Ethics for First-Year Engineers: The Struggle to Build a Solid Foundation

Margot A.S. Vigeant, James W. Baish, Daniel Cavanagh, Thomas DiStefano, Xiannon Meng, P. Aarne Vesilind, and Ronald D. Ziemian

All: Bucknell University College of Engineering. Departments: Chemical Engineering/ Mechanical Engineering/ Biomedical Engineering/ Civil and Environmental Engineering/ Computer Science/ Civil and Environmental Engineering

Abstract

Exploring Engineering is a first semester course taken by all incoming engineering students at Bucknell University. The instructional objectives for this course include introducing the disciplines taught at Bucknell, cultivating technical problem solving skills which serve those disciplines, fostering teamwork and communication skills, and developing an understanding of the history and societal impact of engineering. Two years ago, the course was redesigned and has been successful at achieving the first three objectives (Vigeant et al 2003, Vigeant et al 2004). This paper documents our approach to achieving the specific outcomes associated with the final objective, dealing with societal responsibility.

The course outcomes for societal responsibility are that students should be able to define professional ethics and associated terminology and apply the fundamental canons of engineering ethics to generate and defend appropriate solutions to ethical dilemmas. These outcomes are particularly important because it provides the foundation for each department's meeting ABET Program Outcome 3.f, which states graduates "must have an understanding of professional and ethical responsibility." Historically, both within this course and others, it has been difficult to convince students not only that engineering ethics is relevant, but that it is *teachable*.

In Exploring Engineering, engineering ethics are presented by a combination of techniques, including descriptive lectures from an ethics expert, case studies, and reading books, culminating in a final paper analyzing an ethical problem. The descriptive lectures are accompanied by a book summarizing the ethical responsibilities of engineers, written specifically for this audience. The case studies are a combination of academic responsibility problems and analysis of engineering disasters or near-disasters. The books each center on historical or fictional accounts involving ethical issues resulting from the creations of engineers. The papers are assigned with the goal that students will synthesize all of this information into a coherent analysis of an ethical dilemma presented by their book. This approach has increased the average student response to the statement "This course has improved my understanding of the ethical and professional responsibilities of engineers" from 3.3 to 4.0 on a five-point scale. While student surveys indicate continued resistance to ethics education, our approach is achieving our outcomes.

Introduction

It is widely recognized that undergraduate engineers would benefit from formal education in ethics. In fact, such education is required for ABET accreditation under criterion 3f, "Engineering programs must demonstrate that their graduates have an understanding of professional and ethical responsibility"[1]. However, students are often resistant to ethics in the classroom. In this paper, we examine the efforts to build a foundation in engineering ethics in Bucknell's first semester engineering class, Exploring Engineering (ENGR 100).

ENGR 100 is a course taken in the first semester of the first year by 210 students, comprising all incoming engineering students as well as interested students in the College of Arts and Sciences. The course is run in a modular format described in Vigeant et al 2003, and Vigeant et al 2004 [2, 3]. The course format is summarized in Table 1.

Table 1: Course Timeline

Week #	Module description	Content Summary	Lecture Class size	Lab Class size
1 – 6 ½	Engineering as a profession	Overview of engineering and each discipline	210	12-15
6 ½ - 10	Seminar #1	Discipline related seminar	27	12-15
10 – 13 ½	Seminar #2		27	12-15
13 ½ - 15	Engineering and society	Ethics	210	21

The first course module introduces engineering and each of the six engineering disciplines taught at Bucknell. It also features a team-project in which students suggest improvements to campus to enhance mobility for persons who use wheelchairs[3]. The following two modules consist of student selected, discipline related seminars. Eight different seminars are offered, each representing a different area of interest within the college of engineering[2]. This change, to the small class-within-a-class format was made three years ago, and continues to be the most positively rated part of the course in student surveys.

The final segment is devoted to engineering ethics. The course objectives state that ENGR 100 will "Provide overview of basic engineering practice, including histories, impact on society, skills employed, and professional/ethical responsibilities." The specific course outcomes that relate to the ethics segment of this objective are that students shall be able to:

- Define professional ethics and ethics-based terminology (ex: utilitarianism)
- Use fundamental canons and a decision-making scheme to generate and defend appropriate solutions to ethical dilemmas.

This final course module has undergone significant reworking in the past three years. The ethics segment is now driven by students reading and analyzing ethical problems presented in one of five books. This analysis is supported by a combination of lectures and discussions designed to introduce engineering ethics and to provide the students with a systematic method for dealing with ethical dilemmas.

Lectures

Four class periods are devoted to engineering ethics. The first two class periods consist of a formal lecture by a nationally recognized expert in engineering ethics, given to the entire large class (210 students). In the first lecture, he defines morality and ethics as well as several approaches to ethical reasoning (such as *utilitarianism*). He concludes with a discussion of cheating and academic responsibility. The second lecture centers on professional ethics for engineers, introducing the National Society of Professional Engineers Code of Ethics. Finally, a seven-step rubric for analyzing ethical situations is presented[4]. The seven steps are:

1) Find out what the relevant facts are.
2) Determine what the moral issues are.
3) Who is affected by the decision you have to make?
4) What are your alternatives?
5) What are the expected outcomes of each possible action?
6) What are the personal costs associated with each possible action?
7) Considering the moral issues, practical constraints, possible costs and expected outcomes, what action should be taken?

The rubric is essentially a rewriting of the engineering design process[5] to be applicable to ethical decision making. Emphasis of the formal rubric was a new addition to the course for the 2004 school year, and it was felt to be valuable by the faculty. Previously the absence of a systematic method for dealing with ethical dilemmas meant that student discussions and papers would often make poorly reasoned assertions based upon vague feelings. With the introduction of a formal rubric, both the students and the faculty were given a way to organize the data and beliefs that contribute to a decision.

Two approaches have been tried for the remaining two lectures. For the 2002 and 2003 school years, these lecture times were used to address case studies in engineering ethics. A faculty member presented a famous case of an engineering disaster or near disaster, and analyzed the ethical behavior of key individuals. Examples include the design errors in the Citicorp building in New York, design errors in the Ford Pinto, and the crash of space shuttle Columbia. These cases were presented in large-lecture format to the entire class, and students were not responsible for any assignments in connection with the case studies.

The second approach, used in the 2004 school year, was adopted in response to student comments about the ineffectiveness of the large-lecture format. The class was broken into eight groups of about 27 students, who then met with a professor in a smaller classroom. There, the class viewed and analyzed ethical situations presented in dramatized videos. In the first class meeting, the class viewed and discussed videos on academic responsibility, while in the second videos addressing professional responsibility were discussed (*Academic Integrity*, available from the Program in Society, Technology and Human Values, Duke University).

The smaller format discussions used an in-class assignment based upon the videos. After viewing each video, the students brainstormed a list of ethical dilemmas presented. Then student groups worked their way through the seven step process for addressing ethical dilemmas presented in lecture. Each group presented their findings to the class for discussion.

Book Project

In order to personalize the ethics segment of the course and provide an opportunity for a summative evaluation, students read one of five books and wrote a five-page paper analyzing ethical situations within their book. The timeline and associated assignments for the book project are found in Table 2.

Table 2: Book project assignments and timeline

Assignment	**Date(s)**
Book selection	October 20
Read book	October 21 – December 1
Outline of book due	December 2
Book discussion	December 2
Final paper due	December 14

The books used in this module were:

- Comm Check: The final flight of Shuttle Columbia, by Michael Cabbage and William Harwood (mechanical engineering)
- The Cuckoo's Egg: Tracking a spy through the maze of computer espionage, by Clifford Stoll (computer science)
- The Johnstown Flood, by David McCullough(civil engineering)
- Oryx and Crake, by Margaret Atwood (chemical, biological, and biomedical engineering). *Fiction*.
- Wireless Nation: The frenzied launch of the cellular revolution, by James Murray (electrical engineering)

Each of these books was selected because it highlighted an interaction between engineering and society in which many, often incorrect, ethical decisions were made. Each book was sponsored by one faculty member, who led the book discussion laboratory for that book and graded the resulting papers. Students ranked their interest in the books, with the majority of students receiving their first or second choices.

In addition to buying and reading their elected book, students also read The Right Thing to Do: An ethics guide for engineering students, a book on ethics written specifically for this audience by Aarne Vesilind [4]. The book serves as a written reference for the material covered in the lectures discussed above, including the seven step rubric and the National Society of Professional Engineers Code of Ethics.

Students were responsible for reading the book on their own time, prior to the single two-hour laboratory devoted to book discussion. In the lab period, professors met with two groups of 21 students to give context to the book, discuss ethical aspects of the book, and to further clarify the written assignment. Then, in place of the final exam, students wrote a five page paper in which they were to use the seven-step rubric to analyze one or two ethical dilemmas found in their book in order to determine if the right actions were taken.

Results and Discussion

The success or failure of ENGR100 in engineering ethics can be broken down into three components: 1) Does the class meet the stated course outcomes? 2) Do students feel that the ethics segment of the course is valuable? And 3) Are we impacting the ethical behavior of our students?

One of the assessment tools used to assess student knowledge and improvement with respect to the ENGR 100 course outcomes was a multiple choice quiz. The questions and the student responses are summarized in Table 3**.** The full text of the quiz is omitted; publication of the questions and solutions would compromise the future usefulness of the quiz. However, full text of the quiz is available to educators by contacting the corresponding author.

For the first outcome, four multiple choice questions (21-24) assessed students ability to define ethics, identify the fundamental canon of engineering ethics, and define both "deontological" and "utilitarian". The quiz also had 20 true/false questions asking students to assess if a given situation was unethical for professional engineers *or* cheating for Bucknell students. The situations were constructed such that the engineering code of ethics or the Bucknell code of academic integrity would apply, with one exception (#20). The results of the true/false segment test the students familiarity with both of the codes, which is the first part of our second objective. As these outcomes are level one (knowledge) on Bloom's Taxonomy[6], a multiple choice quiz asking students to "define" or "identify" the correct answer is sufficient. The quiz's goal was assessment of knowledge of ethics and cheating as discussed in class, and should not be understood as a "concept inventory" for ethical behavior.

The quiz was administered twice, first, one week prior to the ethics segment of the course, and second while students were working on their final paper during the final exam period. The same questions were used both times but the order of the questions was altered, as were the instructions. For the pre-quiz, students were simply asked to identify which situations were cheating or unethical for a professional engineer. In the second quiz, students were asked to reference the Bucknell Code of Academic Integrity or the National Society of Professional Engineers Code of Ethics when answering the questions.

From the data shown in Table 3, it is clear based on the pre-quiz results that the students entered the ethics segment of the course with a good idea of what constitutes cheating. Students also generally recalled the fundamental canon of engineering ethics, to which they had been exposed briefly earlier in the course. Students answered many of the more obvious professional ethics questions correctly as well.

Overall, the post-quiz reveals students are well versed in what behaviors constitute cheating, all questions are answered correctly at least at a passing (>65%) level. While significant improvements occurred on all sections of the quiz between the pre-and post-assessment, there is still room for improvement on the professional ethics section. Specifically, questions 12, 14, 16, 17, and 19 had failure-level percentages of correct answers. Student performance was best for questions where similar situations were discussed either in lecture or in the videos. Future classes will address this problem by addressing a broader selection of professional examples in class.

Table 3: Summary of results from ethics pre- and post- quiz. Positive differences indicate students switched from incorrect to correct answer. n_1 = 188, n_2=196, out of a possible total of 211.

#	Question (summary)	% correct pre-quiz	% correct post-quiz	Difference *Bold indicates significant difference (α=0.05)*
	Cheating, true/false			
1	Taking exam for another student	99.5	98.5	-1.0
2	"Patch" writing a paper	99.5	98.0	-1.5
3	Padding a bibliography	89.9	90.8	0.9
4	Using Cliff's Notes	46.3	69.9	**23.6**
5	Summarizing a book for a friend	51.1	74	**22.9**
6	Storing equations on a calculator	90.4	86.7	-3.7
7	Studying from an old test	81.4	95.4	**14.0**
8	Borrowing notes	93.1	94.9	1.8
9	Submitting the same paper in two classes	39.9	75.5	**35.6**
10	Asking professor for help	100	99	-1.0
	Professional ethics, true/false			
11	Bypassing pollution controls	92.0	93.9	1.9
12	Using "boilerplate" text in two reports	55.9	40.3	**-15.6**
13	Charging two clients for one job	79.8	81.1	1.3
14	Taking pencils home from office	50	45.9	-4.1
15	Sharing confidential info. with co-worker	61.2	88.8	**27.6**
16	Drinking a beer with a colleague on-site	18.6	20.3	1.7
17	Publicly criticizing an engineering project	2.7	8.2	**5.5**
18	EE designing structural supports	56.4	79.6	**23.2**
19	City engineer accepting large gifts from businesses	28.2	36.2	8.0
20	Designing land mines	N/A	N/A	**8.1***
	Definitions (multiple choice, four possible answers)			
21	Ethics	2.7	30.1	**27.4**
22	First canon	88.8	97.4	**8.6**
23	Utilitarian	27.1	40.3	**13.2**
24	Deontological	31.9	41.8	**9.9**

*A significant fraction of the class changed their answer to "not ethical" for this question, however no "correct" answer was specified by the faculty.

For the post-quiz, there is little change for questions where the majority of students selected the correct answer in the first place. Where there is a statistically significant change, it is towards the correct answer in all cases but one. For questions 4, 5, 9, 15, 17, 18, 21, 23, and 24 it is apparent from the pre-quiz answers and conversations with students that most students had no strong feeling about the proper answer or had never before considered the situation. For example, on the surface it was not obvious to most of the first-year students that having an electrical engineer do civil engineering work (question #18) would be a problem. Once they had discussed the code of ethics, however, it became obvious that this was a violation of canon #2 ("Engineers, in the fulfillment of their professional duties, shall perform services only in areas of their competence"[4]).

The sole significant decrease in correct answers was for question #12. This arose from an easily addressable misconception on the part of the students in equating questions #12 and #9. Based on Bucknell's code of academic integrity, it is considered cheating for a student to hand in the same paper in two classes without prior consent from both professors. Question #12, which describes a similar situation in professional life, is acceptable behavior for a professional engineer. This discrepancy will be addressed for students in future years.

In order to assess if students can successfully and systematically address more complex ethical situations, we used the final paper. In a five page paper, students worked through the seven-step rubric in order to determine the "best" solution to one of the ethical problems presented in their book. This assignment fully addressed the second course outcome for ethics. Grades were computed based upon the quality of the writing, the use of the rubric, and the appropriateness of the final solution. Nearly all students in the class completed this assignment with a passing score. Based on these data, students are achieving our stated course outcomes. The data should be sufficient to demonstrate the outcomes for the purposes of ABET accreditation.

While achieving the course objectives is our main goal, it would be nice if the students believed that ethics was a valuable component of the course. Unfortunately, the ethics segment continues to be the lowest rated aspect of the course, with the exception of the field trip to the library, scoring 3.2/5.0. The student rating of the book project was slightly better, at 3.42/5.0. The fairly large standard deviation on these scores (1.0 for both) indicates that student opinion was split between those who enjoyed and those who hated the final segment of the course. Student comments give us relatively little guidance on how to improve the popularity of this module. Many comments specifically complaining about ethics simply request that we omit it entirely. The low ratings are likely a reflection of the inherent difficulty of teaching *engineering* ethics to first-year students, many of whom do not yet fully appreciate engineering or think of themselves as engineers. On the positive side, students do agree (4.0/5) that the course has improved their understanding of the ethical and professional responsibility of engineers.

It was hoped by the faculty that the emphasis of the seven step process for addressing ethical problems would improve student comfort and perception of the process. This is not evident from the course evaluation. However, possession of the rubric made it easier for the faculty to grade the final papers on the book project. It also encouraged the students to think though the logical reasons for their proposed actions, rather than simply going on their "gut" feeling, which enhanced overall student performance on the final project.

It was also hoped an improvement would result from the switch from large-lecture case studies to smaller, discussion-based classes for the second two ethics lectures. The course evaluations appear unaffected by this change, perhaps because the complaints about the "large class" have been replaced with complaints about the relevance of the videos.

Comments indicate that many students enjoyed reading a book as part of the course, while many other students were caught off guard by the idea of reading within an engineering class. The positive course outcomes affirm the validity of the book based approach. Another benefit of the book project is that most students are introduced to popular writing about engineering and technology, a genre which many have not previously encountered. The faculty hope that this benefit will help spur life-long learning.

Finally, and most importantly, we would like to know if student behavior is impacted by what they learn about ethics. An indication of this can be seen from a simple quiz given to a subset of the class. After being shown the "cheating" video, one laboratory section was given a multiple choice quiz in which they were asked to identify 1) what the proper course of action for a particular character in the video was and 2) what they would have done in her place. While the majority of students were able to identify ethically acceptable solutions to the problem, 22 out of 28 students changed their answer to a different option when asked what they themselves would do in the same situation. That is, nearly 80% of the students admitted the action they would take would *not* be the one they believed to be correct. While the proper course to address this depressing note is not clear, we can say that we have accomplished the first step to creating ethical engineers: teaching them what behavior is ethical. While we cannot yet force students to behave ethically, the course has at least insured that, in the words of one faculty member, students "will lose some sleep after they make the wrong decision."

In summary, the current approach to ethics employed in Exploring Engineering is effective at achieving the desired course outcomes. Through informational lecture and discussion, students learn to apply a systematic process to the analysis of ethical issues. Students also become familiar with the relevant ethical codes for both students and engineers. However, work still remains to be done both improving student competence in ethical analysis, student attitudes, and compliance. Conversations and other feedback from upper level students indicate that many students recall what they learned in ENGR 100 and appreciated it more after further experience in engineering. Although the current implementation is not perfect, we feel we are providing a solid foundation in ethical education for our first-year students.

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Biographical Sketches

JAMES BAISH
is a professor of mechanical and biomedical engineering and Chair of the Mechanical Engineering Department. He has been on the Bucknell faculty for 18 years.

DANIEL P. CAVANAGH
is an associate professor of biomedical and chemical engineering. In addition to holding the Emmitt Memorial Chair in Biomedical Engineering, he is also Director of the newly formed Biomedical Engineering Program. Dr. Cavanagh has been at Bucknell since 1999.

THOMAS DISTEFANO
is an associate professor of civil and environmental engineering. This is his second year working with ENGR 100.

XIANNON MENG
is an associate professor of computer science. This is his first year teaching ENGR 100.

P. AARNE VESILIND
has entered phased retirement from the department of civil and environmental engineering and is past Rooke Chair for engineering in its social and historical context.

MARGOT A.S. VIGEANT
is an assistant professor of chemical engineering. She has been on the Bucknell faculty since 1999. Her favorite animal is the frog. If you read this, you have found the secret message. Congratulations!.

RONALD D. ZIEMIAN
is a professor of civil and environmental engineering. He has been at Bucknell for 13 years. Ron has been course coordinator for ENGR 100 for the past three years.