AC 2007-1281: DESIGN FOR THE DISABLED AS AN INTERDISCIPLINARY LABORATORY PROJECT

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Design for the Disabled as an Interdisciplinary Laboratory Project

Abstract

The integration of design into engineering curricula is important for the education of well-qualified engineers. While all accredited engineering programs are required to provide a major capstone design experience, the integration of design throughout the curriculum is often challenging. The departments of biomedical engineering and industrial engineering at Western New England College have developed a design experience completed as a requirement in senior engineering laboratory courses. The design project experience is in addition to the capstone design courses. This experience was used to demonstrate students' ability to function on multi-disciplinary teams, design a system within realistic constraints, and understand the impact of design solutions in a societal context.

Introduction

A cornerstone of engineering education is design education. Accredited programs are required to provide a capstone design experience in which students integrate knowledge gained from their coursework. For many engineering programs, design education begins in the freshman year where students are introduced to the design process.[1, 2, 3, 4] Following this freshman experience, many students are not required to implement the design process in a systematic fashion until they perform their capstone project . Integration of design across the curriculum is challenging since the outcomes of most lecture courses rely predominately on mastery of subject matter.

Both freshman and capstone design courses for biomedical engineering students often involve the design of assistive devices for disabled individuals.[5, 6, 7, 8] Much of the impetus for these types of projects is the availability of funding from the National Science Foundation through the Research to Aid Persons with Disabilities program and its predecessor, the Bioengineering and Research to Aid the Disabled program. These programs have been providing funding for the design of assistive technologies by engineering students since 1988.[9] This funding has helped initiate such capstone courses as Devices for People with Disabilities at Duke University.

In an effort to provide design opportunities for undergraduates outside of the freshman and capstone experiences, as well as a chance to work on multi-disciplinary design teams, faculty members in biomedical engineering and industrial engineering at Western New England College have developed a design experience completed as a requirement in senior engineering laboratory courses. Interdisciplinary teams of biomedical engineering and industrial engineering students, in collaboration with a local nonprofit agency, designed assistive technologies for disabled individuals to provide increased accessibility to employment opportunities. While the projects are similar to those performed in some biomedical engineering capstone design courses, the integration of such design projects into a laboratory environment, and the opportunity for students to work on interdisciplinary teams, make this experience unique.

Design Projects

These projects were inspired by the NISH National Scholar Award for Workplace Innovation & Design.[10] The purpose of the National Scholar Award is to foster innovation in the design of assistive technologies by undergraduate and graduate students in collaboration with community-based nonprofit agencies to increase the participation and advancement of disabled individuals in the workforce.

The design projects were developed in collaboration with Goodwill Industries of the Springfield/Hartford Area, Inc., a local nonprofit agency that employs disabled individuals in light manufacturing work. Many of the manufacturing processes at Goodwill were not amenable to individuals having specific disabilities, e.g., visual impairments. The projects were approved by the Institutional Review Board at Western New England College as well as by the appropriate administrators at Goodwill. Since the projects involved individuals with disabilities, the work could not be considered exempt and thus the application was reviewed and approved by the Institutional Review Board, rather that the Human Subjects Subcommittee.

This project was a 5-week experience in the senior laboratory courses for both the biomedical engineering and industrial engineering students. A total of 9 biomedical engineering students and 7 industrial engineering students participated in the laboratory courses. Interdisciplinary teams composed of 3 or 4 students designed appropriate assistive technologies to provide increased accessibility to employment opportunities for individuals working at the Goodwill facility. A single team worked on a particular project. The teams followed a five-step design process of problem identification, analysis, brainstorming of solutions, evaluation of alternative designs and selection of the most appropriate design, and specification of the design using a report meeting the standards of the NISH National Scholar Award guidelines and a prototype device.

The projects revolved around a multi-step process for the assembly of accordion style folders, a manufacturing process performed by Goodwill for the federal government. Assembly of the folders begins with the notching of corners of card stock, followed by cutting of tape used to assemble two pieces of notched card stock into a single folder. The tape is then placed adhesive side up on a flat surface and moistened with a damp sponge to activate the adhesive. Pieces of notched card stock are then placed at the appropriate position, on either side of the adhesion tape and the tape is then folded over the card stock to complete the major assembly of the folders. Once the two pieces of card stock are joined, an accordion fold is manually manipulated in the adhesive tape.

Both biomedical and industrial engineering students toured the Goodwill facility to view the folder assembly process. Based on these observations, three steps of the process were chosen for improvement. These steps were tape cutting, joining of the card stock with adhesive tape, and placing of the accordion fold.

Prototype Designs

The prototypes for tape cutting and folder assembly are presented in this section.

Tape Cutting Fixture

The tape cutting process requires that workers cut tape to a length of 26". The existing process requires the operator to feed the tape to a specified length designated by marks on a table and then, while holding the tape, cut it to length. Workers without fine motor skills could perform the operation, but the resulting tape was frequently cut longer than necessary and the cut was not perpendicular to the tape edge. This resulted in a waste of tape. Workers with limited or no use of one arm were not able to perform the tape cutting operation. The student-designed fixture is shown in Figure 1.

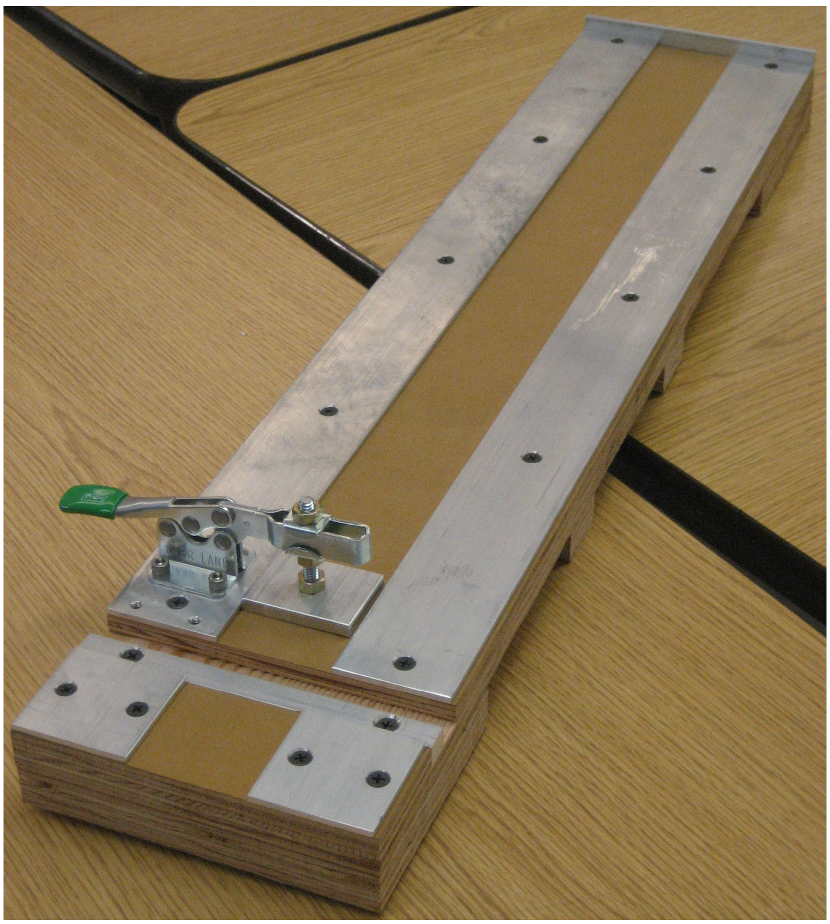

Figure 1. Working prototype of fixture for holding tape during cutting.

The process for tape cutting requires feeding the tape to a positioned stop, closing a toggle clamp and the cutting the tape at the indicated slot (Figure 2). Using the fixture, the tape cutting process can be done with one hand. In addition, the operation is now more accurate with consistent length tape being cut.

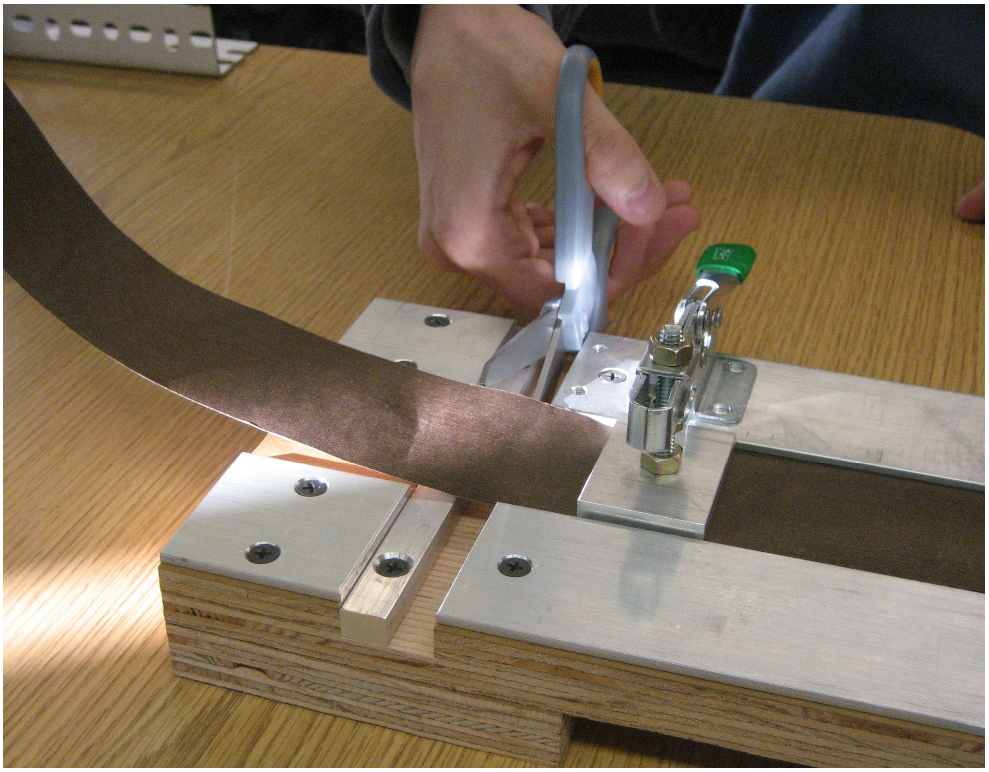

Figure 2. Scissors are used to cut the tape to length while being held in the fixture

File Folder Assembly Fixture

The process for assembling the folders begins with adhesive tape placed adhesive side up and then moistened. The folder covers are then positioned such that there is a ½" space between them on the tape. The tape is then folded over the center to join the two sides. The fixture designed provides recessed areas for locating the tape and the covers. Finger holes are provided for moving tape ends over the center and at the sides for removing the completed folder. The fixture was constructed with aluminum for durability and stability and for water resistance. The design of the fixture enables different orientations (horizontal, inclined, etc.) depending on worker preference. A solid model of the file folder assembly is shown in Figure 3.

Prototype Testing

The prototypes described above were delivered to the Goodwill facility and tested by workers who had previously performed the process as well as by workers who, due to their disability, had not been able to previously perform the process.

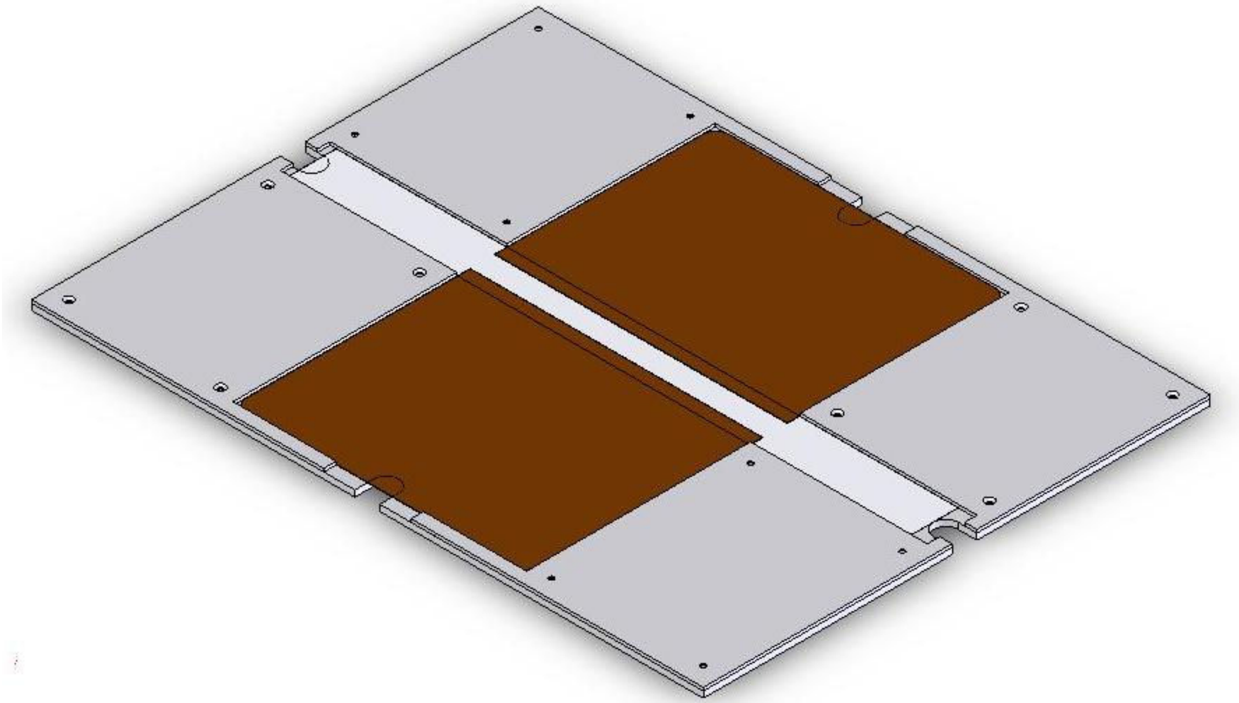

Figure 3. A SolidWorks assembly drawing of the folder assembly fixture showing the tape adhesive side up and the card stock covers in place.

Previous operators of the tape cutting process have reported satisfaction with the fixture. Operators who were not able to perform the process previously include one who has limited use of one arm and another who cannot use scissors. The operator who cannot use scissors has used a utility knife with the fixture to effectively cut the tape. The students have observed the operators and also received feedback from the production supervisors. Based on the feedback, an improved fixture is being designed that can be oriented for left or right hand tape feeding and cutting.

The folder assembly fixture has been used by several operators who have reported on their success in using the fixture. This includes visually impaired operators who are now better able to assemble the folders. Other operators like having the flexibility to orient the fixture to suit their reach. Short operators like to have the tape horizontally; taller operators prefer to orient the tape slot perpendicular to their body.

Integration of Design Experience into Laboratory Courses

The departments of biomedical engineering and industrial engineering at Western New England College have shared a common design experience within their senior laboratory courses for many years. This common experience had previously involved ergonomic analysis and a paper redesign of a biological safety cabinet, but did not involve the building of a prototype. Thus, it was not easy to assess student ability to design solutions within realistic constraints.

The experience was designed to be conducted over a 5-week period in each of the laboratory courses. Students toured the Goodwill facility prior to the beginning of the experience to gain an understanding of the manufacturing environment. Interdisciplinary teams were assigned prior to the first lab meeting. The first laboratory session involved a review of the design process and team meetings to rate the provided projects. Deliverables at each subsequent lab meeting were problem analysis, proof of concept, prototype, redesign if appropriate, concluding with the final report and device design. Due to delays in IRB approval, some of the student teams were unable to test their designs at the Goodwill facility and thus completed only through the prototype phase.

Although the experience was designed to meet the stated outcomes of designing within realistic constraints, teamwork, and an understanding of the societal impact of their designs, students derived many more benefits from this experience. The experience provided an open-ended problem similar to one they may confront in their capstone design course. The students gained an increased appreciation of geometric tolerancing and dimensioning and were able to interact with the machinist model maker to realize their designs. These experiences will be useful as they transition to their capstone projects and beyond.

Assessment of Results

The desired outcomes for this experience were to demonstrate students' ability to design a system within realistic constraints, ability to function on multi-disciplinary teams, and understanding of the impact of design solutions in a societal context.

The ability to function on multi-disciplinary teams was assessed using a peer evaluation form (Appendix). Students were asked to rate each of their own team members on team performance on a 0 to 10 scale, with 10 representing exemplary teaming behavior. A poor peer evaluation by teammates could lead to a lower score on the project for a team member. Students previously used this type of peer assessment during their freshman engineering design course and are familiar with this format. Based on experience using this form in past courses, the faculty members involved with this project are confident that the students fairly assess the performance of their teammates.

Student comments on the experience focused mainly on the logistics of the project. The biomedical engineering and industrial engineering laboratory courses were offered at different times during the week. This situation was unsatisfying for some students as they felt there was not appropriate time to meet with teammates from the other discipline involved in the project. During the next offering of the project, the laboratory courses will be offered at the same time, alleviating these difficulties.

The students' ability to design a system with realistic constraints is measured by the success of their prototype. This is accomplished by testing of the prototype by disabled workers at the Goodwill facility. The results of this testing show that the students have been able to successfully design fixtures that allow disabled workers to more easily perform the manufacturing tasks associated with various tasks of accordion style folder assembly.

The final outcome of the experience is an understanding of the impact of the design in a societal context. All of the students toured the Goodwill facility and saw individuals with a variety of disabilities. They gained an understanding of how their designs could impact a number of workers, many of whom could not previously perform the manufacturing tasks. The satisfaction of the engineering students who watched as a disabled worker was able to perform a task that was not possible without the assistive device is immeasurable. In addition, the design intent for this experience is counter to that to which many of the industrial engineering students are exposed in industrial settings. In general, industrial engineers are educated to make processes more efficient, eliminating steps in the process where appropriate. In this case, however, the intent was to make the process easier for the workers, rather than more efficient for the organization. Finally, the students gained a deeper appreciation of the IRB approval process, highlighting the need to protect special populations in a research setting.

Conclusion

Faculty members at Western New England College have developed a unique interdisciplinary laboratory experience based on design projects to develop assistive technologies to facilitate manufacturing processes for a local nonprofit agency. Outside of a capstone experience, biomedical engineering and industrial engineering students honed their teaming skills, reinforced knowledge learned in their coursework, designed and tested solutions to real problems with multiple realistic constraints, and obtained first-hand knowledge of the impact of their designs to society. This experience was beneficial for both its value as a learning tool and as an opportunity for engineers to contribute to society.

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Appendix

Team Self-Evaluation Form

Please indicate the relative effort of your teammates. Your evaluation will affect the grade of individual members of the team.

Use a scale of [0—10]. Use your personal judgment to evaluate each individual, especially for those team members that do not exactly fit one of the categories below. Be sure to take into account any characteristics not mentioned. For example, if a team member missed four meetings, they may still receive a good rating if they communicated this in advance to the rest of the team and they ensured that their work was supplied to the team for that meeting. Use *Overall Teaming Performance* to evaluate the individual's ability to work on a team. A good indication of your opinion about *Overall Teaming Performance* is whether you would ask this individual to be on a future team project.

10 = characteristic or behavior was shown **consistently** and was of **exemplary** quality
8 = characteristic or behavior was shown **often** and was of **very good** quality
6 = characteristic or behavior was shown **sometimes** and was of **good** quality
4 = characteristic or behavior was shown **sometimes** and was of **poor** quality
2 = characteristic or behavior was shown **rarely** and was of **poor** quality
0 = characteristic or behavior was shown **never**

Team Member Name	Meeting Attendance	Work Finished On Time	High Quality Work Was Performed	High Level of Effort	Overall Teaming Performance	Total (50 Max)
1. (self)						
2.						
3.						
4.						

Please add comments that will assist in assigning an appropriate grade