

Framework for Implementing Engineering Senior Design Capstone Courses and Design Clinics

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Introduction

The capstone course is well established in management and strategy teaching, but not as heavily utilized in engineering (Kachra and Schnietz, 2008). The Accreditation Board for Engineering and Technology (ABET) emphasizes the need for engineering courses that build teamwork, communication, and project-based skills. The capstone courses aid in building and enhancing these skill sets. This paper provides framework and support structures, including a design clinic, for implementing engineering capstone projects that are interdisciplinary and industry based. In addition, this paper relates the course to ABET criteria and provides insights from students that have completed the course. The framework has been established over the past 17 years at The University of Toledo College of Engineering and has been applied to over 90 projects in the Mechanical Engineering Department. Advantages of the capstone course and design clinic are the enhancement of communication skills and a promotion of deeper learning over surface learning. As engineers are called upon to work in cross functional teams, the skills learned using this method will place them in a stronger position to be successful as they move into the workforce upon graduation. In this paper, the author draws upon his experience integrating the capstone course and senior design clinic into the curriculum.

Need Assessment and Background

As discussed by Massie and Massie, there appears to be a general lack of ability by students to function in teams and engineering faculty cannot afford to take a chance to leave team building processes to students without some guidance (Massie and Massie, 2006). A well developed capstone course can aid students in developing these skills. In addition, the adoption of Engineering Criteria 2000 and the requirement to work on interdisciplinary teams makes design projects more challenging. Sev-

eral research studies have been conducted in this field. For example, Massie and Massie examined a framework for organizing and controlling design projects by focusing on goal development (Massie and Massie, 2006). In 2007, a study was conducted at California Polytechnic State University to integrate project-based learning throughout the undergraduate engineering curriculum (Savage et. al, 2007). This study focused on materials engineering and discussed the fundamentals of project-based learning in numerous projects, including capstones. In the United Kingdom, a study was conducted that discussed the development of an engineering design center to integrate industry and academia (Hills and Bull, 2001). This provided a dedicated center for students and industry to interface for civil engineering design projects. The University of Toledo senior design clinic utilizes a similar approach that will be discussed later. From a computer science standpoint, a study was conducted that discussed the win-win aspects for students and industry in capstone projects at North Carolina State University (Fornaro, et. al, 2007). This paper focused on capstone projects to develop software systems for clients in North Carolina and discussed the results of an informal student survey. Overall, the students were very satisfied with the design projects and skills learned from the project. The justification and objective of this study was to demonstrate the benefits of the capstone course and senior design clinic for engineers and provide a framework for other universities to implement a similar program. An in depth case study was described in 1997 at Virginia Polytechnic Institute and State University that integrated rapid prototyping into the engineering curriculum (Bohn, 1997). The focus of this study was to provide mechanical engineering students the exposure to new skills that they may use in the workforce. This course was offered as an elective, but incorporated design aspects.

As a whole, these studies emphasize the importance of senior design capstone projects to build communication and teamwork skills.

Abstract

Senior design capstone projects for engineering students are essential components of an undergraduate program that enhances communication, teamwork and problem solving skills. Capstone projects with industry are well established in management, but not as heavily utilized in engineering. This paper outlines a general framework that can be used by students and faculty to create a strong, industry-based senior design capstone course. The framework has been established over the past 17 years at The University of Toledo College of Engineering and has been applied to over 90 projects in the Mechanical Engineering Department. This paper outlines the course framework, a discussion of the resources required, overviews of typical industry projects, a discussion of evaluation criteria, and a discussion of the benefits and challenges. In addition, commentary of students who have completed the course is included.

Keywords: senior design, capstone course, mechanical engineering

In addition, several demonstrate the benefits of industry-related projects and the usefulness of design centers. This paper builds upon the concepts and relates them to the senior design capstone course and design clinic at The University of Toledo by providing a framework to implement a similar program.

Description of the Senior Design Course in the Mechanical Engineering Department

The catalog description of the ME Senior Design course is provided in the 2009-2010 catalog of the University as follows [The University of Toledo, 2009]:

“Students work in teams using knowledge gained in earlier courses to solve real design, manufacturing, and operational problems relevant to industry. Oral and written communications with participating companies, as well as teamwork, are stressed. Other topics include patents, product liability, safety, ethics, and design for manufacturing.”

Class meetings, participation, and role of Course Director and Project Technical Advisor:

One faculty member serves as Course Director and is in charge of all administrative aspects of the course, including identifying the projects to be conducted by the students. Each group is supervised by a Faculty Advisor (Project Technical Advisor) and a Client Advisor. The Project Technical Advisor and the Client Advisor meet with their groups on a weekly basis.

Activities during the class meetings may typically include lectures and guest lectures on topics such as the design process, creativity, product liability, patents, and the business world. The frequency of the class meetings is determined by the Course Director. Attendance is taken at the beginning of each class period. Part of the grade is determined by attendance. Students are responsible for all materials, announcements, schedule and grading policy changes discussed in class.

Organization of Senior Design Projects:

1. Project Identification:

Senior Design projects are typically proposed by local industries, faculty and students. Each project is supervised by one or more faculty advisors and possibly an industrial contact.

Each prospective project is presented to the class in a brief (about 5 to 10 minutes) presentation by the client or Faculty Advisor during the first class meeting. Each class member submits a list of his first, second, and third choices by the end of the first week of class. Requests are submitted to the Course Director, who assigns students to projects considering, insofar as possible, student preferences. Project groups are typically selected with 3-4 group members.

2. Group Formation:

Each student group selects a Group Leader, a Technical Liaison, and a Purchasing Agent. Each group member must accept responsibility for completing his/her assignments on time and in a professional manner, and recognize that the quality of his/her work and each group member's work affects the total group performance, and, hence, group grade. The Group Leader's duties include scheduling and coordinating meetings, and coordinating assignment responsibilities (that is, when group members cannot agree, the leader must decide). The Technical Liaison communicates with the technician and machinist, when appropriate. The Purchasing Agent is responsible of all purchasing aspects of the project. The project technical advisor meets with his group on a regular scheduled weekly basis.

3. Project Proposal

Each group prepares a project proposal in consultation with their project Faculty Advisor. The proposal should include a) project objectives, b) a description of the methods to be employed, c), the responsibilities of each of the group members, d) a timetable indicating when each step is to be accomplished, and e) a proposed budget for the project.

The project proposal is to be developed as a clearly written document signed by the Faculty Advisor and a copy must be submitted to the Course Director by the end of the third week of the semester. The project proposal is presented orally to the class during the fourth week of the semester.

4. Design Phase:

Beginning in the fourth week, each group must submit brief written weekly progress reports summarizing their activities and the results obtained. These progress reports should be signed by each group member and the Faculty Advisor. For the midterm, each group prepares a detailed report on the status of their

project and makes an oral presentation summarizing the progress made and discussing the challenges and successes.

5. Implementation Phase:

Starting in the tenth week, each group implements its design recommendations by a) constructing and testing a prototype, b) implementing a test program to collect needed design data, or c) continuing analysis to include software development, etc. During this phase, each group will develop a task list and schedule for the completion of the project. Some of the tasks may involve ordering parts and scheduling work with the department machine shop. Only the Technical Liaison contacts the department machine shop, and only the Purchasing Agent contacts the department budget coordinator for all ordering and material pick-up.

Students cannot order any materials before having a budget approved by both the Faculty Advisor and the Course Director. Each project purchase must be approved by the Faculty Advisor or the Course Director prior to release of an order. A Senior Design Projects order form must be used to purchase any item. This form is available on the web and must be approved by both the Faculty Advisor and the Course Director the first time an order is placed. Students cannot exceed their approved budget and are not generally allowed to purchase or order material using their own funds.

A final written report and a web page are due on the last day of classes. A standard engineering report format includes: a) a cover sheet, b) an abstract (executive summary), c) an introduction (this should include a statement of objectives, as well as salient information to bring the reader up to speed), d) the body of the report: methods, analysis, results, etc., e) conclusions, and f) appendices (such as: calculations, data tables, computer programs, etc.). Each group will present its design report orally. Each of these presentations (approx. 15 minutes) is scheduled during the final examination week. Every group member must participate in this oral presentation. Additionally, a design exposition is planned during the final examination week. Participation is mandatory in both of these events.

6. Grading:

Letter grades are assigned at the successful completion of the course objectives. Grading consists of two components: group (same grade for each group member) and individual (distinct grade for each individual). Each group

member will be required to submit an evaluation of all his partners. This evaluation will be used in determining both peer and supervisor ratings.

Course Objectives and Outcomes

Each project is designed to address several of the following objectives included as part of the evaluation criteria for the engineering programs and align with the ABET Student Outcomes (a – k):

- a. Ability to apply knowledge of mathematics (including differential equations and statistics), science and engineering.
- b. Ability to design and conduct experiments, as well as make measurements on and interpret data.
- c. Ability to design a system, component, or process to meet desired need.
- d. Ability to function on multi-disciplinary teams.
- e. Ability to identify, formulate, and solve engineering problems.
- f. Understanding of professional and ethical responsibility.
- g. Ability to communicate effectively.
- h. Broad education necessary to understand the impact of engineering solutions in a global/societal context.
- i. A recognition of the need for, and an ability to, engage in life-long learning.
- j. A knowledge of contemporary issues.
- k. Ability to use the techniques, skills and modern engineering tools necessary for engineering practice.

The following is a list of the course outcomes; many are tied to ABET criteria:

1. To be able to work in self-directed teams.
2. To be able to communicate your work to others.
3. To be able to create product specifications based on customer needs while recognizing environment, economic and societal factors.
4. To be able to perform a design of a system or product based on product specifications.
5. To be able to generate design alternatives.
6. To be able to evaluate design alternatives using both analytical approaches and engineering judgment.
7. To be able to use engineering software packages in design activities.
8. To be able to build a prototype within a specified time period and within a budget.
9. To be able to test a prototype and com-

pare its performance to design specifications.

10. To be able to understand the ethical responsibility of an engineer in design.

The Senior Design Clinic

Joint ventures between educational institutions and area industries have always proven to be beneficial partnerships. These joint ventures are not new for The University of Toledo. Area industries have played a long-standing role in the successful educational process for students. The Senior Design Clinic is a joint collaboration among the ME department Senior Design students, faculty and industries. As participants in the clinic, students work in teams using knowledge gained in earlier courses to solve real world design, manufacturing, and operational problems relevant to industries. Oral and written communications with participating companies, as well as teamwork, are stressed. Other topics include design for manufacturing, patents, product liability, safety, ethics, technical report writing, and presentation skills. Industries play a major role in the success of this program by providing an engineering project challenge and technical, as well as financial, support. As members of the clinic, the industries seek and obtain a solution to a specific engineering project or problem relevant to their organization within a short time. Secure labo-

ratory space is provided for the students and clients that is equipped with computers, fax, phone, hand tools, and dedicated workspace (Figure 1).

Primary Purpose of the Design Clinic

The primary purpose of the senior design clinic was to form a partnership between students and the industry, and enhance their senior design capstone course experience. Students would take the skills they garnered through their three or more mandatory cooperative education experiences and use them to perform as a consulting team during the senior design clinic experience. The clinic was the administrative and financial side of the academic experience. Course work was delivered by a faculty member whereas the consulting activities were administered by the clinic director. Students would graduate with over a year of experience working with industry through co-op and the senior design capstone experience. At the completion of the project, several of the students would garner full time employment through the company they had interacted with during senior design. Additionally, students were given parameters in regards to leadership roles, budgetary preparation, peer evaluation, travel expenses and reporting and accountability to their team. All of these expectations prepared the students to enter the work force full-time upon graduation.



Figure 1: Senior Design Clinic

How Students use the Facilities

Students used the room primarily as a consulting office. The room is secured by individual codes associated with each student's identification number at The University of Toledo. This procedure was put in place so students would be self-policed. The clinic is outfitted with a computer, printer, telephone, fax machine, laminator, office supplies, conference table, and chairs, as well as a refrigerator to keep beverages for clients who meet in the clinic. Students are to use the clinic and the equipment therein to conduct whatever business takes place between the team, the client, and the client's company. This alleviated the need for students to depend on the departmental staff and their offices to conduct senior design business. Students used the room to access research information, call and fax clients, meet with their team and clients, and prepare mid-term and final reports, along with other document preparation. The room was also outfitted so that one entire wall was glass. This window allowed several projects from past clinic experiences to be displayed and showcased to all visitors and potential future students during college and departmental tours.

Professional Development Activities

During the classroom experience students are exposed to a number of speakers from the industry. Many of the speakers are alumni of the college. Speakers present workshops on presentation skills, presentation preparation, patent law, proprietary information, process and planning, financial planning and other topics related to the culmination of their engineering degree experience. Because the department was awarded the NSF grant for work with the disable community, the class is also exposed to a speaker who instructs the students on how to interact with someone with a disability. Past speakers have been a faculty member from the University of Dayton who was paralyzed from the chest down because of a surfing accident at the age of 19, as well as the executive director of the Ability Center for Northwest Ohio, who is also disabled. The speaker is usually someone who has worked with the disabled, or is disabled themselves. Additionally, students participate in a senior design exposition at the end of the semester. The exposition showcases all the projects for the current semester in which senior design took place. Approximately 3,000 invitations to schools, industry, parents, local and state government officials and clients advisors are sent out. Local media is contacted

and press releases on both the exposition and the students' accomplishments are sent out to local newspapers, as well as newspapers of the students' hometown. The exposition takes place the last Friday of the semester for four hours. The event is attended by several hundred guests who visit each table and see students demonstrate their projects. Students are required to dress in business dress, prepare a poster board explaining their project, and have their prototype available for demonstration. They are also required to wear a name tag with their degree/discipline and the name of their project. This allows industry visitors to possibly interview students for a potential position at their company. The booklet that was mailed out with the is also available to visitors that day and is also used as a recruiting tool for visiting students and industry guests.

Initial Challenges Associated with Implementing the Senior Design Clinic

The director of the clinic was given three weeks to organize and coordinate the clinic by the beginning of the fall semester. Challenges facing the set-up of the clinic were internal in nature. A space needed to be identified which could house 10 to 15 students at any given time. A room needed to be set up so groups of four to five students could work cohesively without interfering with meetings or work being conducted in the area. Equipment for the clinic such as a phone, a fax machine, a computer terminal, a printer, a lamination machine, a security key pad, furniture and displays needed to be ordered, installed, and placed. This required a coordinated and cooperative effort from offices at the University of Toledo who were already taxed because of a major construction initiative on campus. The clinic was constructed primarily as a consulting office and as a place for students to meet with faculty and industry advisors. So, an additional challenge was finding a location to build and store the projects once they began to go from design to prototype, as some projects were sizeable in nature.

Interaction with Industry and Problem Resolution

Projects were solicited by the director of the clinic who was the industry and alumni contact for the department. Projects were solicited by tapping into the department's alumni base and industrial advisory board. The department had a consistent record of inviting members of the industry to visit prior to the creation of the senior design clinic. Natural partnerships with these

individuals and companies allowed the director to solicit 29 projects prior to the fall semester. With the abundance of projects available, department students were given the opportunity to give first, second, and third choices which created enthusiastic teams on each of the projects. Projects not picked up for fall semester were carried over to the spring semester once industry members gave their consent and were re-offered to spring semester students. Some of the projects required a team of students in addition to mechanical and industrial engineering students. Should an industry partner request an interdisciplinary team, the department of discipline was contacted and students were given the option of joining the team and given course credit through their home department. Protection of proprietary information was a concern, however forms were signed by all interested parties which protected the company from liability and gave patent rights in name only to the students and faculty members participating. All monetary rights were the sole ownership of the industrial partner.

Overview of Senior Design Projects in the Mechanical Engineering Department

Senior design projects in the ME department fall into one of two categories; industry based projects or devices to assist individuals with disabilities. The industry based projects satisfy a business need for a company, such as vehicle design, or analysis and testing. Some of these projects involve confidentiality agreements and work at the client's facility. The second category, design devices for individuals with disabilities, is funded by a National Science Foundation (NSF) grant. The NSF provided a mechanism in 1988, through the Bioengineering and Research to Aid the Disabled (BRAD) program of the Emerging Engineering Technologies Division and subsequently the Biomedical Engineering and Research to Aid Persons with Disabilities (BME/RAPD) programs of the Division of Bioengineering and Environmental Systems (BES), to encourage student engineers at United States universities to design and build devices for persons with disabilities [NSF, 2009]. The principal goals for this project are aimed at training undergraduate mechanical engineering students in applied bioengineering design, and to improve the quality of life for disabled individuals, which is in accordance with some of the stated objectives of the BME/RAPD programs [NSF, 2009].

Currently, about 20 universities in the country receive funding from the RAPD program to support undergraduate engineering Senior Design projects directed to aid individuals with disabilities. The University of Toledo is one of those funded universities. These Senior Design projects consist of the design and fabrication of custom built devices for physically challenged individuals. These projects are conducted in collaboration with an agency in town that is dedicated to promoting independent living, and the projects result in the design and construction of devices that will assist disabled individuals to better enjoy their lives and realize their maximum potential without suffering from the associated financial burdens. Written reports on the completed projects are submitted for annual publication in the yearly NSF book for Engineering Senior Design Projects to Aid Persons with Disabilities. Also, an annual re-

Academic Year	# of completed projects	# of students involved
1993-1994	24	95
1994-1995	22	90
1995-1996	24	102
1996-1997	28	112
1997-1998	24	92
1998-1999	22	85
2000-2001	20	86
2001-2002	18	74
2002-2003	22	90
2003-2004	20	83
2004-2005	26	100
2005-2006	28	111
2006-2007	24	89
2007-2008	22	90
2008-2009	22	87
Total	91	1,299

Table 1. Senior Design projects conducted in the ME department at the University of Toledo

port that includes a description of the completed projects is provided by the Principal Investigator by July 1 of each grant year.

Since 1993, over 90 undergraduate senior projects have been successfully completed and implemented by ME students at our University. These projects involved 1,299 senior engineering students, as summarized in Table 1.

Examples of Successful Senior Design Projects

In what follows, we present four representative projects. The first project is a typical mechanical engineering project, while the second one is an interdisciplinary project that combined mechanical and electrical aspects. The third and fourth projects are industry sponsored projects.

Project 1: Development of a compact and mobile scissor lift to transfer a wheelchair user to and from the deck of a pool (Manual et al, 2004).

This project was conducted during the fall 2003 semester and four students were involved: Josh Manuel, Phil Clement, Erik Pakulski and Robert Godiciu. A 17-year-old female with C6 tetraplegia is a competitive swimmer. She has good use of her upper arms, little use of her lower arms and hands, and no use of her trunk and legs. This individual practices at a swimming pool three to five times a week, which requires her to get from her wheelchair to the deck of the pool so she can get into the water. Her previous transfer system was very dangerous and stressful, as she transferred manually from her wheelchair to an intermediate step approximately half-way between the seat height and floor. That procedure required the assistance of another person, which is why the client wants to move from her wheelchair to the pool independently and as comfortably as possible.

At that time, no specific product was available on the market for this type of situation. Seat lifts were available on the market; however, such devices are primarily used in assisting an individual out of a chair and are directed toward the elderly. Since the client has absolutely no use of her legs, this device would be useless in this application. Another option would be the use of a scissor-lift mechanism, which is primarily used in construction applications. However, those scissor lifts on the market deal with large applications and loads; and they are heavy, cumbersome, and expensive. Since no commercial item fits the needs of the client, it was

necessary to develop a small, compact scissor lift to raise and lower her from the height of a wheelchair seat to the deck of a pool and vice-versa.

The design requirements were specified by the client as follows: the unit must be stable on wet surfaces, allow easy and independent setup by the client, durable and rust-proof. Also, the seating must not be slippery or irritating to the skin, and the unit should be lightweight for transportation. The initial design was an automated system that would have a scissor-lift frame powered by locking gas charged springs, a linear actuator, or hydraulic cylinders. A switch or lever arm within reach of the client would activate any one of these motion generation mechanisms. This design would allow minimal effort to be exerted by the client to operate the system and would provide great stability. A House-of-Quality approach was used to evaluate the different methods of powering the scissor lift. The linear actuator was found to be the best choice. Aluminum framing was used with a cloth seat.

As shown in figure 2, the unit includes a lower frame and an upper frame. Both frames were made from 1" diameter round aluminum with 1/8" wall thickness. Cross members were added to provide stability. They were attached to linear slides that were connected to the upper and lower frames. One linear actuator was attached to the fixed lower frame and the moving upper frame. As it extends, the cross members slide along the upper and lower frames and the upper frame rises. Two 12-volt rechargeable batteries were used to power the linear actuator. The batteries were attached to the lower frame and were wired to a toggle switch within reach of the user. The linear actuator was rated to provide 1,350 lbs of force to lift 250 lbs.

The dimensions of the unit are 19" from the seat to the floor, 15" wide and 20" deep. The lower frame is elevated 4" from the floor. To facilitate the transportation, two 24-inch wheels were attached to the rear of the unit, and two small wheelchair caster wheels were added to the front. To provide a stable unit during transfer, locking brakes were added to the rear wheels of the unit. The brakes were activated by a single lever within the reach of the client.

Machining and several parts were donated by Invacare Corp. The unit was tested by the client, as shown in figure 3. It was found stable. Transfer to and from the unit was easy and comfortable. The unit itself functions fully as a manual wheelchair and as a powered lifting device. The unit can be easily disassembled for

storage. For this purpose, the seat is moved to the lower position and the wheels are removed. The scissor lift can be picked up and rolled away. Total cost of parts and supplies was \$1,300.00. The students designed a web page that describes this project that can be found at the following URL address:

http://www.eng.utoledo.edu/mime/design_clinic/design_expo/Fall03Pages/2003-04-06/home.htm

Project 2: Development of a vertical wheelchair platform lift for home access (Bellante et al, 2004)

This project was conducted during the fall 2000 semester and five students were involved in this project: Susanne Bellante, Eric Stevens, Tully Esterline, Anthony Vonderembse, and Kurt Knapke. This project involved the design and construction of a vertical wheelchair platform lift to be used by a paraplegic man with limited use of his arms. The individual used to enter and exit his home using a long ramp

in front of the house. This was inconvenient and unsafe for him and his family; he could not easily exit his home during the winter when the ramp is covered with snow and ice, and he would be at risk if the ramp would ever be inaccessible during a fire or other disaster. The objective of the project was to safely lift this physically challenged individual 14 inches from the garage floor to the house level.

Five methods of driving the lift were investigated, which included using a hydraulics system, linear actuators, scissor lifts, a wench and pulley system, and power screws. A dual linear actuator system using a matrix approach was selected based on several design criteria: a smooth and independent operation, platform height, design simplicity, safety, and costs. The design parameters included the platform size, the weight to be lifted, and the amount of travel of the lift.

The platform size needed to be large enough to fit the wheelchair, leaving extra room for the client's arms as he turned the wheels to enter and exit the lift. The rear wheels of the client's wheelchair were 32 inches apart. Allowing for ample room for the client's arms as well as the switch box, the platform was designed to be 42 inches across. The weight of the individual, his motorized scooter, the platform, and its holding frame was estimated to be 500 lbs. (2224 N). A design load of 1,000 lbs. (4448 N) was used to ensure a minimum safety factor of 2. The amount of travel for the lift was 14 inches, the height of the step between his garage and his home. Also, the platform height at the lowered position could not exceed two inches from the ground to allow the client to easily roll himself onto the platform. Since the individual would operate the lift independently, the design must allow him to roll onto the platform using a forward motion from either the garage or his home.

The system, shown in figure 3, consisted of two main parts: a part that moved up and down along a fixed part: the outer frame. The platform and its inner holding frame formed the moving part. Steel rectangular tubing was used for constructing both frames. All pinch points on the lift were enclosed to prevent injury and enhance aesthetics.

The linear actuators were attached to the holding frame and the fixed outer frame, as shown in figure 4; they were wired to a capacitor and connected to a power source using a regular 110-volt wall outlet. The wire routing and electrical boxes were mounted to move up and down with the inner frame so that the only



Figure 2. CAD drawing of the unit



Figure 3. This picture shows the unit being tested

wire that would tighten during travel would be the extension cord to the wall outlet.

Structural analysis was conducted using finite element analysis software (SDRC I-DEAS) on the inner holding frame to determine the maximum stresses. The total cost of parts and supplies was \$1,200.00. The students designed a web page that describes this project and can be found at the following URL address:

http://www.eng.utoledo.edu/mime/design_clinic/design_expo/fall00pages/2000-01-06/home.html

Project 3: Development of a Letter Tray Palletizer for the Emdon Corporation

This project was completed in the spring of 2010. The objective of this project was to design, analyze, build, and test a device that would stack empty letter trays from a conveyor belt to a pallet layout of three by four and ten trays tall. This was designed for a Toledo-based company, Emdeon, which was taking steps to reduce corrugated cardboard use by replacing containers with reusable plastic trays. One major issue was that the final design of a letter tray that incorporates injection molding design, grip point features, and an acceptable stack up tolerance. The design project focused on the end effector for the tray palletizer as well as coordinating the installation and layout of a robotic arm for the conveyor system through a systems integrator. This operation was to be reliable and used five days a week for 20 hours a day with minimum down time. By using automation, a worker would be able to focus less on repetitive tasks and more on quality and organization.

Project 4: Improved Method to Apply Mold Release for Rieter Automotive, Inc.

This project was completed in the spring of 2007. Several problems existed with the method Rieter previously used to apply a Mold Release solution which affected safety, quality, waste, and cost. The previous spray system produced a large amount of overspray; this overspray caused irritation to nearby press operators and covered periphery equipment, causing cotton fibers to stick and create a fire hazard. Eliminating, or at least controlling, these safety hazards was the top priority for the new design.

Another issue with overspray was excessive waste and cost. A significant amount of Mold Release solution was going to waste when uncontained spray missed the target tool surface area. Improving the design of the spray geome-

try was very important in addressing this issue. Also, all of the presses are currently equipped with spray wands, which the operators manually control, to apply additional Mold Release as needed. Eliminating the use of these manual spray wands was a key design goal for the team in the effort to improve process control and decrease the total amount of mold release used.

Inadequate and inconsistent coverage of the Mold Release solution on the Mold Press surfaces resulted in damage to the finished parts when they stuck to the tool. This created quality issues and caused parts to be scrapped. Also, nozzles and tool surfaces needed to be cleaned frequently, resulting in lost production and increased down time. Creating a way for the nozzles to be cleaned quickly and/or preventing the nozzles from clogging in the first place were key ends to improving the tool coverage and reducing scrap. Better containment of the Mold Release spray would further reduce the frequency of cleaning.

The team designed a working prototype system to address the problems identified. In order of priority, here were the objectives:

1. Eliminate safety issues.
 - Fire Hazard
 - Operator Irritation
2. Prevent nozzles from clogging (if using a similar spray system).
3. Improve process consistency and system reliability.
4. Increase productivity.
5. Reduce maintenance (cleaning).
6. Keep material cost low and decrease amount of Mold Release used.

The finished product needed to be consistent and reliable. The team obtained materials and some donations to make this a low cost solution. The final design is easily adjustable and widely adaptable, so that Rieter can implement it on other Mold Press machines. It also was designed with many removable and interchangeable parts for easy cleaning.

The final product had four stages of implementation.

1. Spray Arm Assembly. Optimize Nozzle Number, Type, Location, Orientation, & Spray Angle
2. Spray Shields
3. Spray Curtain
4. Automated Spray Arm Cover

Figures 4 and 5 display the previous and modified designs. The modified design was completed at a cost of \$1,960 which was provided by Rieter Automotive.



Figure 4 Previous Design



Figure 5 Modified Design

Broader Impacts of Senior Design Projects Aiding Individuals with Disabilities

The objective of the grant awarded to our university by the NSF is to support the Senior Design projects performed by undergraduate engineering students. These projects consist of the design and fabrication of custom-built devices for physically challenged individuals. These projects, as they did in the past 17 years, will help and impact individuals with disabilities within the local community. At the same time, these projects increase the collaboration between our university and different rehabilitation units in the community. At the end of each semester, an exposition is organized to display the prototypes and students give final presentations. This exposition is attended by community leaders, health care providers' representatives, patients and their families, high school teachers, members of local professional societies, and our university community. External referees judge the final presentations and monetary awards are presented to the best projects. The outreach of these projects includes contributions within the discipline, contributions to other disciplines, contributions to education and human resources, and contributions beyond science and engineering.

Issues Faced Between Clients with Disabilities and Students

The students and disabled clients face a variety of issues related to the senior design projects. Initially, many of the students have had limited contact with individuals with disabilities. The students are unsure of the appropriate communication approach to make the disabled clients feel comfortable. To alleviate this concern, all students that are involved with disability related projects are required to attend a training session at the Ability Center of Greater Toledo under the direction of the Director of Community Outreach. The Director discusses the abilities and limitations of each client and shows a video titled "The Ten Commandments of Working with Individuals with Disabilities" that was created by the Ability Center of Greater Toledo. In addition, the Director attends all initial meetings involving the student and client.

Another issue faced that is related to these projects involves arranging meetings and communication. Many of the clients are wheelchair bound, have limited motor control, limited speech capabilities, have lost their sight, or have lost hearing. Travel for these individuals can be difficult and students may be required to visit these

clients at their homes. The communication barriers are reduced with support and mediation from the Ability Center of Greater Toledo.

Feedback from Disabled Clients Regarding New Assistive Technologies

Feedback from disabled clients regarding the new devices occurs through four methods. The first method occurs during the design phase. Students are required to meet with the client (or client representative) at least bi-monthly to discuss design ideas and gather feedback regarding preferences. The second phase occurs at the end of the semester; the clients (or client representatives) complete an evaluation form to assess how well the design meets the client's needs. The third phase occurs when the new assistive technology is released to the client. At that time, a waiver is signed by the Ability Center, the students, and faculty advisor to release the project to the client. At this point, the students train the Ability Center and client regarding the use of the device. The final phase occurs continuously after the new assistive technology is released through the Ability Center. The Ability Center monitors the usage of the device and reports back to the course instructor regarding functionality, concerns, repair, or modification needs. This usually occurs twice per semester and more frequently for high priority concerns.

Feedback from the clients and Ability Center have been very strong. Many of the students that are involved with these projects continue to maintain a relationship after the course has ended. Quantitatively, on average the disabled clients have rated the quality of the final designs a 4.2 on a scale of 0 (does not meet client's needs) to 5 (strongly meets client's needs).

Contributions and impact within the discipline:

These projects will have the following impact:

- 1) Helping the engineering needs of the local Ability Center (our partner)
- 2) Impacting the educational infrastructure by allowing students to enhance their understanding of physiological, environmental, psychological, and biomechanical factors that influence the design of products that are aimed at enhancing quality of life for disabled individuals.
- 3) Enhancing the education of engineering students by providing them with the opportunity to design and build a device that meets a real need.

Contributions and impact to other disciplines:

These projects will have the following impact:

- 1) Impacting the special needs community to contribute to an educational process that they normally would not be aware of.
- 2) Impacting the health care providers by providing a fertile atmosphere with an organized setting to solicit and carry out projects in a very positive way.
- 3) Allowing disabled individuals' participation in recreational activities that they may not have been able to get involved in.

Contributions and impact to education and human resources:

At the end of each semester, an exposition is organized to display the prototypes designed and built by the engineering students. This exposition is attended by community leaders, high school teachers, patients and their families, and the university community. These activities provide exposure to science and technology for pre-college teachers, young people, and other non-scientist members of the public.

Contributions and impact beyond science and engineering:

These projects will help and impact disabled people within the local community by providing them with devices that are designed to improve their quality of life at no cost. The outreach and impact of these projects include:

- 1) Allowing the viewing audience of television, radio and newspaper to know what is going on at the university in relation to the types of projects being conducted to aid people with disabilities.
- 2) Allowing the viewing audience to know what types of services are provided within the community to aid people with disabilities.
- 3) Allowing the viewing audience to see what difference an educational experience can be when community, hospitals, and universities work hand in hand.

Technology Transfer and Intellectual Property

Considering that the end result of the project is a technological project, students have a tremendous opportunity to learn about technology transfer and intellectual property. The Design Clinic integrates this into the course by dedicating one lecture period to the related issues. A

Patent Lawyer from the university's Technology Transfer Department provides a presentation and holds a question/answer session that covers patents, trademarks, commercialization, and entrepreneurship. The Patent Lawyer also discusses the university's role in technology transfer, the evaluation of potential ideas using a standardized process, financial support inside and outside of the university, and legal aspects associated with working with an outside client on a new design.

Outcomes of the Senior Design Course in the Mechanical Engineering Department

The ME Senior Design course is the capstone event of undergraduate education. Each project is designed to address several of the "a-k" ABET evaluation criteria for engineering programs discussed previously in the Course Objectives and Outcomes section.

Assessment of outcome achievements:

An achievement of course outcomes is tested through instructor evaluation and student questionnaires, followed by faculty focus group assessment. For a course to be considered assessed, the instructor, students, and focus group must have tested and evaluated an achievement of at least 75 percent of the course outcomes. Because of the variation in grading schemes by different faculty, the acceptable achievement level in each course outcome is set by each instructor, and the level is reviewed and discussed when the focus groups perform the actual assessment. To assess their perception of the level of course outcome achievement, students rate their achievement of the course outcomes based on a scale: 1 = excellent, 2 = high level, 3 = adequate level, 4 = below adequate, and 5 = none or not covered. The acceptable level for the achievement of course outcomes is 3. Based on data from the student questionnaires and instructor's evaluations, each course outcome is rated as achieved, not achieved or not assessed by the focus group assigned to assess the course. The metric goal is 1 for achieved, 0 for not achieved and NA for not assessed.

Each course outcome is then mapped to one or more of the (a-k) program outcomes with the basic premise being that achieving the course outcomes contributes to the achievement of the (a-k) program outcomes. The assessment

method, then, is based on the measurement of the levels of achievement of course outcomes, which are then mapped to achievement of the (a-k) outcomes.

During fall 2008 and spring 2009 semesters, 48 and 39 students were enrolled in the ME Senior Design class, respectively. Table 4

summarizes the methods used to determine if the course outcomes were achieved during the 2008-2009 academic year.

Table 4 indicates that outcome number 10 related to understanding the ethical responsibility of an engineer in design and was not assessed quantitatively. We plan to use the

Course Outcome	Method of Assessment	Assessment Document	Level of achievement				
			Fall 2008		Spring 2009		Acceptable level
			Avg.	Std. Dev.	Avg.	Std. Dev.	
Outcome # 1	Peer evaluations; progress reports	Midterm evaluations peer	88.7%	12.7%	92.9%	10.7%	80%
		Final evaluations peer	87.3%	19.2%	86.9%	20.9%	80%
		Progress Reports	98.3%	5.4%	95.4%	6.1%	80%
Outcome # 2	Oral individual and group presentations	Group presentation oral of proposal	92.2%	3.8%	92.7%	4.4%	80%
		Individual presentation oral of proposal	89.4%	4%	90.6%	5%	80%
		Group Midterm oral presentation	95.1%	4.8%	93.7%	4.5%	80%
		Individual midterm oral presentation	94%	5.8%	93%	5.7%	80%
		Group final oral presentations	92.6%	3.0%	95.2%	2.3%	80%
		Individual final oral presentations	92%	3.0%	95%	3.7%	80%
Outcome # 3	Midterm report and final report	Midterm report	88.2%	5.9%	93.2%	5.4%	80%
		Final Report	90.0%	6.4%	93.1%	7.7%	80%
Outcome # 4	Midterm report and final report	Midterm report	88.2%	5.9%	93.2%	5.4%	80%
		Final Report	90.0%	6.4%	93.1%	7.7%	80%
Outcome # 5	Proposal and Midterm report	Proposal	88.9%	6.2%	90.9%	12.8%	80%
		Midterm report	88.2%	5.9%	93.2%	5.4%	80%
Outcome # 6	Proposal and Midterm report	Proposal	88.9%	6.2%	90.9%	12.8%	80%
		Midterm report	88.2%	5.9%	93.2%	5.4%	80%
Outcome # 7	Final Report	Final Report	90.0%	6.4%	93.1%	7.7%	80%
Outcome # 8	Final Prototype	Final Prototype	94.3%	4.6%	75%	33.2%	75%

Table 4. Methods used to determine if the Senior Design course outcomes were achieved

Value-Sensitive Design (VSD) approach to systematically integrate ethics into the senior design projects. In the VSD methodology, conceptual, empirical, and technical issues related to a particular design are investigated (Cumings, 2006). Specific human values that have ethical significance will be considered in the design process such as: privacy, human welfare, informed consent, usability, and other values. The VSD approach allows for incorporating ethical concerns in the design process with clear objectives and goals.

The results of the assessment of this Senior Design course that are mapped to the (a-k) program outcomes for these two semesters are shown in Table 5. This Table shows the (a-k) program outcomes across the top. Each program outcome is subdivided into three columns labeled Ok, No and NA for the number of outcomes that were achieved, not achieved, or not assessed, respectively. Focus groups, comprised of faculty members with expertise in the associated field, review each course outcome report that was prepared by the instructor of the course. The focus groups evaluate each outcome to verify the instructor’s findings and consider an assessment of 3 or higher as meeting the outcome. In addition to columns for each outcome, there is an additional column labeled 75 percent of course outcomes assessed. It is possible that a single course outcome covers material for multiple (a-k) outcomes. For this Senior Design course, and for the two semesters discussed above, there were six multiple (a-k) outcomes that the course outcomes addressed.

As identified by students, the major challenge to this capstone course is time pressure. Each group has 16 weeks to identify the client’s needs, develop proposals, develop a budget, design, build, and test the prototype. Additionally, identifying faculty members to agree to serve as project advisors can be challenging because of research and teaching loads.

Engineering Students’ Perspective on the Senior Design Course

This section provides firsthand perspectives from several current mechanical engineering students at the University of Toledo. These comments were taken from end of the semester course evaluations.

“The senior design capstone course was one of my favorite and most useful classes; it helped to improve my communication, teamwork and problem solving skills while working on a real world project”.

“Overall, I would rate this course as excellent, the resources made available to us throughout the semester, including the use of the Senior Design Clinic, made the project work much easier”.

“Being able to provide our preferences on project choices and teammates made a big difference; I was able to select projects that I would enjoy working on versus being assigned a project that was not very interesting to me”.

“The pace of the course moves very quickly and it is easy to fall behind, but regular meetings with our faculty advisor and client advisor

	A			B			C			D			E			F		
	Ok	No	NA	Ok	No	NA	Ok	No	NA	Ok	No	NA	Ok	No	NA	Ok	No	NA
Spring 09	2			1			3			1			2			1		1
Fall 08	2			1			3			1			2			1		1

	G			H			I			J			K			75% of course outcomes assessed
	Ok	No	NA	Ok	No	NA	Ok	No	NA	Ok	No	NA	Ok	No	NA	
Spring 09	2			1						1			1			Yes
Fall 08	2			1						1			1			Yes

Table 5. Achievement of Senior Design course outcomes for fall 2008 and spring 2009 semesters

helped to keep things on track”.

“The best part of the Senior Design course was being able to work with other MEs on a real world project where we could apply the skills and theory we learned over the past four years at UT”.

Results and Future Directions

The overview of this course and design clinic provided in this paper demonstrates that through a cooperative effort and a creative alliance, businesses, universities, and industries can work together to create a strong design experience for engineering students. Over 90 projects were conducted since 1993. In addition, this paper provides a framework for other institutions to duplicate the concepts and processes and adopt similar programs. The program also educates college students through practical, real-world environmental work experience and trains them to become future leaders. The projects promoted an increased involvement of the University of Toledo with the surrounding community, which contributed to an increase in media coverage on and off campus. These projects also increased collaboration between the University of Toledo and various institutions in the area.

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