Synergy Between ABET EC 2000 and Capstone Senior Design Projects

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Abstract--**This paper examines the synergy between senior-level capstone design courses and the fulfillment of ABET accreditation requirements under Engineering Criteria 2000. Also, specific examples of design projects in the power engineering area are presented. Assessment results are used in a course feedback process to improve metrics.**

Index Terms—**ABET, Capstone design projects, Electrical engineering education, Undergraduate senior design.**

I. Introduction

IN the United States, engineering programs are accredited by the Accreditation Board for Engineering and Technology (ABET). Since the mid-1990s, ABET has required that engineering programs include "a meaningful, major engineering design experience" in their curriculum.[1] For a history of engineering accreditation in the U.S., see [2]. This paper examines the synergy between a properly developed senior capstone design course and the fulfillment of ABET accreditation requirements. This is not the first time that educators have endorsed the use of capstone design courses as an engineering program outcome indicator.[3]

This paper also lists some of the power engineering related design projects at Arizona State University (ASU) over the past few years. Two general reviews of capstone design projects and courses can be found in [4] and [5]. A summary of various power engineering applications in senior design projects at another university can be found in [6].

II. ABET EC2000

In 1996, ABET began implementing an improved method of evaluating engineering programs by an objectives and outcomes driven assessment process. Pilot visits were conducted in evaluation years 1996-98, in preparation and as transition to requiring all institutions to meet Engineering Criteria (EC) 2000 by fall 2001.[7]

Of the eight criteria of EC2000, Criteria 3 and 4 are of special importance to capstone design courses. These criteria are given below, and places where they are addressed by the design course are pointed out in this paper.

A. Criterion 4

ABET EC2000 Criterion 4 is the *Professional Component* and includes the requirement that "Students must be prepared for engineering practice through the curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating engineering standards and realistic constraints that include most of the following considerations: economic; environmental; sustainability; manufacturability; ethical; health and safety; social; and political."[8]

B. Criterion 3

Design projects may also be used to supply evidence demonstrating that graduating students have achieved the Criterion 3 (a) through (k) outcomes: [8]

(a) an ability to apply knowledge of mathematics, science, and engineering
(b) an ability to design and conduct experiments, as well as to analyze and interpret data
(c) an ability to design a system, component, or process to meet desired needs
(d) an ability to function on multi-disciplinary teams
(e) an ability to identify, formulate, and solve engineering problems
(f) an understanding of professional and ethical responsibility
(g) an ability to communicate effectively
(h) the broad education necessary to understand the impact of engineering solutions in a global and 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) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

III. ASU Capstone Design Course

This section describes the undergraduate capstone design course in electrical engineering at ASU. A senior design course was first introduced in fall 1989 as a one-semester, three-credit-hour experience. Based on feedback from its three constituent groups---students, faculty and industry---effective fall 2001 the electrical engineering program changed to a two-semester course of two credit hours each semester.

A prerequisite to the present senior-level course is the junior-level course entitled, *Intermediate Engineering Design* (ECE 300), which educates the teamed students on the engineering design process including defining problems, and generating and evaluating ideas. As the college requires ECE

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300 for all engineering majors, the student teams in that course are interdisciplinary in nature---ABET EC 3(d).

A. Course Overview

The electrical engineering capstone design experience is a two-semester course (EEE 488 and 489) entitled, *Senior Design Laboratory* I and II. In the first semester (EEE 488), the students concentrate on the design process including background research, conceptual designs, feasibility study, simulation, specification generation, and benchmarking; the ultimate product of the first semester is a detailed design proposal (document). With a solid plan in place by the end of the first semester, students are in a position to order and procure any necessary materials so that they are received by the start of the second semester. In the second semester (EEE 489), the design teams implement, evaluate, and document the proposed design, including considerations such as those of a social, economic and safety nature.

B. Course Objectives

The course goals can be directly traced to meeting engineering accreditation requirements, specifically, ABET EC2000 *Criteria 3* and *4*. The course objectives for the ASU Senior Design Laboratory are

1. Students can define and plan an engineering project involving multiple tasks and contributors.
2. Students can carry out team-oriented electrical engineering projects.
3. Students can communicate and critically evaluate technical information.

These first two goals are strongly connected to ABET EC 3(a), (b), (c), (e) and (k).

The first and second objectives are primarily applicable to the first and second semesters courses, respectively; whereas, the third objective applies equally to both semesters. These course objectives have been realized as the following corresponding course outcomes:

1(a) Students can define an engineering project, setting objectives that are appropriate for the project purpose and scope and that incorporate most of the following considerations: economic; environmental; sustainability; manufacturability; ethical; health and safety; social; and political.

1(b) Students can plan an engineering project involving multiple tasks and contributors.

2(a) Students can effectively and actively participate in teams to complete the project.

2(b) Students can use a formal design process to create a project design.

2(c) Students can implement, evaluate, and document a project design.

3(a) Students can communicate technical information in writing.

3(b) Students can communicate technical information in oral presentations.

3(c) Students can provide informed and constructive criticism on engineering projects.

Paralleling the course objectives and outcomes, a student's grade is based on three aspects:

1. Contribution of the individual to the team (weighting factor).
2. Technical Communication: written reports and oral presentations (50%).
3. Technical Assessment of the group design (50%).

The *technical advisor* predominantly grades the technical work (30% of total grade). The *course coordinator* assigns the remaining 20% in order to equitably smooth any differences between groups working under different technical advisors.

C. Design Projects

Faculty members, and on occasion engineers in industry, propose the unique design projects. Industrial sponsors often fund the projects to a level not normally available to the student team; however, student transportation to company facilities, if needed, and concerns with proprietary materials must be dealt with early on. The projects are created under the following guidelines:

1. The design problem should be a comprehensive problem that integrates those major areas covered in the student's coursework.
2. The problem should be open-ended, encourage creativity, and require making assumptions, evaluating alternatives, and justifying the final solution.
3. The problem size should be appropriate for a small group.

The individual proposing the project becomes the *technical advisor* to the project for the yearlong course. Some faculty take on multiple projects, and faculty often link projects to their current research projects or utilize the senior design project to lay the foundation for writing a research proposal. The continuing link of the design projects to contemporary topics serves to accomplish EC 3(j).

D. Course Organization

A single faculty member acts as the design *course coordinator*. The course coordinator gathers project ideas from faculty and industry, and distributes these to the students. Student teams are given a couple of weeks to discuss project particulars with the various *technical advisors* before being required to make a final project selection. Sign-ups for a particular project are first-come first-serve basis with the particular technical advisor.

The undergraduate electrical engineering enrollment at ASU is around 700 students with about 110 students graduating each year. As such, the program has elected to provide students with the opportunity to begin the senior design sequence in either the fall or spring semester. In some cases, honors students continue the design projects they are involved in to complete honors thesis requirements.

The entire class convenes weekly as a whole group. Since the technical content of the design projects is quite diverse, the weekly class meetings concern topics that are applicable to all design teams. These lectures focus on issues such as: data presentation methods including mechanics of figures and tables; design proposal contents and format; project management including planning and budgeting; intra-team dynamics including personality types; oral presentations including development of effective visual aids; technical reporting including literature referencing; and engineering ethics.

In addition to the class assembly, the individual student design teams meet weekly with their technical advisor. Besides the exchange of technical information, this weekly meeting serves to monitor the team progress and to prevent them from falling behind schedule. Each student is expected to spend 5-8 hours per week on the project outside the meetings.

E. Design Teams

Students are allowed to form their own design teams consisting of three or four students. Typically, the class size is around 50-60 students, which results in 15-20 design teams within each class per semester.

The team composition remains the same over both semesters. The overall completion of the design project rests entirely with the student design group. Each team is encouraged to select a member to act as the group facilitator, who acts as the project manager. Teams are further advised to rotate the facilitator position among the various student team members.

To insure individual accountability, students are asked at the end of the project to confidentially "grade" their team members (including himself/herself). Students quantify each member's contribution as well as the grade that they feel the individual deserves. Significant deviations (that is, high or low scores) must be justified with a textual explanation.

F. Communication Skills

During both semesters, the students' technical communications skills are enriched---ABET EC 3(g). Student teams write four progress reports and two major documents (a proposal and a final design report), and they make four oral presentations plus a poster session. To emphasize individual accountability, each student must prepare an individual, written report summarizing his/her work during each of the two semesters.

The senior design sequence satisfies one of two university-level literacy requirements (the first being fulfilled by the junior-level engineering design course, ECE 300). For this reason, at least 50% of the course grade is based on written and oral reporting. Written reports are simultaneously submitted to both the course coordinator and the technical advisor. The timing for the written reports and oral presentations and their weight toward the final grade in the first and second semesters are given in Tables I and II, respectively. These reports serve as student portfolios make excellent materials to assess the achievement of course and program outcomes.

TABLE I
TECHNICAL REPORTING SCHEDULE FOR FIRST SEMESTER (EEE 488)

Week	EEE 488	Grade Percent
3	Resume (individual)	5%
5	Progress Report (group written technical memo)	5%
7	Progress Reports (individual oral five-minute presentation)	5%
9	Progress Report (group written technical memo)	5%
11	Progress Reports (individual oral five-minute presentation)	5%
13	Semester Summary Report (individual)	10%
15	**Design Proposal** (team written report)	15%

TABLE II
TECHNICAL REPORTING SCHEDULE FOR SECOND SEMESTER (EEE 489)

Week	EEE 489	Grade Percent
3	Progress Report (group written technical memo)	5%
5	Progress Reports (individual oral five-minute presentation)	5%
8	Progress Report (group written technical memo)	5%
11	Progress Reports (individual oral five-minute presentation)	5%
13	Semester Summary Report (individual)	10%
15	Poster session (design team)	5%
16	**Final Design Document** (team written report)	15%

The evaluation of the reports and presentations is the responsibility of the course coordinator. Each design team makes four oral presentations over the two semesters. The audience consists of other design teams. The student presentations are graded as individuals rather than as a group, although the team works together for proper flow and to insure that one member does not impede the others (team flow is part of the grade).

The major deliverable in the first semester is a comprehensive proposal that includes details of the background research, preliminary feasibility studies, and project deliverables of the second semester. Within the proposal students must address such items as project objectives, statement of work (project tasks), project schedule (Gantt chart), and budget.

The final oral presentation is an interactive public display, that is, a poster demonstration that is held on the last two days of the second semester. These presentations are generally well attended by electrical engineering faculty as well as faculty, staff and students from other engineering and science departments. Design teams use posters, computer displays, hardware demonstrations, and other means to create presentations that both capture the attention of the audience and show the results of the semester's efforts (see Fig. 1).

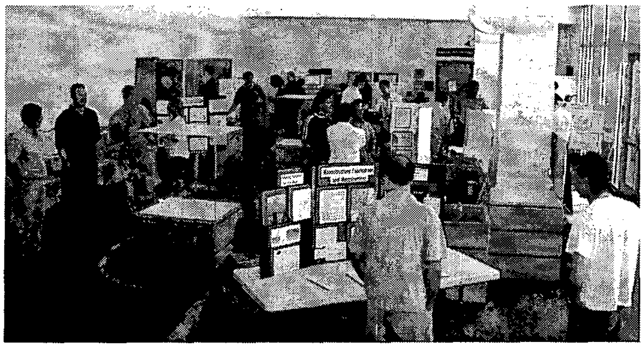


Fig. 1. Senior design public poster session.

G. Assessment

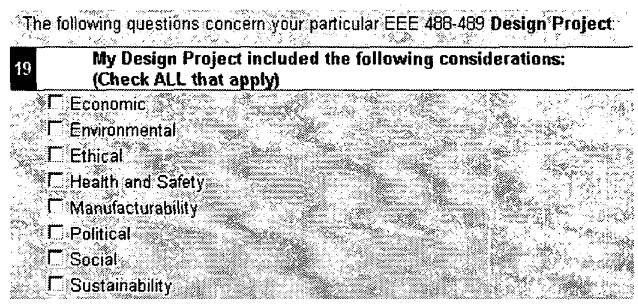
As part of the Electrical Engineering (EE) Department's assessment of the undergraduate program, the student's work is extensively evaluated. Part of this assessment process involves student completion of anonymous surveys during the semester. These surveys are conducted using a web-based interface. The end-of-semester student survey for EEE 489 is particularly important since it generally represents the students' opinions in their graduating semester.

In addition to the student surveys, the course coordinators evaluate the course effectiveness in terms of its strengths and weaknesses, and they make suggestions for course improvements, which are reviewed by the EE Undergraduate Curriculum Committee. In addition, the course coordinators quantify what percentage of the students is achieving each of the course outcomes.

Fig. 2 shows the interface of the web survey form as seen by the student respondents for question 19, which addresses whether a student's design project considers other factors---ABET EC 3(f), 3(h) and 4. The results of surveying 210 of the 267 enrolled students over the past two years are given in Fig. 3. The graph shows that recent projects have seen an increase in the inclusion of the other design considerations found in Criterion 4. This column chart shows that the projects are addressing *most* of these other design factors.

Similarly, Fig. 4 shows survey results from question 20, which is intended to determine the courses and technical areas from which students draw knowledge and skills to complete their design project. The specific classes listed in the column chart represent required courses in the curriculum, whereas the technical elective areas are senior-level concentrations selected by the students. The total percentage of the senior technical electives is 116%, which is expected since projects often require knowledge and skills from multiple concentration areas.

The survey results of Fig. 4 show that 28% of the students are utilizing knowledge and skills gained from the required *Energy Conversion and Transport* course, EEE 360. Considering that there are six power professors out of 45 faculty in the electrical engineering department, one would expect about 13% of the projects to be power engineering related. However, only 6% of the design projects applied concepts from the senior-level power area technical electives. An initial explanation might suppose a lack of relevance of those electives to the design projects. However, data indicate that students are less motivated to power engineering careers because students perceive power as an area of old technology as compared to concentrations such as solid-state electronics, communications and signal processing.[9]


The following questions concern your particular EEE 488-489 **Design Project**:

19 **My Design Project included the following considerations: (Check ALL that apply)**

- ☐ Economic
- ☐ Environmental
- ☐ Ethical
- ☐ Health and Safety
- ☐ Manufacturability
- ☐ Political
- ☐ Social
- ☐ Sustainability

Fig. 2. Question 19 from web-based assessment survey form.

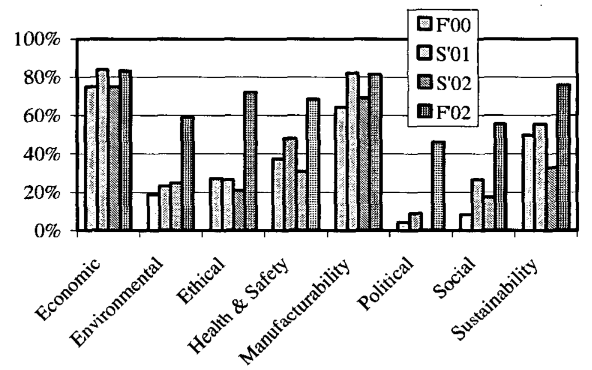


Fig. 3. Student responses to question 19 of web-based assessment survey.

Another figure of merit is faculty participation. During the past two calendar years (2000-01), approximately half of the faculty advised design projects. Some faculty who did not advise a project had actually proposed a project, but no student design team elected to undertake the offered project. Normally, the course coordinator for EEE 488 follows the students into EEE 489.

H. Senior Design Prize

In 1998, the Department of Electrical Engineering established an award to recognize the best senior design project. The award is presented each semester to the student team whose capstone design project is judged the semester's best. The evaluation criteria include: (i) originality and creativity of the students' contribution, (ii) level of technical skill, teamwork, and dedication manifested in the completed project, (iii) attention to non-technical aspects of the design such as cost, marketability, social impact, and manufacturability, and (iv) professionalism in documentation and presentation of the design project.

In recent years, the semi-annual meeting of the Electrical Engineering Industrial Advisory Council has been scheduled to coincide with poster demonstration such that industry selects the team and project awarded the Senior Design Prize. The Senior Design Prize consists of an individual trophy and a cash award for each member of the winning design team. The team members and their technical advisor also have their names added to a public display plaque.

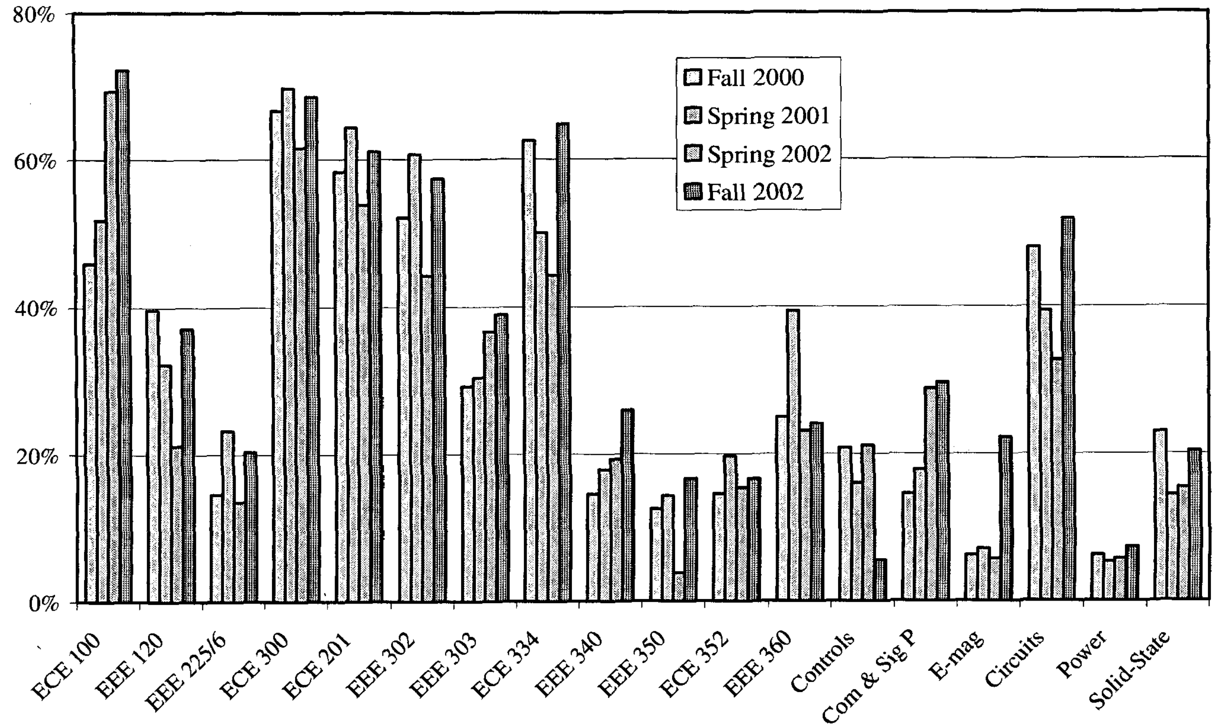


Fig. 4. Student responses to question 20 of web-based assessment survey.

I. Power Engineering Projects

Students in electrical engineering at ASU typically concentrate their studies in one of six technical electives areas, including power engineering. Those students whose interest lies in power engineering would typically select a project being advised by a member of the power area faculty. Recent power engineering related projects have included:

- Digitally Programmable Switch-Mode Power Supply
- A Phase Controlled, Series Boost Voltage Conditioner
- Remote Current Measurement
- Voltage Measurement Using Fiber Optic Cables
- Multiplexing Data Communication onto Power Distribution Lines
- Bi-Directional DC-DC Converters for the 42V Architecture of Future Automobiles
- Electric Airplane
- Development of a Digital Power Quality Measuring System
- A Series Voltage Boost Voltage Regulator
- High Efficiency Switch-mode Music system
- Passive Lighting System

The latter project utilized solar energy that was concentrated into and then transmitted through a fiber optic cable. The light was reemitted into the building interior as shown in Fig. 5.

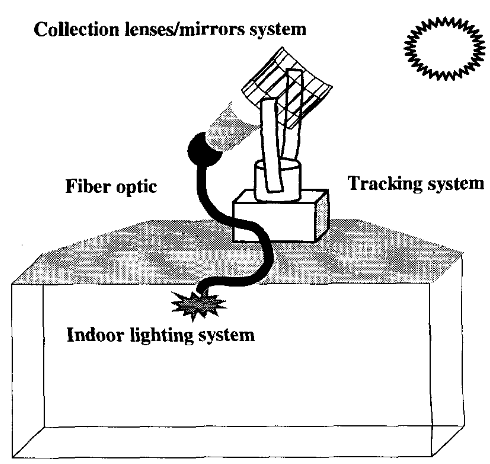


Fig. 5. Schematic of the passive lighting system.

IV. Discussion

As seen above, activities within the context of a capstone design course can be used to achieve and verify fulfillment of ABET Engineering Criteria 2000. This is neither to say that all criteria must or should be equally addressed by the senior design course, nor to suggest that an engineering program should rely upon a single course. In fact, the level of support that a particular course has toward achieving various ABET and program outcomes can be rated as illustrated in Table III. Further, the unique nature of the capstone design course and its location at the end of the curriculum, where students represent graduates in terms of Criterion 3, presents a unique opportunity to assess student achievement of ABET and program outcomes.

Course refinements and enhancements are always possible; however, educators should not attempt to create a megacourse that tries to accomplish everything. For example, students from other disciplines (*e.g.*, business) could be recruited as additional team members to better achieve EC 3(d), but such cross-college cooperation is not without its logistical difficulties.

TABLE III
Capstone Design Course Support for Achieving ABET EC 2000 Criterion 3

ABET Criterion 3 Outcome	Level of Support
a) Apply mathematics, science and engineering	Strong
b) Design and conduct experiments; analyze and interpret data	Strong
c) Design a system, component, or process	Strong
d) Function on multi-disciplinary teams	Modest
e) Identify, formulate and solve engineering problems	Strong
f) Professional and ethical responsibility	Moderate
g) Communicate effectively	Strong
h) Understand engineering impact on global society	Modest
i) Lifelong learning	Modest
j) Contemporary issues	Modest
k) Techniques, skills and tools for engineering	Strong

V. References

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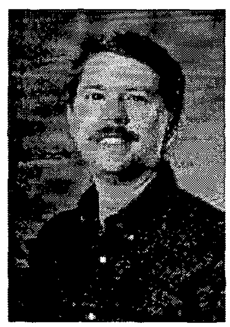
VI. Biography



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