AC 2011-846: FIRST-YEAR ENGINEERING STUDENTS AND ETHICAL ANALYSIS

Gretchen L. Hein, Michigan Technological University

Dr. Hein is actively involved with developing and implementing new material and strategies in first-year engineering courses. Additionally, she is interested in how student learning and creativity changes as they progress through their first-year courses.

Amber Kemppainen, Michigan Technological University

First-Year Engineering Students and Ethical Analysis

Abstract:

Each year 800 first-year engineering students at Michigan Technological University study engineering ethics. These same students complete some type of engineering design project. What would happen if these students explored the ethical issues surrounding their design topic? Would their understanding and application of ethics improve? Would their ability to analyze ethical case studies improve? Traditionally, students first learn about engineering ethics and ethical decision making and then apply these concepts in analyzing typical introductory engineering ethics case studies.

At Michigan Technological University, the effect of integrating engineering ethics into the semester-long design project was explored in four sections of a first-year engineering course. Within the four sections (approximately 160 students), there were three team design projects: Wind Energy, Aquaculture and Biomechanics. The Wind Energy and Biomechanics projects were piloted in one ENG1001 section each, while two sections completed the Aquaculture project. The specific design project was integrated into all aspects of the course. For example, students learned about unit conversions through completing design project related calculations. Engineering ethics topics were designed the same way. Students investigated the potential ethical decisions that would result from the design, manufacture, use, and disposal of their projects. Students learned about the techniques of ethical decision making and applied these skills to the ethical issues surrounding their design project. As a team, they analyzed not only their design topic, but an unrelated ethics case study.

To determine if completing ethical analyses related to their design work affected student understanding and application of engineering ethics, students' knowledge of ethics was assessed prior to learning about engineering ethics. The students were post-assessed regarding their knowledge of engineering ethics. The results of this small-scale study will be described, along with the design projects and their related ethical issues. Student comments regarding the ethics and their understanding of engineering ethics will also be explored.

Introduction:

One of the program outcomes for accreditation of an engineering program is that their students demonstrate an understanding of ethical responsibility by the end of their undergraduate degree.[1] At many universities, first-year engineering students are introduced to engineering ethics. For most of these students, the introduction relates to standard ethical case studies. By investigating these cases, students increase their awareness of ethical issues affecting the engineering profession and sensitize themselves to ethical issues before they confront them in the workplace.[2] In lieu of ethical case studies, universities are exploring novel approaches to students learning and applying engineering ethics. In 2005 at Bucknell University, students learned a seven step method for ethics analysis that included: finding out the facts, determining the moral issues, defining the affected parties, exploring alternatives and the associated outcomes, determining the costs of the decisions, and identifying the moral issues, constraints and outcomes for each action.[3] Students applied this process when evaluating the ethics involved in one of five books. The selected books covered a range of engineering disciplines and social/political issues. A second approach was to have students learn about engineering ethics via four on-line case studies. The first three cases focused on ethics solutions, with the first two supplying answers and not the third. The last case study required students to write their proposed answer and justification.[4] Another way to analyze ethical issues that has been used at Union College is to create an ethics matrix with the NSPE Canons along one axis and the situation alternatives along the other. Students fill in the matrix with "Yes, No, and Maybe", along with a justification.[5]

These studies indicate that faculty recognize the importance of engineering ethics in contemporary society and the need to update the teaching of ethics to reflect current student learning preferences. To investigate what students think about contemporary ethical issues, a survey of first-year students was completed at Manhattan College. The issues did not just focus on engineering, but also included "philosophy, politics, economics, law, sociology, and psychology".[6] This one-year survey found that students had the highest interest in "weapons of mass destruction" (WMD) out of the ten issues included in the survey; 19% of the students had a "high" interest in the "ethics" of violent video games. The survey investigated whether or not a student thought their viewpoint regarding the issue would change when studying the ethics of it. Only 9% of students indicated that their opinion of violent video games would change, but 25% or more of the students indicated that studying the ethics of: new transportation corridors, agricultural enhancements, and nuclear power would cause them to change their opinion. Furthermore, students did connect the importance of different issues to society when they rated the importance of WMD and new transportation corridors as "important to society" and "violent video games as not as important.[6]

Background:

Like most first-year engineering programs, students at Michigan Technological University are introduced to many seemingly unrelated engineering topics. In Engineering Analysis, ENG1001, a first-year engineering course for students enrolled in pre-calculus, students have their first exposure to many engineering topics. These topics include: problem solving, unit conversions, technical communication (reports, memos, posters), problem analysis using engineering tools, sustainability and engineering ethics. The course is conducted in an active learning setting where students work on teams to complete class and team assignments. One way to connect these topics together is to have the design project integrated throughout the course. This method lends continuity to a class that covers many seemingly unrelated topics. Three integrated projects were piloted in the four sections of ENG1001 for 156 students (16% women) in the Fall 2010 semester. Underrepresented groups in engineering comprised 7% of the students. Additionally, a new first-year engineering learning center was available for students to receive homework assistance, construct and test their designs, and have space for team meetings.

All students who were enrolled in ENG1001 participated in this pilot program. Since first-year engineering students are block scheduled for their engineering and math courses during the fall semester, students did not know prior to the course that they were participating in a pilot program. They were notified that these design projects were new and that their feedback would be used to improve the projects and the course. The distribution of the majors is shown in the table below. Many of the students choose either electrical or mechanical engineering. A few students have not selected an engineering major or were not College of Engineering students.

Table 1. ENG1001 Engineering Major Distribution

Engineering Major	Number	Percentage
Biomedical	9	6%
Civil	16	11%
Chemical	19	13%
Computer	18	12%
Electrical	9	6%
Environmental	9	6%
Geological/Materials	5	4%
Mechanical	45	30%
General/Undeclared and Non-Engineering	25	17%

As part of this pilot project, the team design projects completed were: wind energy, biomechanics and aquaculture. The wind energy focused on researching wind energy, designing and constructing a lab-scale wind turbine, testing the device and analyzing its performance. Students who completed the aquaculture project focused on the research and design aspects of aeration systems and applied that knowledge to the construction of a lab-scale aeration system for a fish farm. They analyzed the data collected and hypothesized how the lab-scale system would perform at full-scale. The biomechanics project involved the design and construction of an artificial leg. Students tested the leg and analyzed their results to determine the forces generated during a simple kicking motion.

At Michigan Tech, first-year students historically have been introduced to engineering ethics using traditional methods of analyzing standard case studied.[7] In the Fall of 2010, in four sections of a first-year engineering course, students were provided with a different way of learning and applying engineering ethics. Instead of studying engineering ethics and then applying these concepts to traditional case studies, students learned about engineering ethics and professionalism, followed by the analysis of an in-class ethics case study related to their design project. They summarized the engineering ethics that could apply to their design project while they were involved in the design process. This allowed for ethics to be actively integrated into the project instead of being applied later as an afterthought. At the end of the ethics portion of the course, they created a team ethics case study poster.

The ethics introduction includes introducing students to the National Society of Professional Engineers (NSPE) Code of Ethics and Fundamental Canons[8], and the “RESOLVEDD” strategy for making ethical decisions.[9] The RESOLVEDD method consists of: Reviewing the case, identifying the Ethical issues, Solutions, Outcomes, Likely impact, Values (NSPE Cannons) upheld or violated, Evaluating the alternatives, making a Decision, and Defending your solution. Instead of the instructor formally illustrating how to apply this methodology, student teams develop lists of ethical issues relating to their design project. Students were encouraged to investigate all aspects of the design, use, manufacture, and disposal of their designs for possible ethical issues. For example, issues students listed regarding wind energy included: noise/light pollution, impact on wildlife habitat, impact on agricultural operations, individual compensation for approving/permitting wind farms near homes, power distribution networks, long-term effects (power generation, landscape alteration, health issues).

As a class, students selected one issue to evaluate using the RESOLVEDD method. For the wind energy project, students chose to analyze the ethics surrounding communities and individuals who receive cash incentives when a new wind farm is permitted and installed.[10] Figure 1 below outlines some of the student comments and ideas. This was a class discussion and the information students obtained for the discussion was from the internet or their team’s initial research on wind turbines. The class came up with three alternatives (no public comment, public input and implementation of "quiet" technologies), along with cash incentives for permitting and installing a large-scale wind farm. The alternatives were evaluated to determine their potential impacts and the values upheld or violated with respect to the NSPE Fundamental Canons[8]. An example is the analysis of Alternative 3, where the wind farm was installed and "quiet" technologies were used. "Quiet" technologies referred to wind turbines where the system was engineered to reduce the noise generated during operation. This option upheld all of the NSPE Canons except 2 ("Perform services only in areas of their competence"[8]). Students evaluated each alternative and selected Alternative 3 as the "best" choice. They noted that this option meets most of the public's needs but would result in additional costs. Their defense of this alternative was that it was the only one that addressed the public's concern regarding noise pollution.

As shown in this table, the students understood the basic ethical issues involved in this single case. The challenge for them was to extend this knowledge to evaluating three ethical issues in wind energy. Students summarized the ethical issues in a team memo. In this memo, student teams described in detail the ethical issues involved and provided substantial evidence of the ethical issues. Similar exercises were completed in the aquaculture and biomechanics sections of ENG1001.

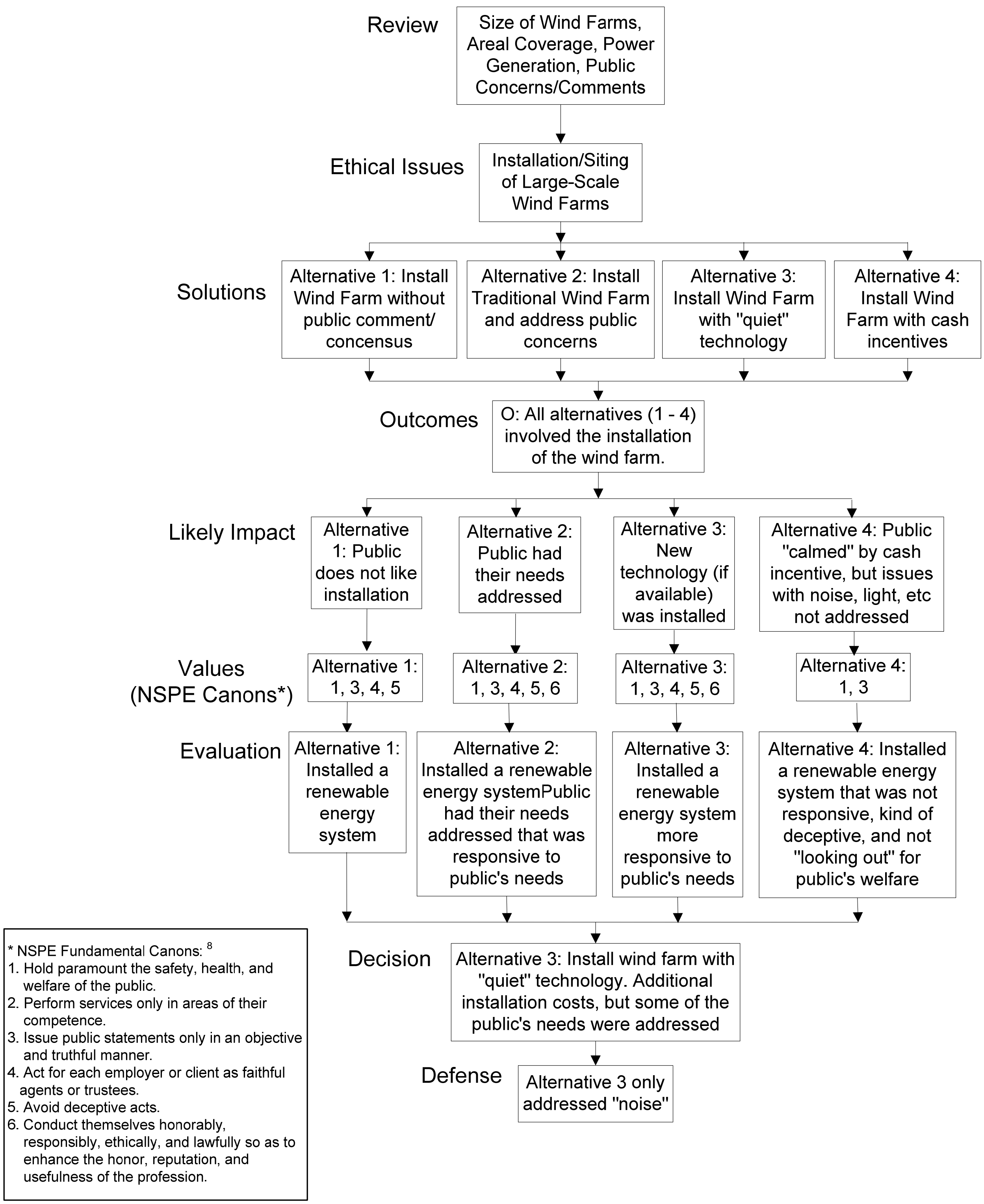

Figure 1. First-Year ENG1001 Student Ethics Evaluation with respect to Wind Farm Installation with Respect to Cash Incentives

The most common issues identified in the biomechanics project dealt with the materials used in the construction of the artificial leg. Due to budget constraints on the teams, most designs were made from wood or PVC using nylon rope or cable to connect the limbs. The first ethical issue identified was the durability and stability of the materials. Since the students were designing the leg to test only a kicking motion, there was an issue regarding the limited use of the leg as well as the inability for it to actually attach to a person. All groups agreed that more research, access to better materials, and more time to develop and test the project could alleviate most of these issues. Several groups identified the NSPE canon "perform services only in areas of their competence" as a violation as they were not qualified engineers, but were designing an artificial leg.[8] To avoid violation the ethical code, students suggested having a certified professional engineer look over and approve their designs before they could be implemented.

The aquaculture project had issues regarding the materials used to construct the aerators for the same reasons as the biomechanics project. In addition, the aerators would be in contact with the water used to raise fish for human consumption. Students quickly identified this as a potential ethical issue (NSPE Canon 1[8]) if the aerator were constructed of parts that were toxic in nature. Teams spent quite a bit of time finding materials that were safe to use in an aquatic environment and that would not adversely affect the health of the fish and consumers. Health concerns were identified with the flowrate of water through the aerators; if the flowrate was not high enough, the concentration of pollutants in the water would increase to toxic levels, again impacting the health and welfare of the public. Students completed lab-scale testing of their aerators and calculations to determine the number of aerators needed and the ideal flowrate for their aquaculture system to maintain the water quality standards in the facility. Again, these teams suggested having a professional engineer approve their designs before actual use.

After investigating the ethical issues related to their design project, student teams analyzed an traditional ethics case study and summarized their findings in a technical poster. In each section, students evaluated the posters and selected the "best" two posters to be part of an ENG1001 Ethics poster competition. The 8 posters were printed and evaluated by engineering faculty outside the first-year engineering program.[11]

Evaluation of Student Understanding of Engineering Ethics:

Prior to ethics being introduced in the course, students completed a pre-assessment of their knowledge of ethics along with their self-reported knowledge of engineering ethics. The pre-assessment was completed as a homework assignment on Blackboard. The same questions were asked during a post-assessment which was part of the students' mid-term exam. The questions are summarized in Table 2. The pre- and post-assessments required that students evaluate case studies, Ford Pinto and the McDonnell Douglas DC-10 Design, respectively.[2] Otherwise, the two assessments were identical. There were three types of questions asked: Personal Evaluation, Long Answer and Multiple Choice. The Personal Evaluation questions addressed the student's perception of their knowledge of ethics, confidence in their ability to recognize potential ethical issues (referred to as "ethical sensitivity", and confidence in their ability to make appropriate ethical judgments. The two long answer questions required students to read an ethics case study, list the ethical issues involved, and identify which of the NSPE Canons[8] were violated. For the pre- and post-assessments, the evaluators looked the number of ethical issues listed and the overall discussion of the NSPE Canons[8].

Table 2: ENG1001 Ethics Pre- and Post-Assessment Questions

Question Type	**Question** **Ethics Case Studies:** Pre-test: Ford Pinto; Post-Test: McDonnell Douglas DC-10
Personal Evaluation 1: Ethical Sensitivity	Ethical sensitivity refers to an individual's ability to recognize ethical situations that may arise. Someone with very little ethical sensitivity may not recognize that an ethical dilemma even exists. What is your current state of ethical sensitivity with respect to issues that could arise in an engineering profession? (1= no ethical sensitivity, 10 = very high ethical sensitivity)
Personal Evaluation 2: Ethical Codes	How knowledgeable are you regarding ethical codes of conduct for engineers? (1 = no knowledge, 10 = very knowledgeable?
Personal Evaluation 3: Ethical Judgment	Ethical judgment refers to an individual's ability to respond appropriately to an ethical situation that arises. Given your current state of education and knowledge, how confident are you that you could make appropriate ethical judgments for situations that could arise in an engineering profession? (1 = no confidence, 10 = very confident)
Long Answer 1: Ethical Issues in Ethics Study	List all ethical issues involved in this case.
Long Answer 1: NSPE Code Violation	Identify all the National Society of Professional Engineers (NSPE) Code of Ethics Canons violated and explain how they were violated. (NOTE: NSPE Canons were provided to students)
Multiple Choice 1: Addressing Ethics in the Workplace	Suppose you were an engineer working on the Ford Pinto/DC-10 Design. You discovered the problem with the cargo door and discuss it with your manager. He/She does not see this aspect as an issue. Should you: a. Go with your supervisor’s opinion. b. Document the problem and your discussion. File it as proof that you attempted to address the problem. c. Document the problem and your discussion. Discuss the issue with your supervisor’s superior. d. Document the problem and your discussion. Discuss the issue with a safety officer within OSHA or a similar organization.
Multiple Choice 2: Ethical Codes Importance	Why are Ethical Codes important to engineers? a. Only valid way to make an ethical decision. b. One way to evaluate an engineering decision/design. c. Codes provide engineers with guidelines in how to make a decision in a questionable situation. d. A & B are correct. e. B & C are correct.
Multiple Choice 3: Affected Parties	Who are the affected parties or stakeholders in this case? a. Ford/McDonnell Douglas CEO. b. Average consumers. c. McDonnell Douglas engineers. d. A and B are correct. e. A and C are correct. f. B and C are correct. g. All of the above are correct.
Multiple Choice 4: Engineers’ Responsibility	What are the responsibilities of the design engineers at Ford/McDonnell Douglas? a. To make products that will meet the demands of consumers. b. To make the safety of the consumers a priority. c. To inform management of potential problems with a design. d. To use their engineering skills to extend this design schedule. e. All of the above are correct. f. A, B and C are correct. g. A and B are correct. h. A and C are correct. i. None of the above are correct.

Results:

Students' pre and post responses to the three personal evaluation items (knowledge, ethical sensitivity, and ethical judgments) were compared using correlated-groups t-tests. Students' (n = 112) self-reported ethical sensitivity increased significantly from a pre-test mean of 6.89 (SD = 1.64) to a post-test mean of 7.65 (SD = 1.49), $t(111) = -5.140$, $p < .000$, on the 10-point Likert-type scale (1 = no ethical sensitivity; 10 = very high ethical sensitivity). Similarly, students' self-reported knowledge regarding the ethical codes of conduct for engineers increased significantly [$t(112) = -13.019$, $p < .000$] from a pre-test mean of 4.23 (SD = 2.33) to a post-test mean of 7.33 (SD = 1.68) on the 10-point Likert-type scale (1 = no knowledge, 10 = very knowledgeable). Students also reported increased [$t(110) = -8.041$, $p < .000$] confidence in their ability to make appropriate ethical judgments, from a pre-test rating of 6.32 (SD = 1.99) to a post-test rating of 7.98 (SD = 1.46) on the 10-point scale.

To gauge the validity of students' ratings of their level of knowledge regarding the ethical codes of conduct, we compared students' scores on the long-answer question requiring them to identify which of the NSPE codes were violated, and explain how they were violated (scored out of 8 possible points). Using a median split method, students who rated their level of knowledge of engineering ethics below the median (mdn = 8) on the post-evaluation scored significantly lower on this question (mean score = 6.0) as compared to students who rated with knowledge of engineering ethics at or above the median (mean score = 6.73). Thus, students who rated their knowledge higher were also able to identify and explain more violations of the codes that were contained in the case studies.

Similarly, students who correctly identified the stakeholders in the case studies (question number 3 in table 2, above) reported higher levels of knowledge of the ethical codes (mean = 7.52, SD = 1.66) than those who were unable to identify all of the stakeholders (mean = = 6.58, SD = 1.67) on the 10-point scale. Unfortunately, students' ratings of their confidence in their ability to make ethical judgments were not indicative of their actual ability. Students who correctly identified the answer to multiple choice item 1 (in table 2, above) had significantly lower confidence ratings (mean = 7.51, SD = 1.75) than those who were incorrect (mean confidence rating = 8.12, SD = 1.39), $t(121.718) = 2.317$, $p = .022$ (t-test for unequal variances used).

The results of the pre- and post-assessments for the multiple choice and long answer items are summarized in Table 3. For 5 of the 6 questions, students' ethics knowledge and their demonstrated ability increased. The only question where student performance stayed constant between the pre- and post-assessment was the item in which they had to list the ethical issues. Additional analyses were completed for this question and are summarized in Table 4.

Table 3. ENG1001 Ethics Pre- and Post-Assessment Results (n = 156)

Assessment Item	Long Answer		Multiple Choice			
	1: Ethical Issues in Ethics Study	2: NSPE Code Violation	1: Addressing Ethics in the Workplace	2: Ethical Codes Importance	3: Affected Parties	4: Engineers' Responsibility
Pre-Assessment						
Average	1.60	3.97				
Standard Deviation	0.93	2.55				
Number Correct			50	84	75	15
Post-Assessment						
Average	1.62	6.30				
Standard Deviation	1.00	2.21				
Number Correct			68	128	121	97

Although the average performance for students in the pre- and post-assessments are almost identical, some interesting results did occur. In the pre-test, 41 students elected not to answer this question, which is likely an indication of an inability to answer it. Students listing no ethical issues on this question increased from pre- to the post-test. This could have been due to the pre-test being a Blackboard assessment and the post-test was part of the mid-term exam (many of the "no answer" students on the blackboard pretest were likely those who identified "no issues" and thus received a score of zero on the mid-term exams). The students only finding one ethical issue declined between the pre- and post-tests, while the number of students listing two or more ethical issues increased between the two tests.

Table 4: ENG1001 Pre- and Post-Assessment Data for Question Regarding Listing the Ethical Issues for a Given Case Study (Pre-Test: Ford Pinto, Post-Test: McDonnell Douglas DC-10)

	Pre-test	Post-test
No Answer	41	0
0	14	28
1	40	34
2	39	61
3	22	31

Students' ability to describe how the NSPE Canons were violated in a given case study significantly increased from 3.97 out of 10 to 6.3 out of 10 [$t(112) = -8.941$, $p < .000$]. The students' performance on the multiple choice questions increased significantly between the pre- and post-test. The most significant improvement occurred on the question that addressed the engineer's responsibilities with respect to engineering design. For this question, the pre-test statistics did not include the 24 students who did not answer the question. The number of students who answered this question incorrectly between the pre- and post-test decreased by 60, while the number who answered it correctly increased by 82.

Table 5: ENG1001 Pre- and Post-Assessment Data for Question Regarding The Engineer's Responsibility for Design (Pre-Test: Ford Pinto, Post-Test: McDonnell Douglas DC-10)

	Pre-test	Post-test
No Answer	24	0
Incorrect	117	57
Correct	15	97

Conclusions:

Students did improve their understanding of engineering ethics throughout the semester. This improvement did correspond to work other researchers had completed. The integration of ethics with the semester long design project allowed students to have a direct connection between ethics and the engineering design process. The students showed marked improvement in their professional ethics skills followed by their ability to describe which components of the NSPE Canons[8] applied, although they did not seem to be able to list the ethical issues themselves. In addition, it appears that asking students to rate their level of knowledge of ethics and ethical sensitivity may be a valid method for identifying students who need more training (i.e., students who reported higher sensitivity and knowledge also performed better on the multiple choice items). However, student confidence in their ability to make ethical judgments does not indicate an actual ability (these findings are very similar to research which examines the relationship between confidence in memory and actual memory). In the Fall 2011 semester, the pre- and post- assessment will be completed again to verify these initial results. The assessment will include comparisons between students learning ethics using a "traditional" approach and this one. Student comments regarding each approach will be incorporated into the analysis. Additional instruction will occur to help students learn how to determine what ethical issues are within an engineering problem or a specific case study.

One interesting aspect of these results is that students are learning about engineering ethics. They are able to apply the knowledge they have gained from analyzing the ethics related to their design project and to another unrelated case study and extend this knowledge to a new scenario. The results of this study are similar to a study completed in 2005 with respect to professional ethics. This study looked at how approximately 200 students answered whether certain activities complied with standard professional ethics. For example, students were asked if it was ethical for an electrical engineer "to design structural supports", and to charge "two clients for one job". For the first case where an engineer works outside his/her field, there was a 23.2% increase in correct responses. For the latter case of double charging on a job, there was essentially no change in the pre- and post-data.[3] In future semesters, it would be interesting to include these specific or similar questions to see if incorporating the course design project into the ethics portion of the course improves students' evaluation of professional actions.

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