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Optimizing the Partnership between Academia and Industry: The Capstone Design Projects

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ABSTRACT

In addition to their primary role as centers of knowledge, universities are increasingly viewed as economic and technical engines that contribute to local and regional growth. Partnerships between universities and industry can provide further opportunities for regional development, with each partner contributing its individual strengths to achieve a collective outcome. University- industry senior design projects partnership represents an organizational form designed to integrate pools of intellectual capital. At Indiana University Purdue University Fort Wayne (PFW), participants in this partnership bring to the table very different skills, capabilities, and organizational contexts. The alliance evolves into a shared innovation: the practical senior design project. This paper presents an examination of the importance of industrial sponsored capstone senior design mechanical engineering projects. It also presents an assessment of the importance of softer skills in the mechanical engineering profession and a discussion of the contribution that universities as well as industry can make in supporting the development of these skills. Examples of industrial sponsored projects are included.

INTRODUCTION

Most of the innovation that ultimately manifests itself in commercial applications comes from within industry, not from the Higher education institutions (HEIs). To create products that work in the marketplace, one needs a deep understanding of market demands, and few of us in higher education have that experience or the related insightful sense. Likins [1] wrote about the key phenomenon of cross- communication between the creative people on both sides, those with a well-developed sense of science or theory and those with a keen sense of market opportunities. HEIs can no longer operate in isolation. The need for engineering education change has led industry and constituents to question the relevancy of engineering programs. According to the analyses conducted by The American Society of Mechanical Engineers [2], it is common for engineers to participate in or lead project management teams, which require working knowledge of procurement, financial analysis, sales and marketing, and other non-technical areas. Rover [3] lists many important questions for educators to ask and answer regarding what to teach, how to teach it and, becoming increasingly more important, when to teach it. Thus, knowledge transfer between HEIs and industry is seen in this article as a key element of innovation in knowledge-driven economies.

Lester [4] has argued that universities have vested interests that tie them to their communities, making them a valuable local asset that can help facilitate regional development. Companies, however, are focused on their bottom line, and are more likely to relocate operations to places that offer more attractive economic conditions and technical expertise. The report demonstrated the value proposition of a university for a company can help foster a partnership that ultimately benefits the local economy.

Promoting the lifelong learning agenda is a clear aspiration within many higher education establishments. In 2000, Burnet and Smith outlined an approach to lifelong learning that has provided a bridge between the needs of small and medium-sized firms in the north east of England and the University of Northumbria [5]. Business, industry, and higher education institutions must come to a consensus on what skills, talents and resources engineers need if they are to survive in a technological society. The results of a national survey by the US Consensus Bureau on hiring, training, and management practices in American business indicate an increasing conviction among employers that colleges and universities have not adequately prepared students for rapidly changing market environments [6]. Thus, there has been an increase in emphasis on 'soft' skills in higher education engineering programs. Reflecting both the demands of potential employers as well as the creativity of course designers, modules such as first year 'study skills' and final year 'professional skills' have become more and more common [7]. Currently, engineering departments widely recognize an increasing need to equip students with effective study skills early in their university education and basic professional skills prior to graduation. These, however, are traditionally difficult modules to teach successfully to larger groups through traditional lecturing.

Knowledge transfer between undergraduate students in HEIs and industry can be achieved in several approaches. For example, at Bucknell University Product Development Center, students and engineering faculty work closely with industry counterparts in the design and development of new products [8]. The center provides assistance on various types of projects, including product design, prototype development, product testing, feasibility analysis, and process improvements.

Cooperative education is a structural educational experience where students alternate between periods sessions of work and traditional study. Thus, an engineering co-op program enjoy a unique relationship with employers in business and government as suppliers of motivated and educated students in exchange for paid on-the-job learning experiences. The impact of co-op education on engineering students was examined by many professionals. For example, Blaie et al. [9]results indicated that engineering students who completed three-semester co-op education program earned higher GPAs than non-coop students, earned more in terms of starting salaries, but it took two semesters longer to complete their undergraduate program. Regarding the co-op learning, in 2007, a qualitative research study by Jones explored the importance of connected learning in co-op education in Canada [10] and there are many important studies about work-integrated learning [11].

The "Teaching in the Factory" approach goes beyond a simple engineering co-op experience, bringing together academic rigor and real-world experiences and generating a winning situation for all constituents. This approach provides teams of engineering students with the opportunity to work on projects in a real factory environment, gives students a solid technical education, and exposes them to significant engineering challenges in a factory/business setting [12].

Mechanical engineering seniors in HEIs culminate their undergraduate educational experience with a capstone course called senior design. Senior design is a unique opportunity for industry to interact with undergraduate mechanical engineering students. In 2009, Maleki addressed the outcomes of such a course and the difficulties encountered and the means of reducing their negative impacts [13].

The focus of this paper is on the uniqueness of IPFW two senior design courses. Specific examples of industrial mechanical engineering projects are given and the methods used in assessing the outcomes of the courses are provided.

SENIOR DESIGN PROJECTS

An online survey of HEIs in the United States, one can conclude that the majorityof ME programs require seniors to conclude their undergraduate education by completing a semester capstone design course. Students organize into teams in which they apply engineering and science principles. On the other hand, students at some universities wrap up theier undergraduate educational experience with two capstone courses as a graduation requirement for their bachelor of science degrees. Usually, the two semesters approch leads to a prototype. Whether a semester or two semesters, many senior design project provides students with firsthand experience at solving real-world problems in a team environment. Educators observe this opportunity to show the final results of a semester/year of hard work by senior engineering students and celebrate with them the completion of the engineering program through senior design expos [14] and senior design banquets [15].

The capstone senior design project is intended to be the culmination of the undergraduate experience, where knowledge gained in the classroom is applied to a major design project. Faculty recognize the value of having the senior projects be sponsored by industry and have the goal of having the majority of senior projects sponsored or defined and mentored in collaboration with an industrial partner. Faculty are creative in assessing the achievements of the outcomes for the senior design courses and have different philosophical views in regarad to the owenership of the industrial sponsored projects. Furthermore, HEIs differ in the process of project solicitation, communication with sponsors during different phases of the capstone project life, and course management.

IPFW CAPSTONE DESIGN

Senior design is a unique opportunity for companies/industry in northern Indiana to partner and interact with our institution. For the students' enrollments, campus facilities, and mission of our regional institution; indeed it is a win-win-win collaboration for our undergraduate students, mechanical engineering program, and our industry partners. While faculty are very creative in developing outcomes assessment methods, I sought to assess the achievements of outcomes through the lens of interaction with industry.

Benefits for students

- Provides design experience similar to current engineering practice.
- Interacting with representatives of the sponsoring organization helps students develop greater professionalism and perspective of local industry. Some students were hired by the sponsoring companies.

- Explore the application of new technologies that are not available in our mechanical engineering laboratories.
- Apply the knowledge they have gained through their engineering courses to solve real-world problems.
- Learn to present their progress and results through regular oral and written communications with faculty as well as company members.
- Deal with real-world constraints such as budget and societal factors, marketability, ergonomics, safety, aesthetics, and ethics.
- Industrially defined problems typically have a scope that favors solution by cross-disciplinary teams.

Benefits for sponsors

- Help the advancement of mechanical engineering education in northeast Indiana.
- Provides an opportunity to see potential hires in action and to establish a mutually beneficial relationship with these students.
- Draw from faculty expertise in variety of disciplines.
- Builds sponsor-IPFW ties that may provide benefits in research and/or consulting in areas of interest to the sponsor.
- Networking at the end-of-semester presentations.

Benefits for IPFW

- Maximizing the opportunity to prepare students for a career in the mechanical engineering profession.
- Assessing the program outcomes closer to the application of knowledge.
- Ease of budget constraints to support senior design projects.
- Explore the application on new technologies with low cost and low risk.
- Draw from industry expertise in variety of disciplines.
- Meet the educational goals of the capstone design courses.
- Assessment tool for the mission of the university.
- Networking with regional sponsors.
- Seniors project's success is a good recruiting tool for HEIs without enrollment cap.

Managing the Projects

All ME students complete a capstone project by taking two semester course sequence where knowledge gained in the classroom is applied to a major design project. The department seeks regional industrial partners willing to participate in a relationship that will bring the organization and a team of students together in a problem-solving project that provides students with practical experiences and further develops their engineering education. All projects involve teams, typically 3-4 students. Multi-disciplinary projects are strongly encouraged, 5-6 students per team. The size and composition of the team match the nature and complexity of the project. Teams conduct major open-ended research and design projects. Elements of the design process including establishment of objectives, synthesis, analysis, and evaluation are integral parts of the capstone. Projects can range from designing cutting edge technologies to engineer for professional engineering societies competitions such as the Baja SAE.

Faculty Advisor: each project is advised by a faculty member from the relevant discipline with modest time release. The advisor follows a departmental grading scheme and has control of 85% of the final course grade for each student in his/her team. Usually the advisor meets with the team on a weekly basis and communicates with the members regularly. Occasionally, she/he functions as the liaison between the sponsors and the students.

Course Coordinator: while each team is supervised by a faculty member or members for multidisciplinary teams, there is an overall course coordinator for each senior design course [16]. The functions of the coordinator are:

1. Being in charge of the weekly common meeting hour.
2. Request from the engineering faculty titles and brief descriptions of any project they would like to supervise. The faculty member should indicate if the prospective senior design project is being supported by outside funding. This request should be made four weeks before the end of each semester.
3. Publicize all the prospective senior design projects received from the faculty. Students should be encouraged to go and discuss the prospective projects with the relevant faculty advisors.
4. Collect student applications for projects.
5. Organize a meeting, during the first week of the semester in which the project begins, with the senior design committee and project advisors to assign students to projects.
6. Post a list of the final team assignments on the web before the second meeting of senior design I course.
7. Give lectures (Senior Design I) that cover the following topics:
    - Formulation of design problem and developing a set of requirements which quantify the problem statement.
    - Brainstorming of conceptual designs.
    - Evaluation of conceptual designs.
    - Initial design, modeling and simulation, iteration and development of an acceptable design.
8. Arrange for at least four lectures to cover the following areas which will provide the students (second course) with:
    - Understanding professional and ethical responsibilities.
    - Knowledge of contemporary issues.
    - Recognition of the need for life-long learning.
    - The broad education necessary to understand the impact of engineering solutions in global and societal contexts.
9. Meet with all the faculty advisors by the middle of the semester to discuss the current state of the program, i.e. listen to their suggestions and concerns. Additional meetings can be scheduled if needed.
10. Meet with the capstone senior design committee after the faculty advisors meeting and before the end of the semester to update them on the state of the program and to address revisions or changes in the policies as deemed necessary. Additional meetings can be scheduled if needed.
11. Conduct a course evaluation at the end of each semester. This is an evaluation of the course

as well as of the performance of the coordinator and of the advisors. A special evaluation form is used for this purpose.

12. Arrange the time and place for the team reviews at least a month in advanced (both semesters).
13. Attend all reviews.
14. Coordinate the evaluations of the presenters by the attending engineering faculty members (i.e., distributing the evaluation forms to the attending engineering faculty members before the presentations and collecting them afterwards) and then calculate the average based on a maximum possible points of 15 (fifteen).
15. Assign a maximum of 15% of the final course grade for each student, based on activities/assignments during the common meeting hour and oral presentation performance.
16. Collect grades from faculty advisors and figure out the total grade for each student and submit the final course grade to the Registrar office.

Senior Design Committee: its charge is to continuously assess and improve the capstone senior design program. Whenever the committee deems appropriate it revises the guidelines and presents them to the engineering faculty for their consideration and approval.

- The coordinator of the senior design courses is the ex-officio chair of this committee.
- Each engineering program must be represented by one faculty member from that program.

External Co-advisors: often mechanical engineering students will work with industrial partners in a collaborative research environment. As they tackle real-world engineering projects, our mechanical engineering students and their industry sponsors are afforded unlimited possibilities for learning and achievement. The faculty team advisor usually work with an industrial co-advisors (mentors) recommended by the sponsoring company. While the external co-advisors have no direct role in assigning the grades for the projects, they assume the primary role as site educator while mentoring ME students. Generally, the role of industrial mentor is the result of the interaction with the faculty advisor.

Mentors value not only partnerships with HEIs but opportunities to provide input on quality and relevancy of HEIs curricula. This faculty-mentor-student interaction can help create a bridge between the employer and the student's academic institution by providing a vehicle for corporate input into academic studies. Indeed, mentors of our senior design projects have provided valuable feedback about course curricula and content of courses.

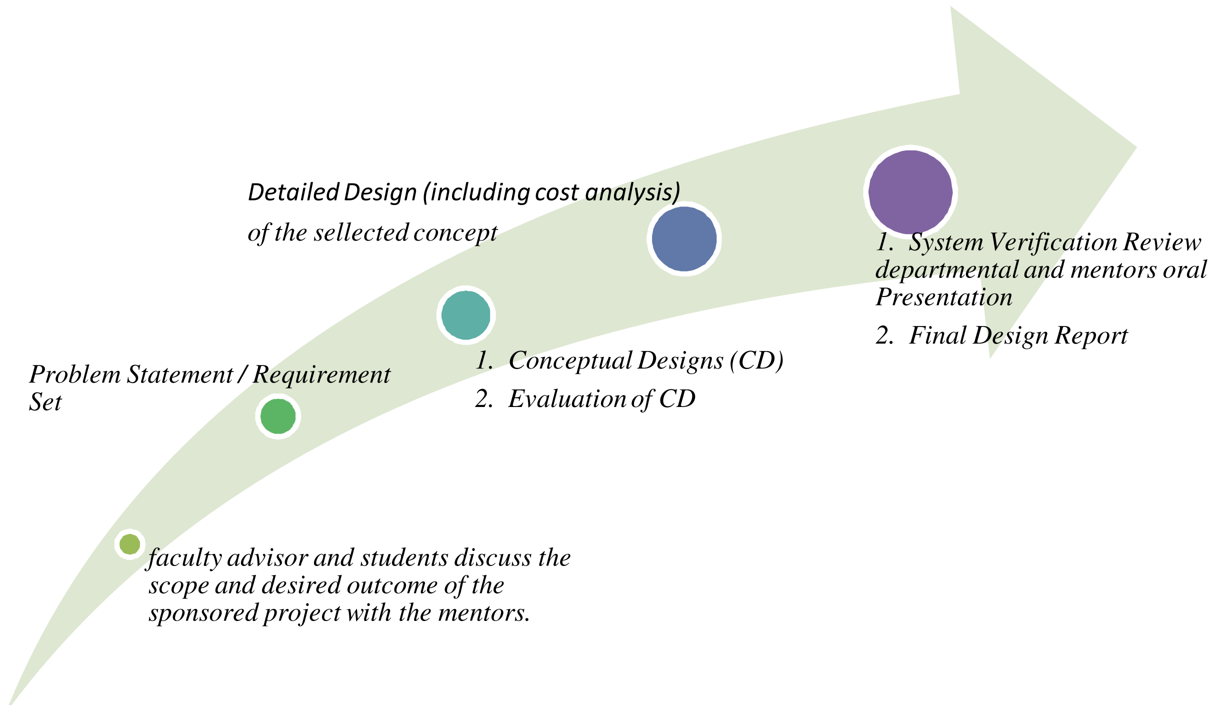
Courses Outcomes

Mechanical Engineering Design I: This is the first course in the senior design project sequence. Emphasis is placed on design team formation, project identification, and production of conceptual designs. Students focus on the development of task specifications in light of the norms for design and preliminary validation of the design by means of basic analysis and appropriate prototyping. Students who successfully complete this course will have demonstrated ability to:

1. Formulate a problem statement.
2. Generate solutions (conceptual designs) using brainstorming technique.
3. Evaluate conceptual designs using well-defined criteria.

4. Obtain a final design including safety, economic, ethical, and engineering standard considerations.
5. Function within a team.
6. Present his/her work both written and orally.

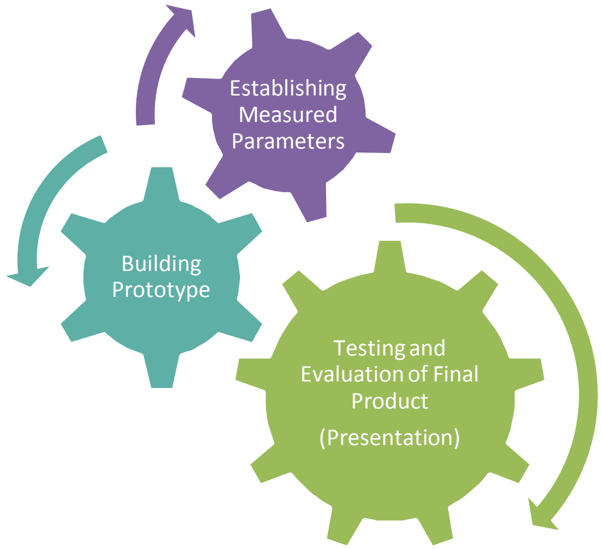
The figure below explains the sequence of achieving the outcomes by every design team.



Mechanical Engineering Design II: Emphasis is placed on the completion of a major design project analyzed theoretically in the first course. In this course, students spend more time at the sponsor's site than on campus as the theme becomes prototypes build-test-evaluate. Several mechanical engineering program outcomes can be assessed in this course otherwise difficult to assess across the curriculum. These outcomes include team dynamics, standards, regulations, product liability and quality assurance. Upon successfully completing this course the students have demonstrated an ability to:

1. Identify the various parameters that need to be determined in order to evaluate the prototype with the basic design that was obtained in the first semester.
2. Build test and evaluate the basic design completed in the first semester.
3. Function within a multidisciplinary team.
4. Present his/her work both written and orally.
5. Be knowledgeable of contemporary issues.
6. Understand ethical issues that are associated with the engineering profession.
7. Understand the societal impact of engineering.
8. Recognize the need for life-long learning.

The figure below outline the sequence of major tasks concludes in a working prototype. The issue of intellectual property may be developed. IPFW ensure that such property is protected in a manner that preserves its potential commercial value as well as allowing for its timely disclosure to the public.



Sample Sponsored Projects

Title	Design of a Universal Remotely Triggered Firing Actuator for Finger-Triggered Powered Hand-Piece
Sponsor	Zimmer Corporation
Title	Design and Development of a Fixation Instrument or System following a Trochanteric Osteotomy
Sponsor	DePuy Orthopedics
Title	Fin Compression Station
Sponsor	Parker Hannifin Corporation
Title	Design a Heat Pump That Can Deliver Water at Temperatures Above 140 F
Sponsor	Water Furnace International
Title	Constant Tension Wire Let-Off
Sponsor	Fort Wayne Metals

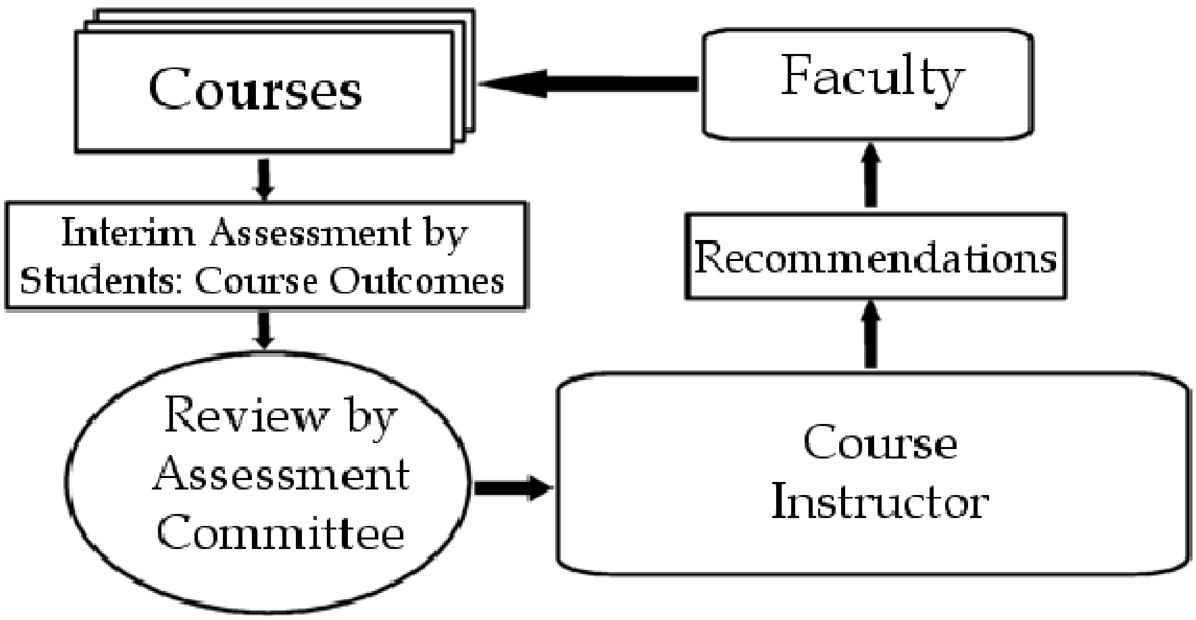
ASSESSMENT

According to ABET criteria, an engineering program must regularly use appropriate, documented processes for assessing and evaluating the extent to which both the program educational objectives and the student outcomes are being attained. The results of these evaluations must be systematically utilized as input for the continuous improvement of the program. Other available information may also be used to assist in the continuous improvement of the program.

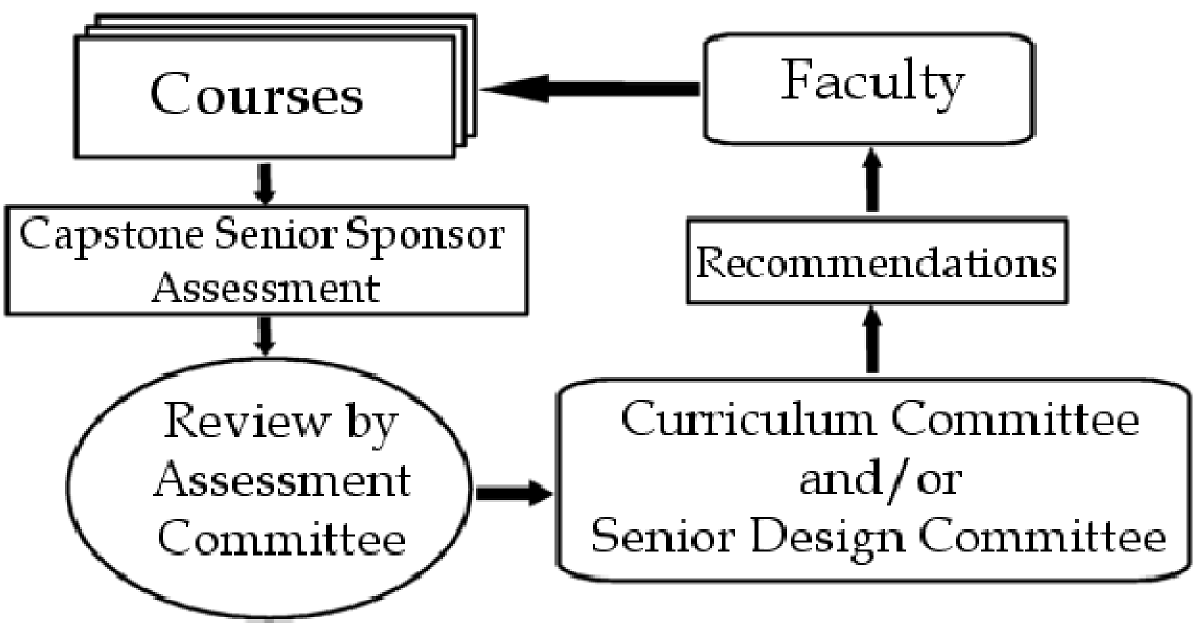
Outcomes

At the completion of each semester, the faculty advisor finalizes the departmental Course Outcome Assessment Form. This form summarizes pertinent information such as measures used to assess the course outcomes, positive and negative reflections on the course outcome achievement, suggestions, and recommendations. The form also maps the course outcomes to the program outcomes as well as ABET outcomes. The faculty feedback is used for the purpose of continuous improvement of the program. To this end, the assessment forms are reviewed by the

Assessment Committee of the Department of Engineering. In order to close the loop, if the outcome was not achieved, the faculty outlines a plan that helps in achieving the outcome. This plan is forwarded to the faculty member who will be teaching the course next time around [17]. Furthermore, the achievement of the course outcomes is assessed by all of the students enrolled in the class at the end of the semester. It is usually carried out during the week before the final exams week. The figure below summarizes the assessment process in regard to the student's feedback.



It is worth mentioning that the achievement of the course outcomes of the capstone senior design is also assessed by the project supervisors of the corresponding industrial sponsors. Utilizing the mentors input, the figure below explains the assessment based improvements.



Soft Skills

Soft skills fulfill an important role in shaping an individual's personality. It is of high importance for every student to acquire adequate skills beyond academic or technical knowledge. In 2008, Schulz discussed how soft skills complement hard skills, which are the technical requirements of a job the student is trained to do [18]. Hillmer et al. articulated the importance of social and soft skills concept in engineering education [19]. It is important to remember that the perception of what is a soft skill differs from context to context because a subject may be considered a soft skill in one particular area, and may be considered a hard skill in another. For example knowledge in solid modeling is "nice to have" for an electrical engineer, but it is a "must to have" for a mechanical engineer.

Engineering curricula are not rich in many soft skills contents. Employers frequently complain about a lack of soft skills (such as marketing, sales, project management) among ME graduates. On the other hand, legislators work on limiting the number of credit hours for bachelor's degree. It is not easy to measure the achievement of soft skill in a typical engineering course, but can be accomplished in our senior design courses.

A significant component throughout the two courses is soft skills. The accomplishments in the capstone senior design courses are assessed by the faculty members of the Department of Engineering, occasionally by graduate students, and representatives from the sponsoring companies attended the capstone senior design presentations at the end of the semester. They participate in the evaluations of the course outcomes. They report their evaluation using a formal assessment form. In the Senior Design I Form, the faculty and engineers from industry are asked to evaluate the ability of senior design students to formulate a problem statement, to generate and evaluate solutions, to obtain a final design, and the ability of the students to communicate effectively. The faculty in charge of writing the ME assessment report presents the results as shown below.

The ability of the students to	*Faculty Average*	*Sponsors Average*
Communicate effectively		
Obtain a final design		
Evaluate the generated solutions		
Generate solutions		
Formulate a problem statement		

In the Senior Design II form, the attendees are asked to evaluate the ability of senior design students to build, test, and evaluate their design and the ability of the students to communicate effectively. The results are reported in the assessment report as shown here.

The ability of the students to	*Faculty Average*	*Sponsors Average*
Build their design		
Test their design		
Evaluate their design		
Communicate effectively		
Build their design		

Communication

Scholars and industry leaders alike are touting the growing importance of communication skills in the engineering profession. Engineers may be technically competent; however, they often lack good communications skills that are necessary in order to transfer information and reasons. This situation makes excellent technical skills superfluous. It is obvious that communication skills are critical tools for success. Dulevičius and Naginevičienė provided a brief outline on the engineering communication study program as it relates to students and discuss the essential features of communication skill [20]. In 2007, Suggestions for communication skills development were made, including the hypothesize that communication skills be integrated across the curriculum, rather than include it as a stand-alone subject in already packed engineering curricula, so as to reinforce student learning [21]. The table below summarizes the communication activities during the senior design year at IPFW.

Communication	Brief description	Audience (evaluators)
Written	Weekly memos	Advisor
Oral and (written)	System Requirement Review – Faculty members and the project advisor assess the completeness and suitability of the problem statement and resulting set of requirements which quantify the problem definition	Departmental faculty and students (advisor)
Oral and (written)	Preliminary Design Review – Faculty members and the project advisor assess the selected conceptual design to confirm that the design approach satisfies the requirements, risks are under control and that the preliminary design is ready to be detailed.	Departmental faculty and students (advisor)
Oral	Critical Design Review – A formal end-of-semester oral presentation of the detailed design.	Students (faculty and sponsors)
written	final design report	Coordinator (advisor/mentor)

Below is the form used by faculty and sponsor to evaluate the end of semester presentations. The average of evaluators' scores is 15% of each senior design grade.

OUTCOMES/CONCLUSIONS

This paper presented the knowledge transfer between HIEs and industry through the senior design projects. It also examined the importance of softer skills in the mechanical engineering profession and a discussion of the contribution that sponsored projects can make in supporting the development of these skills.

IPFW Senior projects focus on the synthesis and application of the basic science, mathematics, engineering and design skills taught in earlier courses. It also provides the students with the opportunity to exercise and apply the more advanced material taught in the senior year. Our sponsored capstone design classes give students a rigorously challenging, real-world, innovative engineering experience. As a result, several practical projects benefited the students, sponsors, and the university.

In today's industry, there is an increasing demand for engineers who don't just have excellent competence in their field of specialization but also a good understanding and practical experience in the so-called social and soft skills. These subjects are usually not adequately addressed in engineering degree programs. A significant component of IPFW senior design courses is soft skills development which is difficult to assess through the curriculum. Thanks to our generous sponsors, the mechanical engineering students learned to handle team managements issues, effectively presented their design ideas, incorporate standards and realistic constraints, and learn the business side of the mechanical engineering profession. The knowledge transfer between the ME program and industry has led to products that are built by students, now being utilized by sponsors. This interaction between academia and industry has enhanced the assessment of the ME program outcomes. Indeed, some industrial senior design mentors serve on the industrial advisory board of the department and few sponsors hired the students as mechanical engineers upon completing the project and thus graduation. The discussion with students and also their course evaluations give a clear indication that the learning for these skills is generally high.

	Score: 0 to 100			
Project Title:	*Presentation Order*			
	1	2	3	**4**
Evaluator: ______________________				
Clarity of presentation				
Level of organization				
Ability to follow the sequence of presentation				
Confidence level of the presenter in what he/she is presenting				
Ability of the presenter to answer questions				
Content of presentation				
Presentation overall				
Average				

Comments: ____

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