The Evolution of a Collaborative Multidisciplinary Engineering Design Experience

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Abstract

The ability to function on a multidisciplinary team is one of the prescribed abilities for graduates of ABET accredited engineering programs. We have developed a multidisciplinary design experience that pairs biomedical and industrial engineering students. This experience is a component of the senior laboratory courses taught by each of the departments. The design experience developed as an outgrowth of the collegiality of the faculty, as well as the proximity of the lab facilities.

Multidisciplinary Design Activities

Many engineering programs introduce design in first-year courses where students begin to implement the design process [1, 2, 3, 4]. While programs may offer design problems within lecture-based courses, many students do not use the design process again until their capstone design experience; and, this capstone project may not be multidisciplinary in nature. Success, however, has been reported on the development of multidisciplinary design experiences with mechanical engineering and electrical engineering students. Popular topics for multidisciplinary design projects between these disciplines include the design of solar vehicles [5, 6] and mechatronics [7]. The main goal for beginning the lab activity described in this paper was to add an additional multidisciplinary design experience into the curriculum for industrial engineering (IE) and biomedical engineering (BME) undergraduates.

The senior laboratory courses in the biomedical and industrial engineering programs (BME 405 Biomedical Engineering Senior Laboratory and IE 428 Industrial Design Laboratory III), offered in the fall semester each year, appeared to be a good place to add this activity. The structure of these lab classes offers flexibility for scheduling the project, as well as longer periods of time than traditional lecture classes for design activities. In addition, this multidisciplinary design experience provides another opportunity to emphasize the engineering design process and apply knowledge learned in fundamental and major courses. In this way, the experience serves as a prologue to the capstone design projects in each of the programs.

For all offerings of the course, students followed a traditional design process of problem identification, brainstorming of potential solutions, evaluation of design alternatives, selection of appropriate design options, and reporting of the design decisions. A summary of the activities for each offering of the design experience follows.

Year 1

The first multidisciplinary design project aimed to pair industrial and biomedical engineering students in the redesign of a biological safety cabinet (BSC). A biological safety cabinet is used to protect laboratory workers and their samples from contamination when working with biological materials. The posture required for the correct usage of the BSC can result in back and shoulder pain in laboratory workers. Thus, a redesign of the BSC, which took into account the ergonomics of various tasks performed within the cabinet, provided a platform for a unique multidisciplinary design project. Biomedical engineering students would provide expertise on the use of the BSC and the laboratory environment, while industrial engineering students would use their knowledge of ergonomics in the analysis of movements required for various tasks within the BSC.

To provide a more realistic experience, role playing was implemented to help define the roles of the BME and IE students and faculty members. BME students served as R&D engineers for a fictitious company (Bone Tissue Engineering, Inc.) that planned to expand its tissue engineering manufacturing capabilities and, thus, would purchase 100 new BSCs. IE students acted as service engineers for the company (BioSL) that had previously supplied BSCs to Bone Tissue Engineering, Inc. To secure the order for the 100 new BSCs, BioSL was required to improve the ergonomics of the cabinet. Faculty members in BME and IE served as executives for the fictional companies.

Because this was the first offering of the BME senior laboratory class, only one BME student was enrolled, providing a challenge for multidisciplinary interactions. This challenge was solved by having the BME student work as a consultant “intermediary” for three teams of IE students to help them understand the processes used for working within the BSC and the associated laboratory environment.

This first experience encompassed three weeks within each program’s laboratory course. The deliverable for each team was a report documenting proposed changes to the BSC and laboratory environment as appropriate, as well as a log book chronicling the redesign process and team communications. A peer evaluation of both the IE team members and the BME consultant were also required.

To facilitate the ergonomic analysis, the first task performed was the construction of a mock-up of a BSC. This mock-up mimicked the work area and window height of a commercial BSC. Using the mock BSC to demonstrate typical tasks performed by laboratory workers, students performed ergonomic measurements, such as joint angles and work envelopes, and performed time studies as shown in Figure 1. These data were used to suggest improvements in the design of a BSC to alleviate ergonomic concerns.

Figure 1: Measurement of Joint Angles Using Goniometry in the Mock BSC

Year 2

For the second offering of the multidisciplinary experience, the number of students in the lab courses was more balanced. Teams of three students, having at least one BME and one IE student, collaborated to again redesign a BSC. As before, BME students acted as advisors on the use of the BSC and the laboratory environment, and IE students took the lead on the ergonomic analysis. The time devoted to the design project was increased to four weeks from the three weeks, as devoted to it in Year 1.

While the redesign of the BSC based on improved ergonomics presented students with a real-world problem, they often resorted to reporting on what BSC companies did to improve the ergonomics of their products rather than proposing unique solutions based on brainstorming and creativity. In addition, since no prototypes were required, the solutions proposed by the teams may not have been realizable or practical to implement. Thus, the experience was overhauled after Year 2 to provide teams with real-world problems that required prototypes of potential design solutions for successful completion of the project.

One such experience involves the design of assistive technologies for individuals with disabilities. The design of assistive technologies has been used to teach design principles in first-year classes [8, 9], as well as in capstone design courses [10, 11]. The NISH National Scholar Award for Workplace Innovation and Design [12], which supports the development of assistive technologies by undergraduate and graduate students that enable individuals with disabilities to participate and advance in the workplace, provided a platform upon which to develop a new design experience for the laboratory classes.

Year 3

Beginning in Year 3 of this experience, student teams focused on the design of assistive technologies for the workplace. The faculty associated with this design project contacted local non-profit agencies that employed individuals with disabilities in light manufacturing work. These contacts led to an ongoing partnership between the School of Engineering at Western New England College and Goodwill Industries of Springfield/Hartford, Inc.

For the design experience, the faculty chose to improve several processes in the manufacture of a product to maximize the number of workers who could perform each process. This is in contrast to the development of assistive technologies for a particular individual, which is often the focus of capstone design projects. Many of the assembly processes at Goodwill were not possible for some workers with particular disabilities, such as visual impairments and limited use of one hand or arm.

The process performed by workers at the Goodwill facility, chosen by the faculty for improvement, was the assembly of accordion-type folders for use by the federal government. The folders are assembled using two pieces of card stock as covers and adhesive tape that requires water for activation of the adhesive. The first step in the process is to cut the adhesive tape to length; the second step is to attach the two covers with the tape; and the last step is to crease an accordion fold into the tape. Each team was assigned to design a fixture for one step in the assembly process to improve access for workers. Students toured the Goodwill manufacturing facility prior to beginning their designs to understand the context of their designs in the manufacturing process. Each team designed at least one prototype fixture; two teams evaluated their fixture in operation and then built an improved prototype. To provide time for the manufacture of prototypes, the design experience was a five-week component of the senior laboratory courses. Deliverables for this version of the design experience were the functioning prototype and a report meeting the guidelines of the NISH Scholar Award application.

The fixture for tape cutting, which made the process more accurate and reduced waste, is shown in Figure 2. The operation can now be done by those workers who previously could not perform this step of the folder assembly process, specifically those who have visual impairments and those who have limited use of one arm or hand [13].

Figure 2: Tape Cutting Fixture

These design projects presented challenges to the students in a number of ways. This lab activity requires creative design and problem solving by the students. The projects provided realistic constraints that students had to consider in their design. For example, the industrial engineering students are often tasked to reduce cost in their designs of manufacturing operations, which often requires combining processes and enables the reduction in the number of workers while maintaining or increasing production rates. A major constraint on these projects was that no processes or workers could be eliminated. The development of a functioning prototype that serves as a proof of concept is also challenging, since this may be the first significant experience in mechanical design for many of these students. In addition, for many of these students, this was the first application of solid modeling since their Introduction to Engineering class. The understanding of the relationship between individual part models and their assembly was reinforced, and the ease of manufacture of the part was also taken into account. Students are likely to face these same challenges in their capstone project; thus, a review of these concepts prior to the capstone course is beneficial.

Year 4

The design experience again involved the design of fixtures to assist workers in performing manufacturing tasks. The manufacturing process selected for improvement was the final packaging of decking screws of various sizes into boxes for delivery to retailers. The tasks involved in this process included the removal of metal decking screws from a large bin into a smaller bin for delivery to a work area; the expansion of flattened tabbed packaging boxes that would be ready to be filled with decking screws; and the removal of a fixed number of screws from the work surface for orientation and placement into the box. In addition to increasing the participation of workers in these steps of the packaging process, attention was also devoted to improving the ergonomics of the processes.

As in the previous year, the students were instructed to incorporate features in their designs to maximize the number of workers able to participate in that particular task, leading the faculty to introduce the concept of universal design. The formal presentation of universal design principles [14] to the students was performed by a NISH rehabilitation engineer.

To allow time for multiple design reviews and modifications to prototypes, this experience encompassed the entire semester in each laboratory course. Students performed the design project throughout the semester in addition to the other assignments in their respective laboratory courses. This schedule allowed for three formal design reviews. The first review was conducted by the faculty, and teams presented the results of their brainstorming. A second review was carried out by the Supervisor of Rehabilitation and the Program Director of Employment Support Services at Goodwill who chose the design concepts that each team would pursue, based on their opinion of which they felt would serve the largest number of workers. The final design review was performed by the NISH rehabilitation engineer, who suggested modifications to designs prior to the final prototype construction.

Figure 3 shows the final prototype for the fixture for box expansion. The sections on either end can slide on a track. Sliding is activated by turning one of the lever-handle door knobs.

The fixture is designed to require little force to initiate sliding, such that either a right- or left-handed individual could use it.

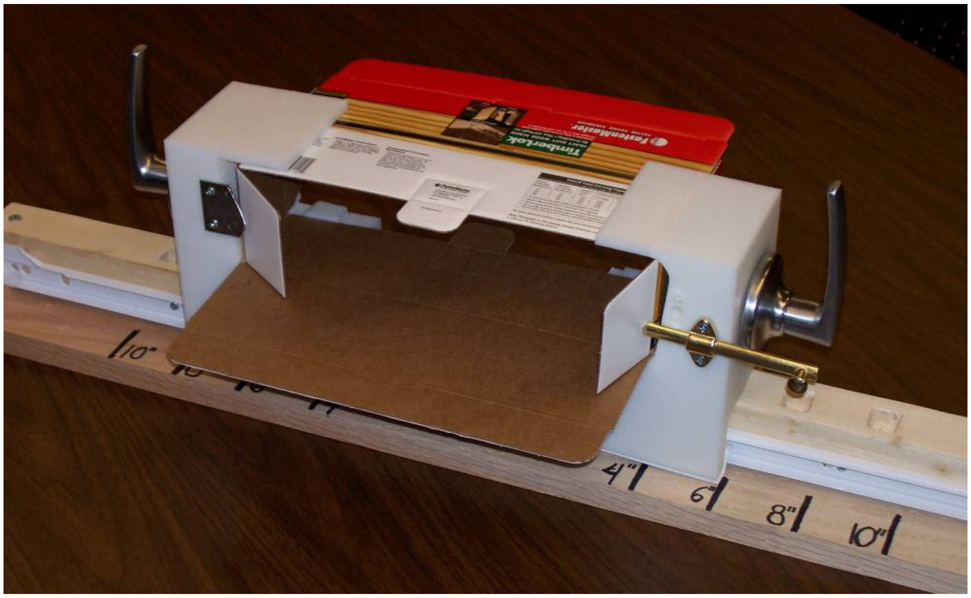

Figure 3: Box Expansion Fixture

Special Considerations for Design for the Individuals with Disabilities

Because the projects in Years 3 and 4 involved design for individuals with disabilities, the faculty members were required to receive approval for these projects by the campus Institutional Review Board (IRB). This required the generation of consent and assent forms for the workers at Goodwill, or their legal representatives, as well as a confidentiality agreement to be signed by the students. The BME students are familiar with the process of IRB approval for research, but this procedure is unknown to many IE students. Thus, in addition to gaining important design skills, these projects emphasized the responsibility of researchers to protect the rights of individuals in a research setting.

While projects involving design for individuals with disabilities require additional administrative effort, these types of projects offer unique funding opportunities. Since 1988, the National Science Foundation has funded senior projects for the design of assistive technology, first in the Bioengineering and Research to Aid the Disabled Program and then its successor, the Research to Aid Persons with Disabilities Program [15]. Additionally, NISH and the American Society for Engineering Education Design in Engineering Education Division provide seed grants to support projects that will be submitted to the NISH National Scholar Award for Workplace Innovation and Design [12]. Three of these seed grants supported projects in Year 4.

ABET Outcomes Addressed

The nature of these design projects makes them appropriate vehicles to measure many of the program outcomes (criterion 3) specified by the Engineering Accreditation Commission of ABET. The specific outcomes [16] that can be measured via this experience include:

- (c) An ability to design a system, component, or process to meet desired needs within realistic constraints, such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.
- (d) An ability to function on multidisciplinary teams.
- (e) An ability to identify, formulate, and solve engineering problems.
- (f) An understanding of professional and ethical responsibility.
- (g) An ability to communicate effectively.
- (h) The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.

In addition, the experiences in Years 3 and 4 can be used to assess one outcome unique to the Western New England College IE program, “an ability to design and improve a safe and productive work environment.”

Thus, these design experiences can be additional platforms by which design-related outcomes can be measured, especially those requiring a societal context. In addition, these experiences can be used as assessment tools for many of the outcomes related to soft skills, such as communication and teamwork.

Interfacing with External Collaborators

The fluidity of projects and the dynamics of changing production schedules at a company can affect the progress of the student effort. Workers at the Goodwill facility perform a variety of light manufacturing jobs, not all of which are performed concurrently. The specific process being addressed may not be running for a week or two, thus limiting the opportunity to evaluate prototypes with the clients.

The rewards of working with Goodwill, however, far outweigh the obstacles provided by their unique work environment. For example, the tape cutting fixture designed in Year 3 is currently in use at Goodwill’s Hartford facility. Use of this fixture has allowed the facility to be competitive and increase the number of workers on a GSA contract from four to 15. In addition, the production time for an order decreased from 90 to 45 days [13]. Moreover, the smiles on the faces of the workers, who can now be productive at a job they previously could not perform, are well worth the effort.

Conclusion

We have described the evolution of a multidisciplinary laboratory design experience performed in senior laboratory courses. We plan to continue this successful experience, which now involves students and faculty from the biomedical and industrial engineering programs, as well as Goodwill Industries of Springfield/Hartford, Inc. This experience is highly successful in providing students the opportunity to design, while considering real-world constraints, as well as strengthening their ability to work on a multidisciplinary team. Moreover, the students' designs have changed the lives of individuals with disabilities by increasing their participation in the workplace.

Acknowledgements

Design projects in Year 4 were supported through grants from NISH and the American Society for Engineering Education Design in Engineering Education Division. The authors would also like to thank Carol Hasenjager and Anne Kaboray of Goodwill Industries of Springfield/Hartford, Inc. for their support.

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ISBN 978-1-60643-379-9