Addressing Professional Issues through an Experimental Capstone Design Experience

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Abstract - A senior level capstone design experience has been developed and offered with a particular emphasis on many of the professional issues raised in Accreditation Board for Engineering and Technology (ABET) Engineering Criterion IV. The course has sought to develop student awareness of the ethical foundation of the engineering profession, the global and societal framework within which engineers practice, and the environmental impact of engineering. The capstone design course also focused upon improving the technical communications skills of the graduating senior class with both extensive instruction in writing and multiple workshops dealing with the art of making an effective oral presentation. The effectiveness of the design course was assessed using Kirkpatrick’s model for evaluating training programs.

Index Terms - Capstone and creative design experiences

INTRODUCTION

ABET (Accreditation Board for Engineering and Technology), the certifying organization for schools throughout the nation, has set forth a series of criteria, which must be met if the institution wishes to receive a favorable review of its various programs. In the present work, we shall focus on elements described in Criterion IV. [1] According to ABET, providing a major design experience for students must include not only a careful consideration of engineering standards and constraints but also a range of other factors including: (a) economics, (b) manufacturability, (c) sustainability, (d) safety and health issues, (e) ethics, (f) global and societal contexts and (g) environmental impact. In the present work, we shall focus on elements described in Criterion IV. [1] According to ABET, providing a major design experience for students must include not only a careful consideration of engineering standards and constraints but also a range of other factors including: (a) economics, (b) manufacturability, (c) sustainability, (d) safety and health issues, (e) ethics, (f) global and societal contexts and (g) environmental impact. Having participated in ABET reviews and workshops, our first-hand experience has been that the last three factors invariably turn out to be the most difficult to interpret, quantify, and, subsequently, satisfy. We view questions related to sustainability as closely linked to questions surrounding the health of the environment and, therefore, will include it in the broad category we term “environmental impact.”

Focusing specifically upon the need to integrate ethics into the engineering curriculum, ABET has written, “Engineering programs must demonstrate that their graduates have...an understanding of professional and ethical responsibility.” [1] Working definitions of phrases such as “professional and ethical responsibility” and the actual means for accomplishing these tasks are left to the individual programs. In response to the ABET position, also according to Shirley [2], the American Society of Engineering Education (ASEE) in a policy statement proposes that, “New engineering graduates need substantial training in recognizing and solving ethical problems.” Also recently, ASEE has established a new group focused upon ethics in the Educational Research and Methods Division and has formed an engineering ethics working committee. The importance of an appreciation for and ability to propose solutions to ethical dilemmas seems to go to the core of engineering as a profession.

Another important motivating force for the newly revised capstone design sequence has been feedback from a wide range of university officials, private companies and governmental agencies that our graduates, though extremely competent in the applied and pure sciences, often struggle with technical communications, including making professional oral presentations as well as producing a persuasive, logical, written argument.

The present work documents our effort to: (a) address the various issues and concerns raised in ABET Criterion IV, focusing particularly on those related to engineering ethics, global and societal contexts for proposed engineering solutions and the impacts of those solution upon the environment, and (b) improve the ability of our students to communicate effectively. The assessment model proposed by Kirkpatrick [3] has been used to evaluate the effectiveness of the newly revised and experimental capstone design sequence. The four steps of evaluation include the following: (a) how students reacted, (b) what students learned, (c) whether what was learned was applied, and (d) assessment of long-term impact. Because the course has concluded only its second offering, the last step in the Kirkpatrick model of evaluation is not yet possible though a mechanism has been developed which will permit a collection of the long-term data needed for this final stage of evaluation.
COURSE DESCRIPTION

Each year more than 100 students receive undergraduate degrees in electrical, computer, systems and industrial and mechanical engineering, the engineering disciplines offered by the Watson School of Engineering and Applied Science at the State University of New York, Binghamton (SUNY-Binghamton). The two-semester capstone design course at SUNY-Binghamton involves students and faculty from several programs (i.e. electrical engineering, computer engineering and mechanical engineering) and thus can be considered multi-disciplinary. Projects are generated in the following three ways: (a) in-house through the sponsorship by a SUNY-Binghamton faculty member; (b) externally by an industrial client; or (c) by a team of students who develop a project from their own imagination with the only restriction being the requirement of a SUNY-Binghamton engineering faculty member to serve as the technical advisor.

The course sequence is a two-semester design experience that is worth four credit hours for each semester or a total of eight credit hours. By the end of the first term, students are expected to complete a preliminary design, write a technically accurate and complete engineering design report, and make an effective design presentation. Also, during the first term, considerable time and attention are paid to the issues identified in Criterion IV. Formal classes are regularly held, using both lecture and experiential formats. The experiential activities included in-class mini-design projects. There are four required formal essays designed to develop the students’ writing skills, and one essay assigned in the general area of engineering ethics. In addition, students may opt to submit up to three additional essays focused on a variety of topics including the impact of technology on the environment and societal/global issues associated with technology. In order to stress the notion of writing as a process, students are permitted and encouraged to revise their essays and resubmit.

While the grading schema to be employed was made exceptionally clear to the students in the beginning of the course, it was received with considerable distrust. The final grades for the class were linked solely to the design project; or (c) by a team of students who develop a project from their own imagination with the only restriction being the requirement of a SUNY-Binghamton engineering faculty member to serve as the technical advisor.

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The focus of the second half of the capstone design sequence was upon the completion of the project begun during the fall term. The design project had to be completed, on time, to the satisfaction of the client and faculty member, with the satisfaction of the client and faculty member, with the revision/resubmission rate equal to approximately 50%.

Addressing Engineering Ethics

Goal: Students will recognize the ethical dimension of the engineering profession.

Activities: In-class design projects, readings in world literature, videos and in-class discussions

Our approach to integrating ethics into the course sought to encourage students to understand the usefulness and importance of engineering ethics in, at least, four different levels: literal, analogical, moral and anagogical. [4] At the literal level, students become aware of the various engineering codes and their potential usefulness in solving ethical dilemmas in the engineering profession. Next, at the analogical level, students identify similarities among engineering or professional dilemmas and difficulties in their own lives. Thirdly, at the moral level, students articulate their own value system and the origins of that value system. Lastly, at the abstract level (i.e. analogical), students reflect upon different views of technology including: (1) technology as liberator, (2) technology as threat, and (3) technology as instrument of power. [5]

Assessment: Overall student reactions to the effectiveness of the engineering ethics portion of the course are shown in Table 1. Targeting specifically the different levels of meaning of integrating ethics, student reactions are presented in Table 2. Reference to the issue in the preliminary and final design reports are shown in Table 3. By the term “reference” we mean that there is, at a minimum, an acknowledgment of the existence of the issue—in this case, ethical concerns.

In an effort to understand the meaning of the results found in Tables 1 and 2, we correlated the individual responses to a solution presented in both a written final report and at the end-of-term formal design conference open to university officials, faculty, staff and the local community.
grade or quality point and then calculated the quality-point average. For example, consider the first question in Table 1: How well did the design course improve your ability to identify ethical situations? Students responded in the following manner: 0% indicated “Not at all” (0); 10% indicated, “Not well” (10 x 1 = 10); 20% indicated “Average” (20 x 2 = 40); 45% indicated “Well” (45 x 3 = 135); and 25% indicated “Very well” (25 x 4 = 100); with the total equal to 285 out of 400 maximum or 2.85/4.00. A similar schema is used in Table 2. The feedback suggests that the course did encourage a large percentage of the class to focus on the ethical dimension of the engineering profession. This portion of the class correspondingly reflected on ethics at the various different levels of understanding from literal to the most abstract, analogical. A similarly high percentage of the students addressed ethical issues in both their preliminary and final design reports.

Addressing Global and Societal Context

Goal: Students understand the global and societal contexts within which engineers work.

Activities: In-class design projects, readings in world literature, videos and in-class discussions

Several in-class mini-design projects were introduced throughout the fall term. Dym and Little [6] proved an exceptional resource for design projects that force students to consider global and societal contexts for the practice of engineering (e.g. The Guatemalan Cooperative Project). Other engineering projects which were effective in generating in-class discussions included the Aswan Dam [7] and electrification in South Africa [8]. Students were asked to read from a variety of other works including Aeschylus’ Prometheus Bound. [9] Aeschylus’ work was chosen because it provides an effective springboard for discussions concerning changes in perceptions of knowledge and technology from ancient classical civilizations to the present time. Following Aeschylus, students were introduced to the changing paradigms in science and technology including the mechanical universe (and its importance during the Industrial Revolution and the modern era of engineering) and new paradigms based on chaos theory, and the principle of self-organizing systems.

Assessment: Student reactions to the global and societal contexts portion of the course are shown in Table 1. Reference to the issue in the preliminary and final design reports are shown in Table 3. Students noticeably struggled with this issue identified in Criterion IV. There was a great sense of unease expressed when issues relating to the conflicts of interest among Western nations, Third World nations and indigenous peoples were discussed. From the faculty’s perspective, the students in this class had nearly unanimously adopted the Western model of economic growth; their concerns for the cultural impacts of proposed designs or technologies were essentially non-existent.

Addressing Environmental Impact

Goal: Students will appreciate the potential environmental impacts of their work.

Activities: Readings, essay, mock debate, videos and in-class discussions

The time frame of the offering of this particular course overlapped with the controversy concerning drilling in the Arctic Wildlife refuge. [10] This hotly debated topic served as an effective mechanism for framing the question of potential environmental impacts of technology in today’s world. A series of provocative videos [11-15] were included in this portion of the class. Readings were also assigned from an anthology of modern nature writings including works by essayists, satirists, and poets. The readings served as the foundation for not only in-class discussions but also a mock debate, which considered issues related to forest fires and preventive, controlled burns.

Assessment: Environmental issues seemed most accessible to students and generated the most impassioned in-class discussions. Student reactions are shown in Table 1. Reference to the issue in the preliminary and final design reports are shown in Table 3. The last quarter of the fall term focused exclusively on environmental concerns. Though class attendance for this portion was completely optional, attendance averaged at approximately the 85% level. In addition, the campus bookstore indicated that approximately 75% of copies of the text, a collection of readings on environmental topics [12], had been sold. Essays which dealt with environmental issues, though optional, held to approximately a 60% submission rate with a resubmission rate of approximately 50%. The presentation by McDonough [16] proved most effective in generating discussion both during class and afterwards. Student chapters of several professional societies used the McDonough video as a focus of their monthly meetings. Additional, one professional society adopted a park clean-up community service activity partly in response to issues raised by McDonough concerning green design and sustainability.

Addressing Technical Communications

Goal: Students will be able to communicate effectively both orally and in writing.

Activities: Essays, case studies, design reports, and design presentations

Individual and team writing assignments were made throughout the two terms. Throughout the fall term, students were asked to prepare four formal essays dealing with topics ranging from personal reflection, a description of a concept, and a description of a process to a definition of a design space. [6] In addition, as mentioned previously, a series of ethical and environmental impact cases were also assigned (i.e. one was “required” while the others were “optional”). A team of senior-level students from the university’s English department graded the papers, provided extensive written feedback, and was available for individual tutoring sessions. The actual identity of the specific grader assigned to a specific paper was withheld from the engineering students in order to prevent any possibility of confrontations. Also, the papers were assigned to the graders in a random fashion. At the start of the semester, a training period for the graders was held, directed by the
faculty from the university’s tutoring center. Throughout the semester, weekly meetings were also held with both the engineering faculty and graders in attendance. In order to promote the notion of “writing as a process”, engineering students were allowed to revise and re-submit their essays once their graded papers were returned with a cumulative average to serve as the final grade. The turnaround time was held at approximately one week. The team writing assignments included weekly activity reports, the preliminary design report and the final design report.

On two separate occasions, hour-long workshops dedicated to the art and craft of making an effective presentation were held, each at the approximate mid-point of each semester. In addition, the design teams were required to make a full presentation (i.e. a “dress rehearsal”) to the course faculty alone prior to the official presentation. At that time, extensive feedback was provided, helping them “fine-tune” their presentations. Teams could (and many did) opt for an additional practice run.

Assessment: Student reaction at the start of the fall term to the formal writing requirements was extremely hostile. A clear majority felt that the attention paid to improving their writing was an unfair burden upon their already heavy course load. Additionally throughout the semester, many expressed resentment that students from another discipline (English) were commenting on the quality of their work. In spite of the students’ negative attitudes, our assessment throughout the term was that the quality of the writing improved remarkably. For example, less than 10% of the students could properly document reference sources for the first assignment, while at the end, 100% attributed material correctly. Faculty from the two engineering departments involved who had the same students in other classes also observed that this particular group of students had developed impressive writing skills. The same observation by both faculty and industrial sponsors has been made concerning the quality of both the preliminary design and final design reports. A similar improvement was noted in the oral communication skills by both the students themselves and faculty from various departments. Surprisingly, student reactions as noted on the questionnaire were the least favorable. This contrasts with the fact that approximately 25% of the teams asked for a second practice or trial run of their presentations even though it was not required. This suggests, in our view, a significant degree of personal commitment to the course and the project.

FINAL THOUGHTS

The future direction of the course is, at present, unsure. It suffers from the inherent difficulties that all multi-disciplinary courses endure: that is, issues related to course ownership and administratve control. The same course is being offered again during the present academic year with revised faculty participation.

A senior-level capstone design course has been developed and offered which focuses upon some of the issues raised by ABET in Criterion IV: specifically, engineering ethics, the global and societal contexts of engineering, and the impact of engineering on the environment. In addition, the course was used as a means to address shortcomings in the technical communications skill levels of our graduating class. Interestingly, the design course brought to our attention several notable shortcomings in the technical preparations of the senior class. As a result, curricula in each of the different programs have changed, in part as a response to this information. Using Kirkpatrick’s model for evaluating training programs, we feel that the senior design experience met the goals that we had established for the course. Most notably, students’ writing and presentation skills improved dramatically according to feedback from faculty advisers and corporate sponsors as well as general faculty and staff not associated with the course.

REFERENCES

How well did the design course improve your ability to...

<table>
<thead>
<tr>
<th></th>
<th>Not at All (0/F)</th>
<th>Not Well (1/D)</th>
<th>Average (2/C)</th>
<th>Well (3/B)</th>
<th>Very Well (4/A)</th>
<th>Avg (4.0 max)</th>
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<tr>
<td>Identify ethical situations?</td>
<td>0</td>
<td>10</td>
<td>20</td>
<td>45</td>
<td>25</td>
<td>2.85</td>
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<td>Make informed ethical decisions?</td>
<td>0</td>
<td>4</td>
<td>10</td>
<td>33</td>
<td>53</td>
<td>3.35</td>
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<td>Comprehend societal and global issues?</td>
<td>6</td>
<td>4</td>
<td>20</td>
<td>50</td>
<td>20</td>
<td>2.74</td>
</tr>
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<td>Comprehend an engineer’s role in society?</td>
<td>0</td>
<td>6</td>
<td>12</td>
<td>50</td>
<td>32</td>
<td>3.08</td>
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<td>Make an effective oral presentation</td>
<td>6</td>
<td>11</td>
<td>29</td>
<td>32</td>
<td>22</td>
<td>2.53</td>
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TABLE 1
STUDENT REACTIONS AS A PERCENTAGE OF CLASS (110 RESPONDENTS)

Focusing on the engineering ethics component of the course:

<table>
<thead>
<tr>
<th></th>
<th>No (0/F)</th>
<th>Seldom (1/D)</th>
<th>Occasionally (2/C)</th>
<th>Often (3/B)</th>
<th>Very Often (4/A)</th>
<th>Avg (4.0 max)</th>
</tr>
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<tr>
<td>Did the course make you aware of the various engineering codes and their usefulness in solving ethical dilemmas in the engineering profession?</td>
<td>0</td>
<td>0</td>
<td>18</td>
<td>54</td>
<td>28</td>
<td>3.06</td>
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<tr>
<td>Did the course help you in seeing or identifying similarities among engineering or professional dilemmas and dilemmas in your personal/private life?</td>
<td>0</td>
<td>8</td>
<td>22</td>
<td>50</td>
<td>20</td>
<td>2.82</td>
</tr>
<tr>
<td>Did the course coverage of moral reasoning theories aid you in understanding your own ethical or moral code? That is, where you more able to articulate your own value system and the origins of your value system?</td>
<td>0</td>
<td>8</td>
<td>21</td>
<td>50</td>
<td>21</td>
<td>2.84</td>
</tr>
<tr>
<td>Did the course encourage you to reflect upon different views of technology, that is, (1) technology as liberator, (2) technology as a threat, and (3) technology as an instrument of power?</td>
<td>0</td>
<td>10</td>
<td>20</td>
<td>45</td>
<td>25</td>
<td>2.85</td>
</tr>
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</table>

TABLE 2
STUDENT RESPONSES AS A PERCENTAGE OF CLASS FOCUSED ON DIFFERENT LEVELS OF MEANING FOR INTEGRATING ETHICS (110 RESPONDENTS)

<table>
<thead>
<tr>
<th>Identification and/or Discussion of Issue</th>
<th>Preliminary Design # Projects/ # Discussion of Issue (%)</th>
<th>Final Design # Projects/ # Discussion of Issue (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering Ethics</td>
<td>25/23 (92)</td>
<td>24/22 (92)</td>
</tr>
<tr>
<td>Global and Societal Contexts</td>
<td>25/18 (72)</td>
<td>24/15 (62)</td>
</tr>
<tr>
<td>Environmental Impact</td>
<td>25/23 (92)</td>
<td>24/20 (83)</td>
</tr>
</tbody>
</table>

TABLE 3
APPLICATION OF LEARNED KNOWLEDGE WITH RESPECT TO PROFESSIONAL ISSUES