AC 2011-71: TEACHING AND ASSESSMENT OF "ETHICS IN ENGINEERING PRACTICE"

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Development and Assessment of "Ethics in Engineering Practice": A New Technical Support Elective

ABSTRACT

Within the engineering and scientific community it is difficult to overestimate the importance of acting with high ethical standards in global, social, intellectual and technological contexts. With this need and consistent with the NAE's Engineer of 2020 directive, a new semester length course was designed to teach ethics to junior and senior engineering students at Purdue University. *The objective of the course was to demonstrate that exposure to and involvement in an ethics course specifically designed for engineers can mature the moral reasoning skills of those students who participate.* The course was organized around three sections. Section I of the course grounded the students in ethical theory. The remaining part of the course utilized faculty-led (Section II) and student-led case studies (Section III) to continue to mature their moral reasoning skills in an engineering context.

The progress of moral reasoning skills was measured using the Defining Issues Test (DIT2). The assessment was given during the second and the penultimate lectures to assess changes in moral reasoning after completing the course. The average "pre-class" N2 score was 40±13. After taking the course, a N2 score of 51±11 was measured, indicating substantial improvement in their moral reasoning ability. It was noted that 17 of the 19 students demonstrated an increase in their moral reasoning skills. Furthermore, the number of students scoring at the same education level as a graduate from a professional school (i.e. a N2 score of 50 or higher) jumped from 5 pre-class to 12 post-class.

I. Introduction and Motivation for Course Development

The primary mission of Purdue University's College of Engineering is to educate the next generation of engineering leaders from across the United States and abroad and to prepare them for work in technical fields. As evidenced by employers' interest in our graduating engineers and consistently high rankings by its peers and national news magazines, Purdue University does a good job of imparting technical knowledge to its students. However, while technical competence is necessary, it is not a sufficient condition for the engineer of 2020 to be successful, as noted in a recent NAE document,[1] and as acted upon recently in the College of Engineering.[2] Within the engineering and scientific community, it is difficult to overestimate the importance of acting with high ethical standards in global, social, intellectual and technological contexts. When this attribute is present in engineers and scientific personnel, people are rarely aware of it, but when it is absent and ethical standards break down, the world notices.

In recent years, there have been many well-documented engineering failures, including the losses of the *Challenger* and the *Columbia*, the Kansas City Hyatt Regency skywalk collapse, and the Exxon Valdez oil spill, as well as several high-profile cases of academic and scientific dishonesty in research. While the circumstances for each example are different, the underlying theme of each is that an individual or group of company employees was faced with ethical dilemmas in the performance of their jobs. Poor choices made in each of these cases had substantial impact on many people and have been the subject of significant public scrutiny. James Kroll, Head of Administrative Investigations in the Office of Inspector General at the National Science Foundation, estimates that between 2003-2008 the number of substantial ethics inquiries at the NSF has increased from 3 per year to 37 per year.[3] These, he said, are "serious investigations where there are breeches of conduct regarding a NSF grant." The National Academy of Engineers has even developed a fairly comprehensive website to educate engineers about this issue.[4] However, according to a 1999 article by Stephan, nearly three-quarters of the engineering programs in the U.S. (including Purdue) allow at least some students to graduate without taking a course whose catalog description mentions ethics.[5]

To meet the requirements for the Engineer of 2020 and specifically to address the need for formal training in ethics, the authors developed a semester-long ethics course that was open to students from any engineering discipline. *The objective was to demonstrate that exposure to and involvement in an ethics course specifically designed for engineers can mature the moral reasoning skills of those students who participate.* This paper is a report on the design of the course and on the use of the Defining Issues Test to assess the maturation of moral reasoning skills of those who completed the course.

II. COURSE STRUCTURE AND MARKETING

The design of this course was influenced by the observations of Haws[6] in his meta-analysis of 42 papers presented from 1996-1999 at American Society for Engineering Education (ASEE) conferences. Each of the papers he analyzed treated engineering ethics as a coherent educational objective. He noted six pedagogical approaches to teaching this class, including discussion of the professional engineer's code of ethics, humanist readings, theoretical grounding, ethical heuristics, case studies, and service learning. Building on the experiences of the authors teaching a 6-lecture ethics unit in the senior capstone course, three of these six approaches were used in this class.

Thus, the entire course was divided in three parts:

I. Present and discuss common ethical theories and applications (including the engineer's code of conduct)
II. Investigate engineering-based case studies (Faculty-led case study investigations)
III. Teach students how to investigate and apply their knowledge to real situations (Student-led case studies and analysis)

Section I grounded the students in ethical theory. Haws[6] noted in his article that not grounding students in ethical theory is "probably the greatest single weakness in engineering ethics instruction." By analogy, it would be highly unlikely for an engineering faculty member to write an equation on the board and say, "Don't worry about understanding this; just use it and you will get the right answer." But that is what is done to students if they are told to read a company or professional society code of ethics and then told "make the right choice," without recourse to an understanding of ethical theories on which these codes are based. The rest of the course used faculty-led (Section II) and student-led case studies (Section III) to continue to mature their moral reasoning skills through application of the theory. In these case studies, the goal was a presentation of both the technical and ethical contexts and an evaluation of how decisions were made. Thus, the overarching structure of the class was presentation of ethical theory, followed by application to issues in engineering practice. It should be noted that most engineering classes of a more technical nature are structured in a similar way (e.g. presentation of theory followed by its application).

In Section I, the three basic ethical systems were presented: consequentialist, principled, and virtue-based ethics. These were chosen because they represent the most widely used approaches to determining ethical behavior. *Consequentialist* ethics asks the question, "What path produces the best results?" Consequentialist ethical theory included discussions of Ethical Egoism, popularized by Ayn Rand, and Utilitarianism, first proposed systematically by Jeremy Bentham in the 18th and 19th centuries. A presentation of *principled* ethics followed, with an emphasis on Immanuel Kant. Principled ethics asks the question "What are my duties in these circumstances?" The final major ethical theory discussed was *virtue-based* ethics. Virtue-based ethics asks the question, "Whom should I become and what virtues should I habitually practice?" The primary textbook was the sixth edition of *Ethics: Discovering Right and Wrong*, by Louis P. Pojman and J. Fieser[7], supplemented by a translation of Aristotle's *Nichomachean Ethics*[8]. Pojman and Fieser's book was chosen because of the generally concise descriptions of each theory and its overall readability.

The ethical theories taught in Section I were also applied to different approaches to evaluating risk and product reliability, interactions of engineers with the legal system, and organizational culture and its influence on decision making. Special attention was given to this last topic, which included the importance of and limits to loyalty between employers and employees, whistleblowing, and obedience to legitimate authority. Because many ethical dilemmas evolve from conflicts between one's conscience and pressure from authority or one's peers, the obedience experiments of Dr. Stanley Milgram[9] were discussed at length. Because of the controversy raised about Milgram's methods in these experiments, they also serve as an introduction to ethical practices in research. Readings from texts and the archival literature on ethics specifically in engineering practice were also used to supplement lectures. Two invited speakers were also part of the course. The first was a Chicago-based attorney who practices product liability law. He discussed the interactions of engineers with the legal system, including how lawyers view the engineering profession, the role of the expert witnesses, and the importance of character in the courtroom. The other speaker was a professor in the Purdue School of Nursing, who addressed the ethics of research on human subjects, including patient rights and informed consent.

For Section II of the course, the following case studies were presented by the faculty:

1. Shiley Heart-Valve
2. Kansas City Hyatt Regency Skywalk
3. Desmarquest Ceramic Femoral Head
4. Bell Laboratories: Research Fraud by Jan Hendrik
5. Space Shuttle *Challenger*

The presentation of these cases included both the technical detail pertinent to the ethical decisions made by the participants, as well as an evaluation of those decisions in light of the ethical theory developed in Section I.

In Section III of the course, groups of 2-3 students gave presentations on several high-profile engineering failures with potential ethical components. These included:

1. Ford Pinto Recall
2. DC-10 Cargo Hatch
3. Citicorp Building and Wm. LeMessurier
4. Chernobyl
5. Three Mile Island
6. Ford Explorer Rollover
7. Boston's Big Dig Ceiling Collapse

The presentations were nominally 20 minutes, with a total of 5 minutes allotted for Q&A. To show a complete understanding of the technical and ethical details of the case, it was important that both aspects be presented by the student groups. In addition to the student-led group case studies, the students also wrote shorter essays, took a midterm exam, and kept a journal of their reading assignments.

To advertise the course, the following course description was used:

> A new 3-cr hour course for junior and senior engineering majors will be taught this spring that will explore both the theory and application of ethics within the practice of the engineering discipline. This new course will include presentation and discussion of common ethical theories and their applications, with faculty- and student-led case studies from real engineering practice. Guest lecturers will also be invited to address key issues such as product liability law, engineering and public policy, etc.

This description, along with a flyer, was emailed to various academic advisors within the College of Engineering during the registration period for the Spring 2010 semester. As this was a new course, promotion of it was required across the 12 engineering schools at Purdue University. A short description of how this class would fit within each school's graduation requirements was also included. Enrollment was capped at 40 students; 19 students enrolled for the class. Subsequent promotion of this course among the undergraduate chairs of each school would make reaching the enrollment limit much easier in the future.

III. Assessment of Student Knowledge and Moral Reasoning Skills

A written exam was used after Section I of the course to measure students' understanding of the basic ethical theories. A series of simple matching and definitions were used to measure basic knowledge. The students were asked to adopt a particular ethical theory and respond to several straightforward scenarios. Short writing assignments were used to assess the students' ability to formulate and defend rational arguments. Student-led group case studies were presented the last two weeks of the semester.

The progress of moral reasoning skills was measured using the Defining Issues Test (DIT2). This test presents five moral dilemmas, each followed by 12 issue statements. In a 1998 paper, Self et al.[10] assessed student's moral reasoning using the DIT in a manner similar to the method used in this study, and measured statistical differences in reasoning skills before and after being taught some ethics content. They concluded that the effect of teaching ethics in engineering can be "rigorously measured." A recent article in the *Review of Higher Education* [11] described the DIT2 test as measuring "the degree to which students use principles to guide their decision making when faced with a moral dilemma." In this case, the test outcome examined is the N2 score, comprised of two parts to include the degree to which respondents demonstrate sophisticated thinking and the degree to which respondents reject simplistic or biased thinking when faced with moral dilemmas.[11] The article goes on to say that "higher N2 scores reflect an individual's increased capacity for reasoning about moral issues based on a system of fairness that serves the public good." [11] The DIT2 test has been used extensively and correlations with educational levels have been noted. [12] Senior high students average in the 30s, college students in the 40s, students graduating from professional schools in the 50s, and Moral Philosophy doctoral students in the 60s. The assessment was given during the second and the penultimate lectures to assess changes in moral reasoning after completing the course.[13]

IV. RESULTS OF STUDENT ASSESSMENTS

The scores for the exam covering Section I (ethical theory) ranged from 36% through 93%, with an average of 60%. It should be noted that this is the first time that most of these students have ever been exposed to a rigorous study of moral philosophy. Writing an opinion paper, where a position is argued and defended using mature reasoning skills, was challenging and may point to a large deficiency in education of engineering students.

Grades for the student-led case studies ranged from 60% to 87%, with an average of 75%. For the most part, students were able to address the technical reasons for failure. However, many students struggled with clearly articulating an ethical analysis of the decision making of the key groups or individuals in the study.

Table 1 shows the average "pre-class" N2 score of 40±14 obtained from the DIT2 test. This small student sample correlates very well with the N2 scores for first year college students in a large multi-university study, who measured N2 scores of 41±15.[11] After taking the course, the students produced a N2 score of 51±11, indicating substantial improvement in their moral reasoning ability as defined by the DIT2 test. Figure 1 compares the pre- and post-class scores of each of 19 students enrolled in the course. What is interesting is to note is that 17 of the 19 students demonstrated an increase in their moral reasoning skills; improvements ranged from a statistically insignificant value of 1 through a more impressive increase of 28. Two cases showed a small decrease of 3 and 4. Furthermore, the number of students scoring at the same education level as graduating from a professional school jumped from 5 (pre-class) to 12 (post-class). Overall, it appears that the course experience has significantly helped the students to mature their moral reasoning skills.

Table 1. Results of DIT2 Tests Given to Students in this Engineering Ethics Class.

Pre-Class N2 Score on DIT2	Post-Class N2 Score on DIT2	Number of Students With Increased N2 Scores	Number of Students Scoring Above 50
40.4 ± 13.6	**50.72 ± 11.36**	**17 of 19**	**5 Pre-Class 12 Post-Class**

One research question that deserves consideration is the effect of each section of the course on the maturation of the moral reasoning skills. No attempt was made in this first course offering to separate out the influence of Section I (presentation of ethical theories) and Sections II and III (application of those theories to engineering). However, there is some intuition based on observation of the students in class discussions that the three major sections of the course are necessary to mature students reasoning ability.

V. Conclusions and Future Work

In summary, a class designed to mature the moral reasoning skills of engineering students in the College of Engineering at Purdue University has been designed and taught. The overall structure of the course emphasized teaching both ethical theory and its application to engineering practice. The Defining Issues Test was used to assess changes in moral reasoning ability from pre- and post-class assessment. The average pre-class N2 score was 40±13, which correlated very well with the N2 scores for first year college students. After taking the course, a N2 score of 51±11 was measured, indicating significant improvement in their moral reasoning ability as defined by the DIT2 test.

While 19 students was a reasonable number for the first time this course was taught, Purdue University's engineering enrollment per class is approximately 1600 students. Thus, a larger impact is desired. With this in mind, an 10 lecture module is being developed that would be offered to the other schools within the engineering college. The module will be designed to emphasize both theory and its application to issues in the engineering profession. The effectiveness of these modules to increase student moral reasoning skills will have to be assessed by methods similar to the study described in this study.

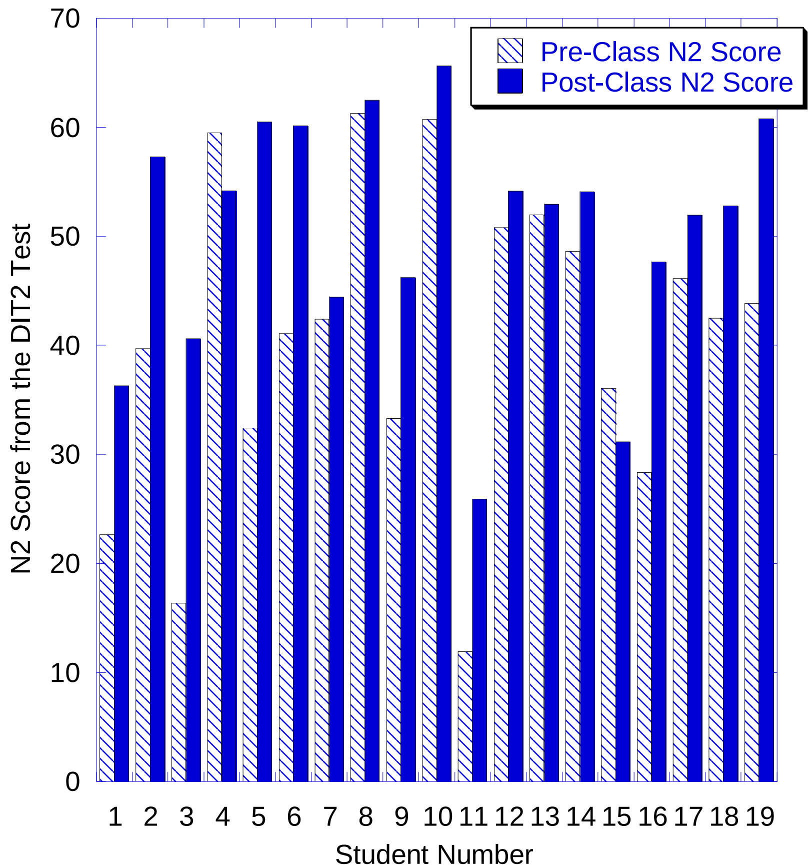

Figure 1. Bar graph of the pre- and post-class N2 scores, indicating substantial improvement in overall moral reasoning ability.

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[1] National Academy of Engineering, *The Engineer of 2020* (2004).
[2] Purdue University College of Engineering internal document, *Adoption of the Engineer of 2020 Target Attributes*.
[3] J. T. Kroll, Office of the Inspector General at NSF, oral presentation at NSF-CMMI Grantees Conference, Knoxville, TN, January 8, 2008, and personal communication, January 25, 2008.
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[5] Karl D. Stephan, "A Survey of Ethics-Related Instruction in U.S. Engineering Programs," *J. Eng. Ed.*, **10** 459-64 (1999).
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[11] M. J. Mayhew, T.A. Seifert, and E.T. Pascarella, "A Multi-Institutional Assessment of Moral Reasoning Development Among First Year Students," *The Review of Higher Education*, Spring 2010, **33** [3] 357-390.
[12] Guide for DIT-2 Test, provided by the Center for the Study of Ethical Development at http://www.centerforthestudyofethicaldevelopment.net/
[13] Developed by James Rest; See the Center for the Study of Ethical Development, University of Minnesota; http://www.centerforthestudyofethicaldevelopment.net/index.html