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FOR ENGINEERING AND SCIENCE

# Designing Engineers: Integration of Engineering "Professional Responsibility" in the Capstone Design Experience

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## Description

This essay discusses the use of industrial sponsored capstone design projects to encourage active discussion of engineering professional responsibility that naturally occurs in engineering design.

## Abstract

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# Abstract

ABET 2000 Criteria encourages development of proficiency in engineering professional responsibility in the undergraduate curriculum. This paper discusses the use of industrial sponsored capstone design projects to encourage active discussion of engineering professional responsibility that naturally occurs in engineering design. The paper will also discuss student participation in designing responses and approaches to issues such as engineering ethics. The paper will include specific examples of topics addressed by students and the approaches developed (by students) in addressing these issues.

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## Body

# I. Introduction: Curriculum Development vs. ABET Criteria

This paper examines an approach to integrating topics of professional responsibility into a capstone design sequence. The paper uses as an example the capstone design sequence required for students in the Department of Mechanical Engineering at The University of Texas at Austin (UT-Austin).

A primary responsibility of faculty (who are developing a curriculum for engineering students) is development of a course of study which prepares engineering students for the practice of engineering in the world that those students will experience during their professional careers. This responsibility inures to the benefit not only of students, but also of the society that those students will serve. Development of curriculum should not be reduced to an exercise in fulfilling the requirements set forth by the Accreditation Board for Engineering and Technology (ABET). This paper takes the position that, fortunately, the responsibility of faculty in developing curriculum for engineering students does not conflict with requirements for ABET

accreditation. In fact, the ABET requirements support the development of strong engineering curriculum.

The importance of the engineering design in the engineering curricula is exemplified by the 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.

### **ABET Criteria I.C.3.d.3.d. (emphasis added)**

The importance of engineering design undergraduate experience is also supported by literature the United States and internationally. Note that the ABET Criteria cited above correctly states that "Design cannot be taught in one course; it is an experience that must grow with the student's development". That is also true for issues of professional responsibility. A student's ability to recognize and address issues of professional responsibility also must "grow gradually with the student's development".

This paper relies upon some of the descriptions (or definitions) found in ABET Criteria. In particular, the ABET Criteria includes an excellent definition of the term "engineering design". A block cite from the ABET definition is included below.

### **ABET Criteria I.C.3.d.3.c.**

*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. *Further, it is essential to include a variety of realistic constraints, such as economic factors, safety, reliability, aesthetics, ethics, and social impact.*

### **Criteria I.C.3.d.3.c. (emphasis added)**

This paper adopts the ABET definition of "engineering design". The only portion of the ABET definition that the author may question is the inclusion of the word "often" in the parenthetical expression found in the second sentence of the design. The difference, however, does not diminish use of the definition in this paper.

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## **II. The Capstone Design Experience in Mechanical Engineering at UT-Austin**

Various aspects of the mechanical engineering capstone design sequence in mechanical engineering at UT- Austin have been described in the literature. This section includes a brief description of the course, which describes the department's general approach in the design sequence.

The capstone design experience consists of a two-semester sequence taken during the senior year. The first semester involves a course in design methodology (ME 366J). The design methodology course involves a series of "minor" design projects which are assigned to teams consisting of up to five undergraduate students per team. Student experiences in ME 366J usually include a project in reverse

engineering.

The second semester of the sequence involves a six semester hour combination of courses: ME 466K (the lecture portion) and ME 266P (the laboratory portion). The two courses are effectively integrated and treated as one course for grading and assignments. (Students refer to the combination of these two courses as "K". For the sake of simplicity, this paper will adopt the student's nomenclature.)

"K" requires four hours of lecture and four hours of laboratory per week. Laboratory activities are described in the following paragraphs. Some of the material discussed in lecture are described in following sections.

Each laboratory (or clinic) consist of no more than 6 design teams. Each design team consists of three students. Each student teams is assigned a design problem submitted by industry, government agencies, or research centers. Tables 1 and 2 include examples of design titles and sponsors for the 1998-1999 Academic Year. Over the last 10 years, more than 100 companies have participated in the capstone design course by sponsoring projects. The range of project topics listed in the two tables indicate the various technical areas offered in the mechanical engineering department including mechanical systems and design, thermal and fluid systems, nuclear engineering, materials engineering, biomedical engineering, operations research, and manufacturing systems. Student design teams make frequent oral presentation to the teaching staff and to their student peer groups.

### **Table 1. 1998 Fall Semester Sponsors & Projects**

<b>PROJECT SPONSOR</b>	<b>PROJECT TOPIC</b>
Abbott Laboratories	The Redesign of an IV Bag Carrier Tray to Increase the Rate of Production of IV Bags Through the Continuous Sterilizer
Abbott Laboratories	Redesign of a Batch Autoclave Tray

ALCOA	Design of a Ergonomic Work Environment for ALCOA's Overhead Crane Operators
ALCOA	Design of a Safety Latching Device for an Anode Lifting Frame
Applied Materials	The Evaluation and Reduction of Ergonomic Risks Associated With the Installation of an RF Generator
Cameron	Design of a Passive System to Heat Flow Above the Wax Appearance Temperature in Sub-sea Flowlines
Center for Electromechanics	Design of a Suspension Test Stand for a HMMWV and a Metropolitan Bus
Folger Coffee Company	Design for the Automation of Control of a Dryer
Johnson & Johnson Medical	Design of Defective Seal Detection System for Medical Paper to Paper Pouches
Lower Colorado River Authority	LCRA Lake Buchanan Wind Power Facility
Meissner + Wurst	Design of a Simple, Repeatable Procedure to Show a Correlation Between Frequency Change and Mass Deposition on the NVR200 Airborne Molecular Contaminate Monitor
Phillips Chemical Company	Design of a Boiling Reactor for Phillips Chemical Company

Phillips Chemical Company	Design of a K-Resin Tower Reactor
Procter & Gamble	Redesign of the HFCS-55 Railcar Unloading System
Procter & Gamble	Design of a Coffee Extract Surge Tank Wash Water Filtration and Recycling System
Raytheon E-Systems Company	Redesign of Standing Wave Acoustic Impedance Tube
Raytheon TI Systems	Effects of Heat Treatment on Aluminum Silicon-Carbide
Solutia, Inc.	Design of a Solids, Oil, Water, and Organics Separation and Removal System
United States Air Force	Design of a Ceramic Oxygen Generating System
United States Air Force	The Design of an Aircraft Fuel Tank Computer Simulation to Produce Nitrogen Enriched Air Flow Rate Requirements
The University of Texas Longhorn Solar Race Car Team	Design of Front Suspension and Steering Systems for The University of Texas at Austin Solar Race Car

**Table 2. 1999 Spring Semester Sponsors & Projects**

<b>PROJECT SPONSOR</b>	<b>PROJECT TOPIC</b>
Abbott Labs	Redesign of the Part-fill Autoclave Tray

Center for Energy and Environmental Resources	Design of Indoor Air Quality to Energy Conservation Retrofits
Center for Electromechanics	Design a Test Fixture for a Electromechanical Suspension Scale Model for a Tracked Vehicle
Center for Electromechanics	Magnetic Bearing Design
Ethicon, Inc.	Needle Positioning Device
Ethicon, Inc.	Metal Tape Marking System
Ethicon, Inc.	Design of a Vision System to Detect Defects in Needles
Ethicon, Inc.	Redesign of Wire Straightener, Feeder, and Cutoff Unit
High End Systems, Inc.	Design a Method for Reducing MSD575 Lamp Temperatures in Studio Spot 575 Product
High End Systems, Inc.	Design a Rotary Dampening System for 3-phase Stepper Motor Driven Yoke Systems
JENOPTIK INFAB, Inc.	Wafer Carrier Design
Jet Propulsion Laboratory	Design of a Camera Mast for a Small Six Legged Walking Rover for Martian Exploration



Lower Colorado River Authority	Design of Land Treatment of Storm-water at Thomas C. Ferguson Plant
Meissner + Wurst	Design of Models for a Semiconductor Fabrication Facility
Photoquartz	Design of Glass Seal
Photoquartz	Design of Vacuum Metallizer
Procter & Gamble	Design a Process to Reduce "Small Bottle" Jam
Raytheon E-Systems Company	Design to Transform Acoustically Hard Surfaces into Absorbent Surfaces
The University of Texas Longhorn Solar Race Car Team	Design of a Model for Use in Predicting Performance of a Solar Car
The University of Texas Society of Automotive Engineers	Design, Fabrication, & Testing of a Fuel Rail for an Ethanol-Fueled 5.3L V8 Engine
Texas Energy Engineering Services, Inc.	Design of an Energy Tracking and Rate Comparison Program
United States Air Force	Bi-level Airlift Loading System
Ventana Energy	Design of HVAC System Tools

Vim Studios	Design Contemporary Exercise Equipment for Practicing Joseph Pilates Method of Physical Rehabilitation and Conditioning.
Zebra Imaging, Inc.	Design of Self-Contained Hologram Illumination System
Zebra Imaging, Inc.	Design of a Hologram Tiling System

The teaching staff carefully monitor the progress of the "K" design teams through the semester. The laboratories also place an emphasis on peer presentations and peer evaluations of the progress of each design team. Faculty assist the teams in defining the design content and the scope of the project, but the responsibility for the successful completion of the design project rests with the individual student and the design team.

The course requires the design teams to submit periodic reports (oral and written) that are graded, but a majority of the grade is placed on the contents of the team's final oral presentation (20% of the final grade) and the team's final written presentation (40% of the final grade). Eighty percent of a student's grade is determined by team's grades on the various assignments.

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### **III. The Approach Toward Professional Responsibility**

"I had a lot of trouble a couple of years ago with the flap over 'design for manufacturability.' I mean, who ever designs anything without intending it to be manufactured? Certainly there is good design and bad design. Good design has always been design for manufacturability, and always will be." Waldron.

The practice of engineering has an inherent (and unavoidable) impact on society. Engineering is based in part upon that relationship with society. As a result, design problems inherently include at least some issues of professional responsibility. The topics of professional responsibility include the following:

1. Safety and Welfare of the Public and of Clients
2. Professional Ethics
3. Legal Aspects (Legal Liabilities of Engineers, Intellectual Property, etc.)
4. Environmental Responsibilities
5. Quality
6. Communications

The lectures associated with "K" address these topics of professional responsibility in the context of design problems. Since engineering design problems inherently include topics of professional responsibility, an engineering design method must encompass the constraints implied in these issues. Consider the quote from Professor Waldron included at the beginning of this section. Waldron's comment addressed the need to include proper considerations for manufacturability in design, but the same is true for issues of professional responsibility. Altering Waldron's wording: Good design has always included considerations of professional responsibility and good design always will. The logic and thought process of design methodology easily encompasses considerations of professional responsibility.

In "K" lectures and laboratories, the department teaches professional as part of the engineering design methodology. It has been the faculty's experience that one of the most difficult challenges facing those wishing to encourage classroom (and out of classroom) discussions of professional responsibility is helping students understand that conflicting interests and obligations are common in engineering or any professional endeavor. The ability to identify and define these conflicts provides a necessary base for developing and analyzing a code of professional conduct.

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## **IV. Integrate topics of Professional Responsibility Into the Student's**

# Current Life

"I am a man's past." Nicholas Nichols (age 5)

Classroom discussions focus on the relevance to the current life of students in this class, as well as their broader academic experience. In order to describe an example of the approach used in class, the author will temporarily adopt the first person. The following true story is designed to set the stage for how codes of professional responsibility for engineers may be relevant to a student's current life.

In 1995, I had a series of discussions with my son about the importance of telling the truth, and of doing what you promised you would do (even if you does not view it in your immediate best interests). This is a conversation similar to what I imagine that all parents may have with their children. I found it surprisingly difficult to fully describe why it was so important for him to tell the truth. "Because I said so" did not seem to serve the purpose. In a conversation that was more difficult than I thought it would be, we shared the story of "The Boy Who Cried Wolf". We both opined that not only did the boy have problems with his immediate situation (with the wolves at his heels), but also that the villagers may not believe the boy on future matters. The "Boy Who Cried Wolf" had developed a habit and a reputation for lying that followed him wherever he went.

After further consideration, my son and I discussed that by lying now, The "Boy Who Cried Wolf" was also making a habit of lying that may well continue into the future. The "Boy" was forming his future code of conduct.

I went about my way for a some time and came back to my son who was sitting in the same location. He looked up at me and stated the following observation, "Dad, what you are really saying is ....'I am a man's past.'" In fact, I had no idea of how to put it as clearly and plainly as my son did, but that was the purpose of the discussion. My son was, at that time, developing the code that he would live by in his adult years. He was, certainly, a man's past.

The purpose of including that personal story is to draw the analogy between a child understanding that he or she is an adult's past, and an engineering student who is an engineer's past. Students are currently developing codes that they will live by in their professional life. They do not start developing their codes when they start their engineering practice, but rather they have been sharpening their professional code

at least since their freshman year. Discussions in "K" tend to center around the codes they have developed. Note the use of the term codes (plural, not singular) in the previous sentence. These students possess personal codes, moral codes, family codes, and religious codes. In their engineering practice, they will also develop corporate and professional codes. Super-imposed upon that set of codes is a set of societal codes as reflected in civil and criminal law, tort law, property law etc.

Classroom discussions focus not only on a particular code of conduct, but also on discussions of the balance in the "tapestry" of that codes engineers face in their daily practice (and on discussions of how to deal with conflicts among these codes). Lectures include discussion of case studies from professional practice as well as topics designed to be of immediate student interest. Examples of previous classroom discussions are included below.

### **Example 1: Reporting of Cheating in Class: Conflicting Codes**

This example will not discuss the academic dishonesty per se, but rather the reporting of academic dishonesty.

Like other universities, UT-Austin has a clear policy on academic dishonesty. The university does not impose on its students an enforceable, affirmative obligation to report academic dishonesty of others. Most students, however, understand that academic dishonesty should not be tolerated. Students are certainly clever enough to understand that the academic dishonesty of others may damage those who do not cheat. Students also understand what the author will refer to as a "Student Code" which discourages "tattle-tales". Students can understand the codes, can understand the conflict in codes, and can understand the relevance of the codes to their immediate (and immediate past) experiences. Rational classroom discussion of the "professional responsibility" of students in this situation yields a rich field for developing a framework for discussions of engineering professional responsibility.

### **Example 2. Peer Evaluations: Conflicting Codes**

Course grades in K include the influence of peer evaluations by the individual student members of the design team. Early in the semester, the evaluations are used to help faculty monitor the progress of the teams, and to monitor problems involving team dynamics. Many of the conflicting codes described in Example 1 are repeated in the case of peer evaluations. The discussions in Example 1 tend to

emphasize conflicting interests of the individual student and the Student Code. Example 2 includes an evaluation of the team's obligation for the quality of the final product of the design team if one (or more) of the members are not contributing their "fair share".

### **Example 3. Software "Sharing": Conflicting Codes**

Students have been known, from time to time, to freely share software with one another without regard to the intellectual property of those that developed the software. Students may not like the fact that much of the software that they would like to use require payments for license to the software. Faculty may not believe that students (or faculty) should have to pay the license fee. Regardless, copyright and patent law leaves little question for controversy of property rights of those issuing these applications. This yields a rich field of discussion of professional responsibility of engineers in the use of licensed software.

### **Example 4. Affirmative Responsibility of Honesty to a Potential Employer: Conflicting Codes**

Most students registered for capstone design courses are interviewing for jobs (or are considering interviewing for jobs). As a result, they face the difficult tasks of what and how much of their personal desires and plans to disclose to prospective employers. Students are interested in discussion in an open forum (such as the classroom) the following hypothetical situations.

- a. Student wishes to work for one year and then go to graduate school. Should Student disclose these specific plans to potential employers?
- b. Student wishes to go to work for XYZ Cooperation. Unfortunately, XYZ has not yet made a job offer. Company A, however, has offered Student a job. Can Student legally and/or ethically accept a job from Company A and then plan on abandoning the commitment if XYZ Corporation offers Student a job?

None of the examples described above represent the cutting edge of debate for professional responsibility, but they do relate to immediate issues facing students in the capstone design course. The hypothetical situation discussed in class any one semester are generally taken from specific questions asked by capstone design students that semester (with permission from the student asking the question). The

name of the student originally asking the question is not disclosed in class, but the instructor does tell the class that the hypothetical factual setting came from someone in the class. This not only helps engineering design students address the issues facing them today, but also encourages them to openly discuss their questions and problems pertaining to professional responsibility. The faculty expects that this encourages graduates of the program to openly discuss professional responsibility as part of normal engineering responsibilities (after they leave the academic environment).

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## **V. Design Projects: Professional Responsibility as Part of the Design Process**

"The rationale for teaching ethics to engineers and computer scientists seems fairly obvious. Their work (developing, designing, and implementing technologies) has an enormous impact on the world." Johnson.

Classroom discussions such as those described in the previous section encourage students to recognize (and discuss) issues of professional responsibility involved in their industrially sponsored design project. This section will include one example taken from specific design projects. Discussions on problems like the example given occur in the lecture hall, in the instructor's office, in peer discussions in laboratory, and in the hallways. The discussions take place as part of the engineering design process as applied in the capstone design course. The name of the sponsor has been obviously altered. They come from actual design projects.

The example discussed below will not cover in any detail all of the technical or professional issues addressed by the team, but it will serve to demonstrate the issues faced by student design teams.

### **Example 5. Landfill at a Chemical processing plant: A Design Problem**

Title of Project: The Design of Movable Low-Profile Temporary Cover for a Hazardous Waste Landfill.

Background: Company X operates a chemical processing plant near the Gulf Coast of the United States. The plant places a portion of its solid waste in a landfill. Solid waste placed into the landfill is exposed to the environment because of the slow filling process (six to eight years). Any water that collects in an active cell and contacts hazardous waste forms "contaminated leachate" which must be treated according to the requirements of the State of Texas and the Federal government. Company X asked the design team to design a low-profile movable cover that is large enough to protect an active cell from rainfall. The sponsor gave the following requirements:

- The cover will be closed at night or when rainfall is imminent. The cover is to be opened to expose the cell for filling.
- The cover should protect an entire cell of about 220 feet wide by 250 feet long by 30 feet deep.
- The cover should prevent rainfall from entering the active cell.
- The opening or closing cycle time should ideally be under thirty minutes in order to reduce lost work time.
- In order to prevent the landfill liner from tearing, structural supports cannot be placed in the cell bottom or sides.
- The sponsor requires that the structure satisfy applicable codes (such as OSHA).
- Movement to a new row may require the use of heavy equipment and may take up to a maximum of eighteen days.

The Landfill project has obvious implications to the health, safety, and welfare of the public as well as economic interests to Company X. Some of the more interesting interactions among the student design team, the sponsor, the faculty advisor, and the course instructor balances of environmental interests and economic interests of the sponsor.

The team's "final design" included a sectional, movable, rigid structure using rails for tracking the lateral motion of the cover. The team analyzed the legal and economic constraint and originally concluded that their "final design" was not economic, since the cost of the structure exceeded the cost of simply continuing to treat the leachate formed when the rain water mixed with waste material. After discussions with the



sponsor, the team found that pure Company X's decision would not be determined by pure economics. The sponsor found the economic analysis sufficient to justify the project.

The term "final design" used in the last paragraph deserves some explanation. While examining design alternatives and evaluating the merits of each of the approaches, the design team initially selected a different design variant than the sponsor preferred. This difference of opinion generated a great deal of discussion among team members and the team's peers in their laboratory. As one may expect, it is not uncommon for the sponsor and the team to have differences of opinion. This difference of opinion generally generates two parallel approaches by the team, a.) Reevaluate the decision matrix and share with the sponsor the team's thought process, and b.) evaluation among the team members about which variant to pursue if the team and the sponsor eventually do not agree. The team eventually chose to embody the sponsor's preferred approach. (The option selected by most teams which do may prefer to pursue another variant than their sponsor prefers.) The discussion undertaken by the Landfill design team indicated the seriousness with which they pursued the project. They no longer viewed the landfill cover design as only the sponsor's problem, but rather as the team's problem. The team assumed possession of their project. Most of the team in the capstone design course come to an agreement on the "best" variant considered after a careful analysis of the sponsor's priorities and criteria. Teams that do not agree technically with the sponsor's preferences generally end up pursuing the sponsor's preference if they do not consider the variant illegal, immoral, or technically unjustifiable.

The faculty encourage this kind of discussion among the team members and their sponsor. It is an ideal time to review, in the environment of a design problem, the role of engineers to the sponsor as well as to the society in which engineers practice. The faculty considers it a positive sign that the team has a position which they are able to articulate and to defend.

It is worthwhile to briefly discuss the variant that the team preferred. The team's preferred variant violated Requirement Number 5 listed above (structural supports cannot be placed in the cell bottom or sides). The inability to use structural supports in the middle of the 220 ft. span, significantly increased the costs and structural demands of the design. The team wished to pursue options that could provide structural supports at the mid-point, but which did not destroy the liner seal. Their preferred variant accomplished the task by providing the structural support in the

middle of the width, but sealing completely around the support. The structural support per se was not included in the sealed container. As stated above, the Landfill team embodied and presented the variant preferred by the sponsor (no mid-point support) in the written and oral final reports. The team also included a rough design of the mid-point support variant. By the end of the final oral presentation, the team had convinced the sponsor that the mid-supported variant was acceptable and perhaps preferable. The design team had coordinated with state agencies in developing acceptable mid-support approaches.

In their conclusions and recommendations, the Landfill team also presented recommendations for future landfill designs (not just cove designs) which held promise to be significantly less expensive than the current designs of their sponsor. This student design team included issues of the health, safety, and welfare of the public, environmental responsibility, legal liability, intellectual property, and engineering ethics in their design experience. The team did not address these issues as additional assignments but as a natural part of the design process.

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## **VI. Concluding Remarks**

"... [W]e have come to believe that professional ethics should be taught in a way most likely to bring home to students that ethics problems do not come free-standing in practice. They are integral to what professionals do." Davis.

Design projects provide an environment rich in opportunities to encourage graduating seniors to remember that professional issues (such as ethical, legal, environmental, etc.) are as integral to solving engineering design problems as analytical tools. The Landfill example indicates the kind of questions of professional responsibility inherent in design problems. Class discussions in topics of professional responsibility encouraged the team to openly discuss their concerns and proposed solutions.

The mechanical engineering faculty at UT-Austin find that industrially sponsored design projects provide fertile grounds for improving the analytical, problem solving, and professional skills of senior undergraduate engineering students.

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## **Notes**

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