THE COMPLEAT ENGINEER

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Abstract

The Accreditation Board for Engineering and Technology (ABET) requires that today's engineering graduates show evidence of a broad education in technical and social issues. Not only must students master the engineering sciences and modern design practice, but they also shall have an understanding of professional and ethical responsibility, knowledge of contemporary issues, and an understanding of the impact of engineering in a global and societal context. In order to address these outcomes as part of a coherent educational process, Christian Brothers University has developed a new senior level course, called "The Compleat Engineer". This course addresses these areas as well as issues like health, safety, environmental factors, reliability, maintainability, manufacturability, and sustainability. This course will be required of all graduates in civil, electrical, and mechanical engineering. This paper provides an overview of the format and content of the course. Student perceptions and other effectiveness indicators are presented and analyzed.

Introduction

It is a commonly accepted proposition that modern engineering schools must equip their graduates with more than the traditional mix of engineering science and engineering design. Engineering within the enterprises of today's economy requires practitioners to have a global perspective and to be sensitive to a variety of socially driven concerns. These concerns start with engineering ethics and include the environment, public health and safety, as well as economic, social, and political factors considerably beyond the usual analyses of life-cycle cost and net present value.

To some extent, these "global issues" can be integrated into traditional general education courses, but this may not be the most effective course of action, given the diversity of the restricted electives available to students. At Christian Brothers University, the faculty of the School of Engineering continually assess our performance in achieving the goals of the educational process, and we have found that these global-issues topics need strengthening. CBU Engineering has developed a new required senior-level course, "The Compleat Engineer", which directly addresses many of the global issues that receive sporadic coverage in other courses.

Engineering Programs

Reflecting the consensus about the importance of these topics, global issues are built into the accreditation criteria for engineering schools. Criterion 3 of ABET's *Criteria for Accrediting Engineering Programs* states:

> "Engineering programs must demonstrate that their graduates have:
> (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."

The course paradigms of the various departments within the CBU School of Engineering address these "a through k" outcomes in what might be called the traditional approach. Specifically, we have a foundation of engineering science and laboratory courses, with a math/physics/chemistry backbone; design experiences built into junior and senior-level courses; a capstone design course; and a variety of general education courses.

Exhibit 1 shows the coverage of the "a through k's" by the various subject areas. Note that the open symbols in Exhibit 1 imply that the subject area may give uncertain support for the outcome. Some capstone projects, for example, may involve contemporary issues (outcome (j)). A recent capstone project in mechanical engineering addressed oil spill amelioration, for example. But other projects may not intersect with contemporary issues to this extent.

Similarly, great latitude is given to students to select general education restricted electives. Whether the courses chosen by any given student address contemporary issues or professional ethics is quite variable. It is clear from Exhibit 1 that the global issues outcomes (f), (h), and (j) have uneven support within the course paradigm.

In addition, selected quantitative measures of student outcomes, such as the Fundamentals of Engineering Examination, indicate that we need strengthening in areas such as Engineering Ethics.

Our Solution: The Compleat Engineer

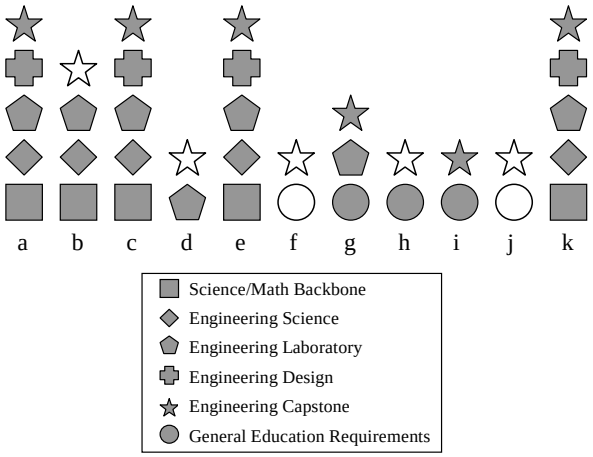
We decided to address these outcomes directly, by designing a course that would fill the gaps left by sporadic coverage by other subject areas. The new course, "The Compleat Engineer", includes three major phases:

- Engineering Ethics
- Quantitative Reasoning
- Current Events

Engineering ethics, addressed indirectly in other courses, here consumes about six weeks of class time. "Quantitative reasoning" in this context means an extension of our students' training in probability and statistics to cover reliability and failure analysis. Our goal is to enable our students to analyze the factual, quantitative aspects of ethical and contemporary issues with the appropriate mathematical tools of statistical inference. Current issues are addressed in the last third of the course; content will vary from year to year, but the concept is to address the engineering aspects of such topics as climate change, world trade, and the revolution in military affairs.

"The Compleat Engineer" has been adopted as a required senior-level course by three of our four engineering departments (civil, electrical, and mechanical), starting with the class of 2007. The course will be taught as an elective until the current freshmen are seniors. (The 4th department, chemical engineering, is recommending the course to their seniors as their senior elective). The course was taught for the first time in the spring semester of 2004.

Exhibit 1. The traditional engineering course paradigm provides coverage for ABET outcomes (a) through (k). Open symbols indicate subject area may only give sporadic preparation for the given outcome, or preparation only in some restricted electives or projects.



Implementation

The ethics portion of the course was presented as a combination of lectures and case studies. Typically, the instructor would give a brief talk on the assigned reading, and then move on to a case study illustrating the topic. Some of these case studies were hypothetical situations designed to illustrate specific engineering ethical situations. Others were actual historical events such as the history surrounding Werner von Braun and slave labor under the Nazi regime, the Challenger disaster and the fuel tank design for the Ford Pinto. Most of the lecture hour was set aside for classroom discussion.

We were aided by the excellent text by Harris, Pritchard, and Rabins, "Engineering Ethics: Concepts and Cases". We covered most of the content of this book, including

- The framework for ethics
- Universalizability and Reversibility
- Line-drawing, creative middle way
- Utilitarianism
- Respect for Persons; Golden Rule
- Responsibility, Reasonable Care, Impediments
- Misusing the Truth
- Integrity and Expert Testimony
- Integrity, Conflict of Interest
- Expert Testimony; Informing the Public
- Whistleblowing
- Intellectual Property

In addition, the Texas A&M web site on engineering ethics, http://ethics.tamu.edu/, was an excellent resource, especially for assignments.

The NSPE Code of Ethics was the basis for much of the ethical discussion. Connections to the code of ethics were made with each lecture and class discussion. A large-format poster of the Code of Ethics, fixed to the classroom wall, was a convenient reference.

The discussions provided the students with opportunities to attempt to discern the differences between the perceptions and the actual facts for various situations. During the discussions, the students were encouraged to develop possible courses of action to resolve various ethical dilemmas found in engineering practice. The instructors and students then jointly analyzed each possible course of action to determine if it could be considered reasonable regardless of an individuals position within the situation and was compliant with the NSPE Code of Ethics.

The quantitative phase of the course comprised a series of seven lectures reviewing statistical methods and hypothesis testing, culminating in an in-depth discussion of topics in reliability and risk analysis. Failures of components, systems, and humans, and associated public health and safety implications were analyzed in detail. We strove to make the connections between our quantitative analysis and the other phases of this course, ethical judgment and contemporary issues.

An interesting case study was discussed in this phase: "A Prayer Before Dying" deals with the case of Dr. Elisabeth Targ, who studied the efficacy of prayer on healing. Dr. Targ's study, though published in a refereed journal, was marred by subtle errors in statistical analysis and thereby became a paradigmatic example of the need for precise and correct analysis.

The current events phase of the course was more traditionally lecture-oriented. Our goal was to increase our students' level of awareness and appreciation for topics frequently in the headlines. Topics in this year's class included

- Internet: Privacy, encryption, confidentiality
- Internet: Intellectual property, file sharing
- Globalization, the WTO, and the anti-globalization movement
- The Revolution in Military Affairs
- The Northeast Blackout of 2003
- Energy Consumption and Production
- The (agricultural) Green Revolution
- Terrorism and security technology

For the last two topics, we required students to fill out a "factoid sheet", a 5"x8" card in which they performed a quick web search and wrote down an interesting fact or set of facts related to the topic. These factoids were collected at the beginning of the class and formed a surprisingly good basis for class discussion.

The mid-term examination involved some basic questions about engineering ethics, and detailed questions about the Goodrich A-7 Brake Case, discussed in Harris et al. and also at the TAMU web site. The final exam consisted of another set of questions about engineering ethics, accompanied by an option to answer questions about topics "Bioidentification" or "EPA Superfund". (Students were informed of that this would be their choice of topic about a week before the final exam).

Finally, students were required to produce a 3-to-5 page "executive summary" on a current events topic related to engineering in some way. Students produced papers on a wide variety of subjects, including genetically modified food, "safe gun technology", offshore manufacturing, and voting technology.

Assessments

At this time, the information available for assessing this course includes qualitative impressions from the instructors, student survey responses and results from the mock Fundaments of Engineering exam. The student survey asked students to rate the course effectiveness on a scale of one to ten in ten different areas. A ranking of ten was defined as indicating highly effective; a ranking of one was defined as indicating ineffective. The specific questions used in the survey are listed in Exhibit 2 on the following page:

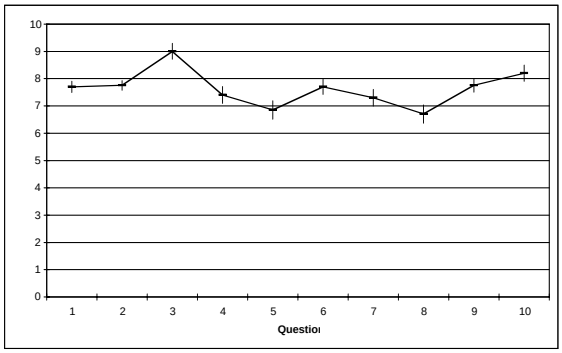
Exhibit 2. Student Satisfaction Survey questions

Q1 This course has significantly improved my understanding of engineering ethics.
Q2 This course has significantly contributed to my understanding of professional issues.
Q3 Did this course familiarize you with the NSPE Code of Ethics?
Q4 Do you feel better equipped to deal with ethical dilemmas in a professional manner?
Q5 Did this course increase your understanding of environmental issues for engineers?
Q6 Did this course increase your understanding of health, safety, and regulatory issues?
Q7 Did this course increase your understanding of social and political factors in engineering?
Q8 Did this course provide you with a better understanding of reliability and maintainability?
Q9 Did this course help to give you a global perspective on engineering?
Q10 Did this course provide a good introduction to current events relating to engineering?

The survey format required the students to provide a numerical evaluation of the class performance for each of the ten questions. A score of ten indicated the student felt the course was highly successful; a score of zero implied lack of success.

The class population consisted of junior and senior level engineering majors. All twenty students in the class completed the student satisfaction survey. A graphical presentation of the responses is shown in Exhibit 3 below.

Exhibit 3. Student Satisfaction Survey Responses



The graph clearly shows that students perceived the course as an effective means of addressing each of the areas evaluated in the survey. Responses indicate that the course was most effective at familiarizing the students with the structure and requirements of the NSPE Code of Ethics. Responses for the other areas showed some variation, however, that variation is consistent with the amount of class time devoted to each of the issues survey.

CBU students are provided with an opportunity to take a mock Fundamentals of Engineering exam each year as part of the preparation for the actual exam. In previous years, student performance has been weaker than desired on the engineering ethics section of the exam. Student performance on the engineering ethics section has risen to 95% this year from 79% last year. We believe that is a significant positive indicator. Additional information will be available when the results of actual Fundamentals of Engineering exam become available.

Conclusions

All available data indicate that the course is achieving the desired outcomes. Student responses to the survey indicate they found the course to be valuable preparation for their professional careers. In addition, the instructors received numerous student comments that the course was also highly enjoyable.

We will continue to expand this course in the coming years. We hope to expand the current events topics to include:

- climate change
- ozone depletion
- genetically modified food
- nuclear power
- voting technology
- the water cycle
- nanotechnology
- longevity
- human cloning

We believe that the course has been so successful that we plan to market the course to science majors. It is our belief that adding these students to the course population would provide additional diverse viewpoints to the discussion.

To facilitate marketing to science majors, we will petition to have the University approve the course as meeting the requirements for one of the general education components. This approval would create additional program flexibility for non-engineering majors.

Finally we believe that we have a creative and effective course that addresses the need for broadly educated engineering graduates and decision makers.

References

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About the Authors

Bernard Beard received his B.S. and M.S degrees in Mechanical Engineering, and Ph.D. in Physics, from the Massachusetts Institute of Technology. He is currently an associate professor and is the chairman of the Mechanical Engineering Department at Christian Brothers University in Memphis, TN. He maintains active research in nuclear physics and continues to be engaged in educational issues in engineering.

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