs thereby verifying the concept that in design there are no unique solutions.

PAST PROJECTS

Projects in the Introduction to Design course (ME 2300) emphasize concept design of mechanical devices. The student teams are expected to conceptualize many solutions, select a final design, build a prototype and evaluate that prototype. Since the students (primarily sophomores) have

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somewhat limited backgrounds, most design projects are focused on geometric and kinematic issues. The following two projects are typical of that course.

One project developed a customized computer mount for a motorized scooter. The teenage client has cerebral palsy and is a marginal ambulator. She utilizes a motorized scooter for mobility and had recently received a new computer system that is designed to help her communicate more effectively. She desired to carry the computer with her on the scooter in such a way that she can easily access it from the scooter chair. The rehabilitation engineer at her state operated school proposed the project after surveying commercially available mounting systems and concluding that she would need at least a partially customized mounting system. He hoped that the class project would develop ideas that he could pursue. The student team proposed several possible mounting systems and then built a crude wooden prototype of their final design. When attached to the client’s scooter, the design was functional but also in need of further refinement and fabrication using more suitable materials.

Another project in ME 2300 was to design an armrest mechanism for a bi-ski. The client has cerebral palsy and has no functional use of his extremities. When seated in his electric wheelchair, his arms are normally restrained to control his spasticity. He skis using a commercially available bi-ski with outriggers that is available at many ski resorts. In the past, his hands have been secured to the handlebars of the bi-ski using duct tape. The skier requested a transportable fixture that could be attached to the handlebar of the bi-ski and still allow some forward and aft motion that could be used to control the ski. Upon completion of the class project, the ATRC took the best features put forth by the 3 student design teams and produced a final device (Figure 1). Two ABS molded arm troughs are each attached to spring loaded linear slides that provide limited motion in the direction perpendicular to the bi-ski handlebar. Straps made from nylon webbing with quick release buckles are used to restrain the skier’s arms in the arm troughs and to secure the device to the bi-ski handlebar. The device was used during the 2002-03 skiing season and continues to undergo minor modifications.

Rehabilitation Engineering (ME3506) is an intermediate level design course directed toward juniors, but with a significant enrollment of seniors. Projects in this course emphasize a higher level of analysis in the design solutions. There is considerable emphasis placed on designing and evaluating the human interface. Project topics may be mechanical or electromechanical and are more sophisticated than the projects used in ME 2300. Fully functioning prototypes or models are expected. Two recent class projects are described in the following paragraphs.

One project focused on improving computer access for a client with late stage multiple sclerosis. The client is a retired engineer who still engages in productive work from his home office. His head movement is limited and he has no movement below his neck. The client uses a mouthstick to access his computer, telephone, television and stereo. He is connected to the outside world via his office equipment and the Internet. His wife works several days a week and on these days a neighbor comes by every 3-4 hours to check on the client. The client is unable to retrieve his mouthstick if he drops it. If no one is at home, he must wait until they return to resume his activities. He desired a means to independently obtain a second mouthstick. In addition, he requested a means of independently obtaining drinks of water. When the client and his wife presented the problem to the class, they also showed a video of his home office arrangement. Student teams working on this project later visited his home office. For this project, student teams constructed models of proposed mechanisms to solve both of the problems. Combinations of mechanical and electromechanical solutions were proposed.

![ARMREST MOUNTED ON BI-SKI HANDLEBAR.](image)

Another recent project involved the redesign of the handle of the harness of an assistance dog. The client for this project was a woman in her early thirties with multiple sclerosis who used a large dog for support while standing and walking. The project was brought to our attention by the nonprofit agency that trained assistance dogs to serve persons with a variety of disabilities. The user interface provided by the harness was an inverted U-shaped handle that was perpendicular to the dog’s spine and pivoted in the harness on each side of the dog. Small pull pins on each side of the harness allowed the handle to be rigidly positioned in the vertical position to allow the user to support herself and also allowed the handle to be rotated to the rear to lower it when it was not in use. The handle was poorly designed to serve a person with her type of disability. She was forced to support her weight with her hand in a pronated position perpendicular to the dog’s spine, the pull pins challenged her level of fine motor control and when not in use the handle did not rotate down far enough towards the ground.
dog’s rear to allow the large dog to fit under a table such as might be present in a restaurant or lecture hall. The student teams produced several independent designs. The sponsor is evaluating whether to pursue the student design shown in Figure 2. This design allows the user to support herself by placing her hand either perpendicular or parallel to the dog’s spine. Grasping a small bar positioned below the handle activates raising and lowering the handle. The profile of the handle in the down position satisfies the requirement that the dog be able to comfortably fit under a table.

**FIGURE 2**

**PROTOTYPE OF HANDLE FOR DOG HARNESS**

**DISCUSSION**

Introductory and intermediate courses are often viewed as preparing students for undertaking more complex and sophisticated problems at the more advanced stages of their educational program. Introductory and intermediate level design courses tend to focus on student preparation for senior year capstone design activities. By using a project based approach in these lower level courses, the students’ programs begin to address many of the items present in ABET Criterion 3 [1]. The students must design a device or system that meets a desired need. They must function on an engineering team that identifies, formulates and solves an engineering problem. The teams must realize their design through the construction of a prototype. In addition, the teams must communicate effectively through oral and written reports.

ABET Criterion 3 also contains a number of items, such as ethical responsibility, safety and societal context, that are often difficult to address in a design project in an integrated as opposed to an “add on” manner. Design projects that aid persons with disabilities naturally address these issues within the context of a “real life”, problem solving situation. Issues such as ethics, confidentiality and professionalism are prominent features that must be addressed while conducting these projects. These projects bring forth an increased understanding of the application of engineering within a societal context. Aiding persons with disabilities is clearly a contemporary and political issue that will become increasingly discussed in public forums as the population of the United States ages. In addition, these projects promote class discussion of the differences in how persons with disabilities are viewed throughout the world.

Several advantages result from having multiple project teams work on the same design problem. The student solutions to the same problem are usually quite different. The teams present their findings to the entire class. Thus, on days when oral presentations are scheduled, there is a continuous reinforcement of the concept that there are many possible and acceptable solutions to the same design problem. Since several solutions are developed, there is a considerable benefit to the sponsor and the client. It is not unusual for sponsor to combine concepts developed by different teams to create the final design. The student teams often develop a considerable sense of pride in their work. Personal interaction with the potential recipient of their design is a strongly motivating factor. In addition, while the project is not intended to be a competition between teams, the students clearly recognize that the sponsor may chose to utilize only one of the solutions and this provides an additional motivating factor.

Student comments about the design projects have been very positive. The course evaluations used at our institution ask the open-ended question “What did you particularly like about this course?” In the most recent available reporting periods, 82% of the students (14/17) in ME 3506 and 41% of the students (17/41) in ME 2300 answered this question by identifying the design projects. Many of the students commented explicitly on the small team approach, the personal interaction with the client, and the experience of building and evaluating the prototype.

It should be noted that several of these benefits can only be achieved when the student teams develop reasonably independent solutions. Student background at the level of introductory and intermediate design courses limits the sophistication of the projects that can be used. Thus there is a real limit to the number of teams that can effectively work on the same project. Final oral presentations are expected to be substantive and to allow time for some questions. As noted previously, teams assigned to the same problem should present their findings in the same class period. If the presentations are scheduled in the standard one hour class period, these factors limit the number of teams assigned to a single project to 3-4 with the higher number being more applicable to the introductory course.

An advantage to soliciting projects for multiple courses is that the cooperating agencies do not have to tailor their proposals to suit a particular level of student. The instructors are able to review the proposed projects and assign them to either course based upon their level of difficulty and sophistication. The introductory course is
offered in the fall, while the intermediate level course is offered in the spring. If a project proposal received from the solicitation for one course is more appropriate to the other course, the sponsor is notified that the project will initiated within 6 months.

Virtually all of the project sponsors have been very satisfied with the outcomes of the student projects and this has led to additional project submissions. Agencies that provide services to persons with disabilities often network in other settings. New sponsors often contact us after having heard about successful past projects. Since the project proposal form is continuously available on the ATRC webpage, we receive project submissions throughout the year.

Six months after completion of the class, we attempt to contact the sponsor and/or client to determine the final results of the project. Design is a consumer/client oriented endeavor. Tracking the final project results can simply be viewed as the final step in the design process. Projects whose results are less successful than originally anticipated can be analyzed and used as case studies in future offerings of the course. It should be noted that commercially produced assistive technology devices have a high rate of abandonment, particularly within the first 6 months of use. In a limited study, student assistive technology produced through capstone design projects has been shown to have a similar abandonment rate [9]. Thus it is advisable to gather data about the effectiveness and impact of the class projects after at least 6 months have passed. These data can be used to identify common deficiencies in the student designs and thus could result in increased emphasis on certain course topics.

Our contacts for soliciting class projects were initially developed while establishing the Assistive Technology Resource Center. However this process [7] could easily be replicated for the sole purpose of developing contacts with potential sponsors for class projects. Briefly, preliminary meetings were held with some service provider agencies to establish initial contacts and gain a better understanding of their needs. We then convened a focus group and invited a wide range of service provider agencies to attend. This focus group then identified the needs and opportunities that we could potentially address.

Several types of problems can occur during execution of the projects. Initially, problems resulted from some student teams significantly underestimating the amount of time it takes to construct and evaluate a reasonable prototype of the design. To alleviate this problem and insure completion of the projects in a timely manner, the instructor now clearly establishes the expected milestones that will be reported in each of the weekly progress reports. There is a need to be flexible when dealing with clients. One project was cancelled just before being introduced to the class, when the client experienced a significant change in his medical status. This resulted in additional design teams being distributed to the remaining projects.

In summary, by focusing upon design projects based upon devices that aid persons with disabilities, we have been able to overcome some of the common problems associated with introductory and intermediate design courses. First, we have been able to readily develop a sufficient number of projects to allow students to work in small teams on real problems that are appropriate to the level of the course. By limiting the number of teams that work on a single problem, we assure that the student solutions are reasonably independent. Thus the final oral project presentations continually reinforce the concept that often a design problem has multiple acceptable solutions. A second major benefit of class projects in this topic area is that they automatically introduce issues such as professionalism, confidentiality, ethics, health and safety and societal impact in a real life situation.

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**REFERENCES**


[8] [http://www.me.wpi.edu/Research/ATRC/](http://www.me.wpi.edu/Research/ATRC/)