ASSESSING ENGINEERING STUDENTS' ABILITIES TO RESOLVE ETHICAL DILEMMAS

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Abstract *- ABET's accreditation criteria provides additional impetus for preparing engineering graduates to act in an ethically responsible manner. However, methods to assess the effectiveness of educational efforts to do this remain primitive at best. We describe the first phase of a joint study at the University of Pittsburgh and the Colorado School of Mines to develop a measurement tool for assessing students' abilities to recognize and resolve ethical dilemmas. Pre- and post-tests at the beginning and end of a semester-long course focusing on engineering ethics are used to assess students' comprehension, analysis, and resolution of ethical dilemmas. Each test consists of two ethical dilemmas addressed through a response essay that is then holistically scored using a rubric that classifies students' level of achievement. Results are analyzed using statistical methods to determine if any "shifts" have occurred to indicate a significant positive change in the cohort's collective ability. A second phase will involve the development of a web-based assessment instrument similar to CSM's Cogito ã that can be easily used by engineering faculty.*

Index Terms: assessment, ethical dilemmas, moral problem solving

INTRODUCTION

Engineers must often make decisions that involve such factors as environmental effects, product safety and work-place hazards. In such cases, data and even knowledge bases may be incomplete or inconclusive. Consequently, such decisions with ethical or moral dimensions may prove to be more difficult than those that primarily involve only financial, marketing or production factors. Ignoring such issues can jeopardize a firm's long-term survival [1]. Such situations - ethical dilemmas - may arise in a number of ways, often unexpected. ABET has now underscored our task as educators: graduates must "understand professional and ethical responsibilities" [2]. While criterion 3-f requires "an understanding of professional and ethical responsibility," this is only a minimum. Ideally, graduates should be capable of moral problem solving, i.e., recognizing an ethical dilemma, analyzing the situation, and finding a creative middle-ground resolution. An increasing number of engineering programs are offering courses that do, in fact, attempt to achieve this objective, and a few ambitious programs are incorporating ethics across the curriculum.

An issue that arises is how do we assess students' ability to achieve this outcome? This paper describes our efforts to date to develop a methodology for assessing students' level of ethical achievement. In doing this, we are also laying out a framework for educators to better determine what level of achievement is appropriate.

BACKGROUND

Much attention has been placed on how engineers have perceived, articulated, and resolved ethical dilemmas that have arisen when complex, advanced technologies were developed such as the explosion of the Challenger, the Three Mile Island Nuclear Power Plant accident, Cherynobl, the DC-10 cargo door, or the Ford Pinto [3, 4]. In fact, an entire field, disaster ethics has emerged from studying such events [5].

While we believe that such lessons remain relevant to practicing engineers, of more importance may be how to recognize and then resolve those dilemmas that arise in the routine practice of engineering. Engineers frequently work under cost and schedule pressures, situations that can lead to increased risk. At what point is that increased risk no longer acceptable? In addition, the multiple loyalties of the practicing engineer also contribute to ethical dilemmas. Practicing engineers can be responsible to at least four constituencies whose goals may be in conflict. Certainly, engineers have a loyalty to their employer, but engineering practice typically also involves a client or contractor, creating a second level of loyalty. Then there is the public, where the "safety of the

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public" as declared by Cicero has been the responsibility of the engineer for almost two thousand years. Every engineering code of ethics places the safety of the public in a prominent position. Finally, the engineer has a loyalty to the profession and to him or herself.

Due in part to ABET, the need to incorporate some form of ethics into the engineering curriculum is no longer debated. Indeed, a number of educators have noted the important relationship between ethics and engineering design and the value of integrating the two within the curriculum [6, 7, 8, 9]. However, this is only a recent happening. Over the past 50 years while engineering educators have focused on providing students with tools and technical skills, providing the education and skills for societal decision-making was not a priority. Consequently, until recently, little had been done to make students aware of the societal dimensions of engineering [10]. Stephan found that only 27% of ABET accredited institutions listed an ethics-related course requirement [11], even though an increasing number of philosophers, engineers and ethicists had focused their research and teaching on engineering ethics [12].

Practitioners' and the professional engineering societies' interest in engineering ethics has also increased. The IEEE (Institute of Electrical and Electronics Engineers) has been especially active [13, 14]. However, if the vision for understanding ethical and professional responsibilities as articulated in ABET is to become reality, educators must now determine: What is the appropriate content? What teaching methods and curriculum models are preferable? Which works best - required course, ethics across-the-curriculum, integration of ethics and science, technology and society, or integration of the liberal arts into the engineering curriculum [15]? Which outcome assessment methods are most suitable [16]? Pinkus has provided an overview of these issues with emphasis on biomedical engineering [17].

Pfatteicher [18] proposes that the current engineering ethics educational 'dilemma' is how to provide meaningful ethics instruction to all students without overburdening faculty, increasing graduation requirements, or removing essential technical material from the curriculum. She notes that the ABET criteria calls for ensuring *understanding* rather than *demonstrating* that graduates are ethical. Hence, students should be evaluated on knowledge and skills, not values and beliefs. Pfatteicher proposes providing students with an understanding of: 1) the nature of engineering ethics; 2) the value of engineering ethics as opposed to the values of an ethical engineer; 3.) the resolution of ethical dilemmas.

Although business programs have been attempting to answer this question for some time [19], much needs to be done to adequately assess engineering students' understanding of their ethical responsibilities. We have been developing a measurement tool to assess students' abilities to recognize and solve ethical dilemmas. Such a tool would provide engineering educators with a means of assessing students' collective abilities to recognize and address a variety of ethical dilemmas. This will better enable faculty to identify areas for learning improvement, and, hence, more effectively educate students to act as ethical professionals by introducing informed curriculum enhancements. When complete, the tool will consist of an interactive user-friendly web-based system that students would use to resolve a series of ethical dilemmas.

As an initial effort, we have developed a rubric to expeditiously assess students' responses to ethical dilemmas. The rubric was developed in conjunction with a pre and post test of a group of students who took an engineering ethics course. This paper provides an overview of the process used to develop a rubric as well as the issues encountered in its development.

RUBRIC BASICS

The nature of an ethical dilemma is such that often a definitive resolution is somewhat nebulous. Consequently, it is desirable to strive for a creative middle ground solution. One way of assessing students' ability to sort out such scenarios is by applying scoring rubrics to their written responses. According to Popham, "Typically, people don't use rubrics unless the constructed response being judged is fairly significant. . . With a few exceptions, teachers use rubrics to judge the adequacy of students' responses to performance tests" [20].

Faculty at the Colorado School of Mines have had success with the application of rubrics to intricate performance appraisals. Specifically, a rubric was developed to assess students' performance on design projects [21]. The design projects under consideration were provided by industry and inherently involve several components. These included three content determinants and two aspects of written communication:

1) **Audience (CLIENT)**: Identification of the client and the client's needs,
2) **Purpose (CONCLUSION):** What is the problem and how can it be solved,
3) **Development (EVIDENCE):** Why is the proposed solution the "best?",
4) **Focus (ORGANIZATION):** Is the organization of the document effective?, and
5) **Coherence (CLARITY):** Is the content of the documentation clear and effective?

When Moskal, Knecht and Pavalich administered their rubric across the spring and fall terms, a statistically significant difference was found, showing improvement in the engineering program.

To develop a comparable rubric for assessing students' performance on responses to ethical dilemmas requires different categories for judgment. Insight into this area is gained from the work of Holt *et al.* [22] in assessing ethics in a business school setting where ethics is often part of the curriculum. In addition, a rubric developed by Pinkus et al., used to assess how graduate bioengineering students learned ethics analysis skills was also incorporated into the development of the initial rubric [23, 24].

In the work of Holt *et al*. the following categories were identified:

- **Relevance**: Analysis establishes and maintains focus on the ethical considerations without digressing or confusion with external constraints,
- **Complexity**: Takes into account different possible approaches in arriving at a decision or judgment about the case,
- **Fairness**: Accounts for most plausible arguments for different approaches,
- **Argumentation**: Presents a well-reasoned argument for a clearly-identified conclusion, including constructive arguments in support of decision and critical evaluation of alternatives, and
- **Depth**: Shows an appreciation of the grounds or key moral principles that bear on the case.

These categories are rated from a low of "1" for "non-proficient" to a high of "6" for "excellent" with guidelines given at each level. They were used as a starting point for the development of the engineering ethics rubric. The Holt *et al*. rubric, developed by faculty from business and philosophy was considered to be a well thought out rubric.

Popham has criticized poorly constructed rubrics that "are masquerading as contributors to instruction when, in reality, they have no educational impact at all" [25] and lists four common flaws that are present in poor rubrics: The first flaw is task-specific evaluation criteria; e.g., providing a picture of a bicycle, asking the parts of the bicycle, and then evaluating if the respondent could identify them. The second is an excessively general evaluative criteria; e.g., giving a score of "advanced" where the scoring rubric says, "advanced – a superior response." The third is dysfunctional detail, the opposite extreme of the second flaw. The fourth is equating the test of the skill with the skill itself; e.g., focusing on the solution of a multi-step math problem when the rubric is meant to assess math proficiency. Popham recommends using three to five evaluative criteria and ensuring that these must represent a key attribute of the skill being assessed. In other words, the criterion should be teachable.

All these points were carefully considered when developing our rubric. In using Holt's rubric as a baseline model there was only a single flaw of concern: "the fifth criterion, moral depth, is admittedly vague, and was included so that readers might take into account factors such as the creative resolution of ethical conflict or development of philosophical considerations underlying choices of moral principles" [26].

RUBRIC DEVELOPMENT

A quasi-experimental design was used to obtain written responses from students to ethical dilemmas contained in case scenarios. The cohort consisted of 39 junior and senior engineering students enrolled in a semester-long ethics focused course at the University of Pittsburgh School of Engineering during the fall 2002. The pre-test was administered as an in-class assignment on the first day of class and the post-test as a take-home assignment at the end of the term. Each test consisted of two brief, matched cases that were analyzed by the student, as discussed in the next section. Responses were coded and transcribed into a common document to remove any bias that may have been introduced by the respondent's handwriting or identity.

One of the pre-test scenarios was medical in nature and the second was more focused on engineering policy issues. The first, "Artificial Heart," was written for the Ashley and Pinkus project based on the circumstances surrounding the first artificial heart transplant [27]. An accident victim is placed on a heart/lung machine after rejecting a transplant heart. However, the machine will not be able to sustain the patient until a second donor heart arrives. The physician calls the developer of an artificial heart, heretofore only tested in a calf, and requests it for the patient. Placing the experimental heart into human being would violate FDA regulations, yet it is given as the only option to save the patient. With some reluctance the experimental artificial heart is implanted and sustains the patient until a new donor heart arrives. Although the second donor heart is transplanted successfully, the patient expires a short time later.

The second scenario, "Borrowed Tools", is one of the cases prepared by Harris and colleagues as part of an NSF funded project [28]. The employer allows employees to borrow company tools for personal use. However, a subordinate discovers one employee purchasing tools for use at home. The subordinate, never having gotten along well with the suspected employee or the chief engineer, brings the matter to the attention of a purchasing agent. The purchasing agent tells the chief engineer in confidence who then confronts the employee. The employee, irate about the confrontation, questions each subordinate to find out who "ratted" on him. The subordinate, when confronted claims to know nothing of the incident and then feels bad for having "had to lie." This scenario involves multiple actors and dilemmas.

The post-test scenarios were "BioVis," another case written for the Ashley and Pinkus NSF project using primary sources from an FDA recall case [29] and "Trees" [30] developed by Harris and colleagues. Both were selected to be more or less parallel to the two pre-test cases. "BioVis" centers on a victim who gets a chemical in the eyes and will lose vision if an experimental drug is not tried. The experimental drug is used but the victim loses his eyesight anyway.

"Trees," involves a narrow tree-lined road that was designed years ago when the traffic capacity was lower. Due to a number of accidents, often caused by speeding drivers, the engineer develops a plan to widen the road that calls for removal of thirty long-standing, healthy trees. A group of environmentalists present a petition to save the trees. Like the "Borrowed Tools" scenario, there are several ethical dilemmas involved, and several opportunities to propose creative middle ground resolutions.

An initial review of one of the pre-tests looked for patterns and trends in the responses. This insight was used as the starting point in a daylong meeting to develop a preliminary rubric through the combined efforts of the University of Pittsburgh and Colorado School of Mines faculty. The rubric development team included participants from engineering, philosophy, and bioethics. In this first pass, nine persons reviewed student responses (in batches of ten) using a modified Delphi approach. After making independent ratings for each batch, discussions followed to assess convergence of the scores. Participants with scores differing farthest from the main group were asked to justify their grading and this served to clarify several points. This process was followed in an iterative fashion for the responses to the "Artificial Heart" scenario. Five attributes were identified, as listed below, with the parenthetical reference to the parallel Holt *et al.* category. Each category incorporated elements from the scoring tool developed by Pinkus for assessing bioengineering students. Four levels of achievement, designated 1 through 4 were then established for each attribute.

1) **Recognition of Dilemma (Relevance):** This ranges from not seeing a problem at all to clearly identifying and framing the key ethical dilemmas. On the pre-test, some students did not identify that any issue existed, whereas others noted several. It was argued that, at minimum, each case contained two ethical dilemmas because there should always be consideration of the impact on the profession, the firm, or some societal context. As rubric development proceeded, clarification was introduced to better distinguish a problem from a dilemma; i.e., problems have coincident alternatives, dilemmas have opposing alternatives that must be reconciled
2) **Information (Argumentation):** At the lowest level (Level 1), respondents ignored pertinent facts or used misinformation. Moving higher on the scale, some students listed information without justifying relevance or applicability. At the high end of the scale, respondents were able to make, and justify, assumptions, sometimes bringing in information from their own experiences.
3) **Analysis (Complexity and Depth):** The lowest level respondents provided no analysis. Of concern from the initial meeting onward was the rating of those respondents who were "rule driven without justification"; e.g., in the case of the "Artificial Heart" where many of the individuals defaulted to FDA rules as being the only acceptable answer. Ideally, although neither seen nor really expected from the pre-test, thorough analysis could have included citations of analogous cases with consideration of risk elements with respect to each alternative. The highest level would expect such a response.
4) **Perspective (Fairness):** Perspective starts with lack thereof—a wandering focus. The score moves higher for taking one point of view, then several, then an overall view. In the ideal circumstances, again not expected on the pre-test, the respondent would consider the global view of the situation, and the perspectives of the employer, the profession, and society.
5) **Resolution (Argumentation):** Other than those respondents who were not responsive to the original dilemma, the base category was that when rules were cited as the resolution, even if used out of context. There is a steady progression from this point to the ideal case where the respondent's resolution considers potential risk to the public and/or safety, and other stakeholders. The highest category of resolution proposes a creative middle ground ("win-win" situation).

After the initial development, smaller groups of three to five participants met for subsequent sessions, continuing to use the modified Delphi approach. Both "Artificial Heart" and "Borrowed Tools" case scenarios were used in the further refinement of the rubric. In total, five iterations would be required before the rubric reached its present form. As differences became less readily obvious, statistical methods including cross-tabulation, descriptive statistics, and non-parametric tests were introduced.

After the third iteration of rubric development, applying the four-level rubric to groups of ten responses from the post-test cases showed reasonable convergence of scores among evaluators. However, at the fourth iteration it was decided to expand the rubric to five levels to increase its sensitivity. (The level was added between Level 3 and Level 4.) This provided a centering level (3) and allowed for better discrimination among the levels without any changes to the established categories.

RESULTS

Four raters (including two faculty) participated in the refinement of the rubric. Two raters (a graduate IE student and a graduating IE senior) used the resultant rubric to rate the complete collection of pre (80) and post test cases (78). The raters evaluated each of the five components for each case (scoring from level 1 to 5). The resultant case rating was the average score for the five components.

In order to obtain a measure of the internal consistency among the raters, Cronbach's alpha was calculated. The values ranged from 0.74 for the "Artificial Heart" scenario to 0.90 for the "BioVis" scenario indicating very good consistency. (See Table 1.)

Table 1: Cronbach's Alpha for Rater Consistency

Case	Alpha
Tools	0.875
Trees	0.880
Heart	0.740
BioVis	0.902
Overall	0.875

As a second test of rater consistency, under a normality assumption, a series of paired t-tests were performed between the two students' ratings for each of the five components of each case. These results were encouraging, with 14 of the 20 comparisons not being significant ($\alpha = 0.05$). (If an adjustment had been made for multiple comparisons, only one of the 20 would have been significant.)

The two raters' scores were then averaged to obtain a final rating for each case. Then the ratings of the two pre and the two post cases were averaged respectively in order to obtain an assessment for each student (pre and post). Table 2 shows these distributions of average scores.

Table 2: Average Ratings – Pre and Post-Test

Range	Pre-Test	Post-Test
1.00 – 1.49	6	5
1.50 – 1.99	14	9
2.00 – 2.49	15	6
2.50 – 2.99	4	12
3.00 – 3.49	1	6
> 3.50	0	1
Ave. Rating	1.90	2.37

Table 3: Pre to Post-Test Changes by Student

Range	Number	Cumulative
- 0.90 to – 0.76	3	100%
- 0.75 to – 0.26	2	92.3%
- 0.25 to + 0.25	11	87.2%
+ 0.26 to + 0.75	10	59.0%
+ 0.76 to + 1.25	10	33.3%
+1.26 to + 1.75	1	7.7%
+1.76 to +2.25	1	5.1%
+ 2.26 to 3.00	1	2.6%

The table indicates that the majority of students improved between pre- and post-tests (i.e., over the duration of the course), with an average overall gain of 0.47 per student i.e., half a level). Overall, eight students showed a decline in performance (ranging from -.05 to – 0.9), one student's scores didn't change at all, and 30 showed improvements (ranging from 0.05 to 3.00). (One student dropped the course and hence didn't take the post-test.) Table 3 demonstrates how these changes occurred – 59% of the students had gains of at least 0.25 points, and a third had gains of 0.75 points or more (nearly a full level).

DISCUSSION AND FUTURE WORK

Several insights have been gained from this initial phase. Most important, it has been shown that it is possible to develop a rubric for assessment of student responses that is relatively consistent among raters and has face validity with ethics experts. This measurement tool can be used in the assessment of students' comprehension, analysis, and resolution of ethical dilemmas in an engineering context. An important caveat for a pre- and post evaluation is that the responses are highly context sensitive. Hence, the cases used must exhibit a high degree of similarity.

Although the pre- and post-test cases were intended to be similar in nature, application and refinement of the rubric suggested that student responses were highly sensitive to the scenarios themselves. While the parallel in the medical scenarios is fairly evident, there are some important differences that appear to have been noticed strongly by students. Foremost, the victim in "BioVis" lost eyesight whereas the victim in "Artificial Heart" lost life. Second, the individual with the experimental spray was explicitly identified as a biomedical engineer.

Students indicated that the "Artificial Heart" case was serious because the outcome resulted in a loss of life, in contrast to the "Borrowed Tools" situation. One-third of the respondents to the "Artificial Heart" case (pre-test) defaulted to the FDA rules as the supreme authority, indicating that the dilemma was not a dilemma at all--one must always follow the rules. While this strikes at the heart of why ethical dilemmas are dilemmas (that is, the answers are in "gray areas"), such responses were not unexpected on a pre-test at the beginning of the semester. It is also possible that the medical nature of the "Artificial Heart" scenario was somewhat outside the traditional thought patterns of an engineering student even though bioengineering issues were implicit in the case. The ability to relate was less, perhaps, and defaulting to existing regulations seemed to be the "correct" response. The post-test responses defaulted less to the FDA authority. Also, the responses to the engineering policy scenarios typically were more lengthy and involved than those to the medical cases.

The development of this rubric establishes the feasibility of assessing the students' ability to understand ethical concepts. We have shown that it is possible to divide a cohort of students' ability to identify and resolve moral problems into levels. Faculty could then use this information to make curriculum improvements.

The scoring tool is a prerequisite to the development of a software-based assessment tool that eliminates the need for paper and hand-scoring. The development of an assessment tool that is administered by computer is the next step. The format would follow that used for Cogito, developed by the Colorado School of Mines [31, 32]. In addition to addressing the ethical dilemmas encountered by the various professions, once complete, the system may possibly be adapted to assess the acquisition of other ABET "professional" skills including understanding engineering in a global and social context and knowledge of contemporary issues.

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