University-Industry Joint Programs:
Engineering Design Education

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Abstract: This paper describes cooperative efforts among academic and industrial entities in offering instruction in engineering design. The Department of Mechanical Engineering at the University of Texas at Austin offers a capstone design course, which requires student teams to create engineering design solutions to problems found in industrial and commercial environments. The paper discusses pedagogical advantages provided by industrial sponsored design projects. Students cooperate in student design teams addressing open-ended engineering problems. The teams address design problems requiring both analysis and synthesis on technical issues. Additionally, students must address issues involving safety, aesthetics, professional ethics, professional liability, and intellectual property. This kind of design experience not only prepares engineering students to enter the practice of engineering, but also addresses many of the topics required for accreditation by the Accreditation Board for Engineering and Technology.

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1. Introduction

The world provides an infinite opportunity for engineers to add value to the society they serve.

The Department of Mechanical Engineering at the University of Texas at Austin uses industrially generated and industrially sponsored problems as a basis for capstone design projects. The Department includes an unusually broad range of disciplines including Energy and Fluid Systems, Mechanical Systems and Design, Nuclear Engineering, Operations Research and Industrial Engineering, Materials Science and Engineering, Manufacturing Engineering, and Biomedical Engineering. The Mechanical Engineering Degree Program requires its students to complete a "capstone" design experience" during their senior year. The capstone course represents a "major engineering design experience that builds upon the fundamental concepts of mathematics, basic sciences, the humanities and social sciences, engineering topics and communication skills".[1] The Department offers capstone design projects that reflect the diversity of the department's various disciplines.

The Department places emphasis on the capstone design experience. The importance of engineering design undergraduate experience is supported in the literature[2,3,4,5] and is also exemplified by the Accreditation Board for Engineering and Technology (ABET) Criteria cited below.

> ABET Criteria I.C.3.d.3.d. Each educational program must include a meaningful, major engineering design experience that builds upon the fundamental concepts of mathematics, basic sciences, the humanities and social sciences, engineering topics, and communication skills. ... Design cannot be taught in one course; it is an experience that must grow with the student's development. A meaningful, major design experience means that, at some point when the student's academic development is nearly complete, there should be a design experience that both focuses the student's attention on professional practice and is drawn from past course work. Inevitably, this means a course, or a project, or a thesis that focuses upon design. "Meaningful" implies that the design experience is significant within the student's major and that it draws upon previous course work, but not necessarily upon every course taken by the student.
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> ABET Criteria I.C.3.d.3.d. [6] (Emphasis added)

2. Nature of Design Projects

This paper uses the following definition of “engineering design”.

> *Engineering design* is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences and mathematics and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing, and evaluation. The engineering design component of a curriculum must include most of the following features: development of student creativity, use of open-ended problems, development and use of modern design theory and methodology, formulation of design problem statements and specifications, consideration of alternative solutions, feasibility considerations, production processes, concurrent engineering design, and detailed system descriptions. <u>Further, it is essential to include a variety of realistic constraints, such as economic factors, safety, reliability, aesthetics, ethics, and social impact.</u>
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> ABET Criteria I.C.3.d.3.c.[7]
> (Emphasis added)

Faculty in the Department have worked close with industry to offer capstone design experiences to students that satisfy the definition of design found in the ABET criteria. Industrially sponsored projects offer pedagogical and practical advantages. The design projects provide open-ended technical problems that require students to cooperate in student design teams. The teams address design problems requiring both analysis and synthesis of technical issues. Since the problems come from a globally competitive commercial environment, students have an opportunity to apply (and better understand) concepts of engineering economic analysis. Additionally, students must address issues involving safety, aesthetics, professional ethics, professional liability, and intellectual property. This kind of design experience not only prepares engineering students to enter the practice of engineering, but also addresses many of the topics required for accreditation by the ABET. The faculty has also found that industry can supply design problems which taken as a whole largely reflect the broad range of disciplines found in the Department.

3. Examples of Design Projects

Students Teams in the Department completed approximately 60 industrially sponsored (capstone) design projects during the 1999-2000 Academic Year (Fall and Spring Semesters). Sponsors come from large companies (3M, Abbot Laboratories, Cameron, Dell Computer, Ford Motor Company, Motorola, and Lockheed-Martin) and from small companies, from established companies and from start-up companies. Table 1 shows a selected list of sponsors (and project titles) from the 1999-200 Academic Year. The Table indicates the broad range of topics examined by undergraduate students in the capstone design course. Each project “tells a story”, but space limitations do not allow description of the selected projects. The projects included manufacturing issues, quality control issues, thermal problems, heating ventilation and air conditioning problems, materials problems, optimization problems, biomedical issues, engineering economic analysis, dynamics, and numerous other technical topics. In addition to those technical and analytical issues, the projects included issues of engineering professional ethics, safety, liability, intellectual property, and questions of human and social impact of engineering work. Note that the Department uses the term “industrial” in a very broad sense, meaning that the problems came from a “client” need rather than from a faculty member’s imagination. For the purposes of the capstone design course, the nature of the sponsoring entity is not relevant *per se*, but the existence of an external customer need is important in the execution of a structured engineering design methodology. (See discussions in Section 4)

Table 1
Selected Examples of Senior Design Projects Offered in the 1999-2000 Academic Year

Sponsor	Project Title
3M	Redesign of a Folding Post Mechanism for a 3M Overhead Projector
3M	The Design of a Superstructure for the Fresnel Alignment System
Abbott Laboratories, Inc.	Industrial Noise Reduction for an Intravenous Solutions Manufacturing Facility
Aker	Design of Deep-Water Subsea Reservoir Storage Tanks for Use in the Gulf of Mexico as an Alternative to Current Oil Storage Methods
Ambion	The Design of a Semi-Automated Batch Process Liquid Filling Station
Applied Materials	Chamber Build Stand Design for Applied Materials' Lightweight Process Chambers
Applied Technologies	Design of a Flight Control Mechanism for the C-130 Cargo Plane
Cameron	Design of a Position Indicator for a Subsea Gate Valve
CEM	Design of a Gimbal Mount for Laboratory Testing of Flywheel Energy Storage System
CEM	Design of a Method to Measure the Stain-to-Failure of Composite Material Hoop Wound Cylinders
Dell	Design of an Automated Laptop Multi-Media Bay Tester
EMS	Design of a New Ambulance Module for the City of Austin Emergency Medical Services Department
EMS	The Redesign of an Ambulance Module to Prevent Dirt Infiltration into the Interior
Ethicon, Inc.	Product Mix Reduction for Ethicon, Inc
Ethicon, Inc.	Design of an Automated Drying System for Suture Needles
FMC	An Adjustment Tool to Remove and Install Straight Bore Metal Seals
FMC	FMC Model 120 Gate Valve Input Force Reduction Mechanism
Ford	Automated Application of Stick-On Wheel Weights for Automobiles
Ford-Visteon	Design of an Energy Transmission Device to Provide Power to an Automotive A/C Compressor
Forney	The Design of an Explosion-Proof Housing for Utility Burner Flame Detectors
Isochron	Design of a Device to Remotely Monitor Ice Bag Compartment Temperatures and Eight Pound Ice Bag Inventory Levels of Ice Merchandisers
JPL	Design and Prototype of a Camera Mast for a Martian Hexabot Microprobe
Lockheed Martin	Proprietary
Raytheon Systems Company	Design of Electromagnetic Environmental Effects Cable Test Fixture Enclosure
SAE	Design of a Process for Cold-Start of an Ethanol Fueled Engine
Solar Car	The Design and Implementation of a Solar Car's Suspension and Steering Systems
TNRCC	Design of an Oil Water Separator for Dyess Air Force Base
TXU	Design of a Transportation Device for a 6.9 kV Circuit Breaker
Ventana Energy	Ventana Energy: Central Chilling Station Redesign
Zebra Imaging, Inc.	Design of a Hologram Display Fixture

4. Pedagogical Advantages of Industrial Cooperation

Faculty can provide capstone design projects from many sources, including outside ("industrial") sponsors and faculty imagination. This paper certainly does not suggest that faculty generated problems are inherently inferior to industrial sources of problems. In fact, faculty have proven excellence sources of problems in teaching engineering science, engineering analysis, and engineering design courses. Textbooks are good examples of the benefit of faculty generated problems. When teaching a course in heat transfer, faculty can state problems such that issues are limited to one specific technical issue under examination. This allows students to work on solvable problems with unique and known answers. As a student matures in technical abilities, faculty generate problems which require multiple steps and which also may require the development and application of engineering judgement to develop "reasonable assumptions" necessary to solve many complex problems. At the level of capstone design experience, students are expected to solve an open-ended engineering problem. Faculty can and regularly do supply design problems that fulfill the pedagogical objectives of the capstone design experience. The various departments in the College of Engineering at the University of Texas at Austin use both faculty generated and industrially generated capstone design projects, and faculty have been pleased with results under both scenarios. The Department of Mechanical Engineering has found that using multiple industrial sources for these problems provide the following distinct advantages

a. Interdisciplinary Problems and Student-Centered Learning. The "industrially sponsored" problems addressed by students tend to be inherently interdisciplinary. The problems have been generated by customer needs and as a result have not been limited to heat transfer design problems, or structural problems. Because of this students receive a broad exposure to the various areas of mechanical engineering, and they have the opportunity to work in related areas in which they have no classroom training. These problems usually require students to develop additional technical skills. The interdisciplinary nature has provided opportunities for student design teams from mechanical engineering to work with student design teams from the departments of electrical and computer engineering, chemical engineering, aerospace engineering, engineering mechanics, and civil engineering. Faculty work closely with the sponsor and the student teams to assess the team's capability to address difficult technical problems. (Faculty expect the student teams to address difficult technical problems, but student teams need to address topics falling within their general competence and abilities.) The Department encourages students to work with faculty from other departments (in the College of Engineering and in other Colleges at the University), to work with engineers at the sponsoring organization, and to work with multiple resources including libraries and other sources of technical information. Each team works with a faculty advisor, generally from mechanical engineering, but mechanical engineering student teams have selected faculty from each of the departments mentioned previously as well as faculty from petroleum engineering, environmental engineering, and faculty from the College of Natural Sciences.

b. Mentoring by Industry. Student design teams have an opportunity to work closely with the sponsoring engineer serving as a mentor. This provides two mentoring sources, the faculty advisor, and the sponsoring engineer.

c. Professional Responsibility. Faculty encourage the student design teams to consider the sponsor as their "client". This assists the student's understanding of their professional responsibility to their client and to society. Students are expected to develop an understanding of safety, economic, and ethical issues of the project at the same time that they are developing the project definition. Student teams analyze issues of professional responsibility as a regular part of their design methodology, not as issues separate and distinct from engineering. Teams (and individual members of teams) frequently approach faculty to discuss issues of conflicts among their various "customers" with respect to economic analysis as well as issues of professional ethics. Students also have an opportunity to deal with issues of intellectual property. Sponsors retain the intellectual property resulting from the work of the student design team. As part of this process, student teams learn to deal with proprietary information. Table 1, for example, includes a project sponsored by Lockheed Martin. The Table includes the term "Proprietary" in the Project Title indicating that the oral presentations for the project were closed to anyone who had not signed a non-disclosure agreement with the sponsor. (While this project served as a learning opportunity for the student, it also presents some interesting challenges for students, faculty, and sponsors.) The sponsor and the faculty are both clients for the purposes of the project, and both receive the final written and final oral design presentation. [8]

d. Student Interest. Students have demonstrated an enthusiasm for these sponsored projects. This could be because the projects are inherently more interesting than faculty generated projects, but the author does not agree with that proposition. The author suggests that it is the context that attracts student interest. Students perceive a real need for the project they are addressing. As an example, the author suggests that the Mars Hexabot mast, sponsored by JPL (see Table 1), might have seemed inherently more interesting to the students simply because JPL was the client. Faculty certainly could have generated the project, but JPL provided an "outside customer" for the student team. Students do not have to have excitement for their design project in order to fulfill course requirements, but motivated students tend to better learn how to become self-driven learners.

e. Multiple Student Design Experiences. 104 students addressed 34 unique design projects in the Spring Semester of 2000. Student teams shared their design experience through a series of oral presentations to their peers. This allows each student to observe not just one design experience, but to a more limited degree also to share in 33 additional design experiences, as well as 33 additional sets of ethical issues, economic analysis, etc.

f. Project Definitions and Student-Centered Learning. Perhaps the most important aspect of industrially sponsored projects is that students have the opportunity to define the problem. They cannot turn to their faculty mentor and ask, “What is the problem?” because the faculty mentor does not know. Students can ask the sponsor, “What is the problem?” and they may receive an answer, but the author has found that if the sponsor had carefully defined the answer that they probably would not have submitted the problem to students in the first place. This initially ambiguous problem definition requires the student team to carefully structure the problem statement themselves based on their observations; a vast majority of students have not had an opportunity to do that at this point in their academic career. Student teams work with their client, their client’s customers, and faculty to understand the project needs, as well as project requirements, constraints, and limitations. The teams learn to rely on their own skills to solve the problem (with the support of faculty and sponsors), and to search for information necessary to address their problems. This experience helps students develop the judgement and technical maturity necessary in engineering practice and in graduate training.

4. Concluding Remarks

Industrial sponsors become a productive partner in the educational process by actively sponsoring student design problems. The projects submitted by industry can provide definite advantages as described above. It is useful to state the obvious; faculty generated problems can also provide most of these advantages. University laboratories and related faculty have also sponsored projects with similar results to those sponsored by companies.

References and Footnotes:

[1] Criteria for Accrediting Engineering Programs Effective for Evaluations During the 1999-2000 Accreditation Cycle, Approved November 1, 1998. Accreditation Board for Engineering and Technology. See also: www.abet.org.

[2] Waldron, K.J. (1992), Secret Confessions of a Designer, *Mechanical Engineering* Nov. 1992, p. 60-62.

[3] Chaplin, C. (1998), *Creativity in Engineering Design--The Educational Function; The Education and Training of Chartered Engineers for the 21st Century*. A Study Undertaken for the Fellowship of Engineering, 2 Little Smith Street, Westminster, London, November 1989.

[4] American Society for Engineering Education, *Engineering Education for a Changing World. A Joint Project of the Engineering Deans Council, and Corporate Roundtable of the American Society for Engineering Education*, 1994.

[5] Ercolano, V., Designing Freshmen, ASEE Prism, Vol. 5, No. 8, pp. 20-25, 1996.

[6] Criteria for Accrediting Engineering Programs Effective for Evaluations During the 1999-2000 Accreditation Cycle, Approved November 1, 1998. Accreditation Board for Engineering and Technology. See also: www.abet.org.

[7] Id.

[8] For additional information of the use of a capstone design course to develop issues of Professional Responsibility, see, Nichols, Steven P., Designing Engineers: An Approach to Integrating “Professional Responsibility” in Engineering into the Capstone Design Course, *Science and Engineering Ethics*, Volume 6, Issue 3, 2000.