Ethics for First-Year STEM: A Risk Assessment Based Approach

Prof. Tobias Rossmann, Lafayette College

Tobias Rossmann is an Assistant Professor in the Department of Mechanical Engineering at Lafayette College (Easton, PA). He received his PhD in 2002 from Stanford University. His research interests have focused on the development and application of advanced optical measurement technology to complex fluid flows, from micro-optical sensors to large reacting flowfields. He has received the 2011 Ralph R. Teetor Educational Award (SAE International), is a five-time winner of the Rutgers School of Engineering Excellence in Teaching Award, and is an Associate Fellow of the AIAA.
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Abstract

This paper describes the development of a first-year seminar focused on the discussion of ethical issues in engineering for STEM students. The seminar course is intended to provide a broad introduction to ethics through discussions and writing assignments focused on case studies of engineering catastrophes, meeting once a week for ninety minutes, as well as encourage students in college level critical thinking skills. Involving first year students with both technical and philosophical discussions, showing the broader reach of engineering, can be critical in the retention of students to engineering as well as the translation of engineering ethics to other STEM majors. The main goal of the seminar is to engage first year STEM students to discuss ethics from an engineering perspective, give them tools beyond their intuition, and assist them in their transition into collegiate level academic work. Students are introduced to a risk assessment based approach to ethical decision making. This approach attempts to incorporate the basic questions of risk-benefit analysis with information on the decision makers, constraints and context, and implementation of the system. This simplified framework is employed to allow students to more easily explore complex catastrophes from multiple points of view and draw parallels with current technological issues, with these skills significantly improving over the course of the semester.

Introduction

One of the biggest hurdles in infusing courses with ethics and professional issues as required by the Accreditation Board for Engineering and Technology (ABET) is when to begin. Often single courses can be introduced into the curriculum, but a sustained effort in ethical instruction, infusing several courses, offers students more chances to consider the material, more opportunity for growth and reflection, and better retention of both content and ethical reasoning skills. Engineers also benefit from the ability to take the view of a non-engineer, develop empathy, and think divergently which is facilitated by the discussion of ethical theory in environments where other majors (both STEM and non-STEM) are engaged.

This paper describes the development of a first-year seminar focused on the discussion of ethical issues in engineering for STEM students. By starting the introduction to ethical reasoning in the first year, further elements (or modules) of engineering ethics can be introduced in later major courses that build upon a solid foundation and represent a vertically integrated learning approach. The seminar course was intended to provide a broad introduction to ethics through discussions and writing assignments focused on case studies of engineering catastrophes, meeting once a week for ninety minutes, as well as engage students in college level critical thinking skills. While not all engineering failures are due to ethical failures, this course focused on well-known catastrophes with a significant ethical component so that the students would be somewhat familiar with the events before beginning their exploration.

The course is largely case study based due to the short ten-week (one lecture per week) format to allow for sufficient preparation outside of class time for active discussions. Because
the course is geared towards first-year students from diverse majors, the case study based approach was focused more on the historical relevance of typical engineering ethical examples to current events. While a case study approach seems appropriate for learning about engineering professionalism and ethics\textsuperscript{4,5}, students found it difficult to defend an individual’s actions when they appeared on the wrong side of history (or the pervading ethical argument). Students saw the shortcomings of relying on their own belief system (e.g. “seems right to me”) but also saw the difficulty in applying strict moral reasoning that they had a very faint grasp of in such a short time frame. Thus, the logical framework that was presented relied heavily on the concepts associated with risk assessment (of which the students were more familiar from a personal health and safety viewpoint). Since the course was based upon catastrophic events associated with engineering failures, a failure based, risk assessment and cost benefit analysis methodology was seen as a useful context with which to attack the underlying ethical issues\textsuperscript{6,7}.

Since this course was also a first-year seminar, the secondary goal was to introduce students to academic life by energizing them about college level classroom discussion, participation, preparation, and group work. While first year engineering majors were the target audience, students from many other science majors also chose to participate. The engagement of first year students with both technical and philosophical discussions, showing the broader reach of engineering, can be critical in the retention of students to engineering as well as the translation of engineering ethics to other STEM majors. While the teaching of ethics in a seminar course is not unique, this course attempted to teach ethical reasoning to first year students of varying STEM backgrounds (including a significant percentage of non-engineers) using a simplified risk-assessment approach to facilitate the analysis of historical catastrophes. This type of seminar is envisioned as the entry point into the infusion of ethical discussion in an engineering curriculum through future courses, guest lectures, or micro-insertion problems\textsuperscript{8}.

Course Description

This seminar course was offered as part of the Byrne Freshman Seminar program at Rutgers University. A Byrne Seminar is a one-credit course designed to introduce first-year students at Rutgers-New Brunswick to academic life. Byrne Seminars are open to all first-year students and are closed to all other students. Most Byrne Seminars tend to focus on a professor’s research interests where the students consider many of the same questions and issues the faculty member deals with in their research work. Each seminar is unique; some include work in a laboratory on campus, and others might require the completion of a creative group project. Most seminars involve an out-of-class excursion, to see a play in New York or visit a museum in Philadelphia. Broadly, Byrne Seminars are discussion-based, interactive courses. There are no final exams or lengthy research papers.

First year seminar courses are widely used in engineering curricula as a way to excite students about engineering, expose them to the many different major possibilities, and retain students in the field at a time where their schedule largely consists of the initial math and science requirements for the degree. Since engineering ethics and ethical thinking have been shown to be very effective when infused into multiple courses over the undergraduate engineering curriculum\textsuperscript{9}, the first-year seminar is an excellent place to begin that discussion.

The course was described broadly to attract engineering, STEM, and non-technical
majors to the discussion. In fact, the title of the course, “Engineering a Catastrophe”, explicitly did not mention ethics to appeal to the widest audience. This seminar was described as exploring both the engineering and cultural implications of recent and historical disasters with examples taken from: natural (such as levee failures and earthquake damage), engineering (nuclear power generation and aerospace), and conflict (terrorism) tragedies. Students were prepared that they would learn and discuss which factors led to these cataclysmic evens and how engineering development, public policy, and society have responded. To focus on the relevance of the course to future events, the description stated that readings and discussions would center on how advancements in engineering both solve current problems and cause new issues and unforeseen complications. With this description, the course enrolled 19 students: 9 first-year engineering students, 5 science majors (Chemistry, Biology and Physics), 2 Philosophy majors, and 3 undecided. Enrollment in the seminar was capped at 20 to facilitate the classroom discussion environment. The wide spectrum of students was not expected (especially with a seminar that had engineering in the title) but speaks to the broad and inclusive way the description was focused on the advancement of engineering.

The seminar course was focused on the historical aspects and technical specifics of engineering related catastrophes (case study based approach using Inviting Disaster: Lessons from the Edge of Technology by J.R. Chiles). These descriptions were correlated with current events and concentrated on the examination of the ethical implications of the decisions and approaches taken. The students were instructed on the mechanics of risk assessment and cost benefits analysis as an ethical framework with which to analyze the case studies. Classical ethical structures and moral decision making were discussed in brief (e.g. Deontological, Teleological, Fairness, Common Good, etc.) but these philosophical theories were streamlined in favor of more group discussion on professionalism and ethics. During the small and large group discussions, the class explored both the engineering and cultural implications of recent and historical disasters with examples take from recent and historical tragedies. The course structure (Table 1) was based upon the Chiles text as way to ground the first year students in a recognizable study form for their work outside of lecture/discussion.

Table 1. Topic list for Course

<table>
<thead>
<tr>
<th>Lec. #</th>
<th>Daily Topic</th>
<th>Chiles Reading</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Introduction</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Oil Exploration, Drilling, Transport</td>
<td>Ch. 1: Shockwave</td>
</tr>
<tr>
<td>3</td>
<td>Nuclear Power</td>
<td>Ch. 2: Blind Spot</td>
</tr>
<tr>
<td>4</td>
<td>Human Flight</td>
<td>Ch. 3: Rush to Judgment</td>
</tr>
<tr>
<td>5</td>
<td>Space Exploration</td>
<td>Ch. 4: Doubtless</td>
</tr>
<tr>
<td>6</td>
<td>Human Factors</td>
<td>Ch. 6: Tunnel Vision</td>
</tr>
<tr>
<td>7</td>
<td>Structures</td>
<td>Ch. 8: A Crack in the System</td>
</tr>
<tr>
<td>8</td>
<td>Natural Disasters</td>
<td>Supplemental</td>
</tr>
<tr>
<td>9</td>
<td>Chemical Processing</td>
<td>Ch. 9: The Healthy Fear</td>
</tr>
<tr>
<td>10</td>
<td>Nanotechnology</td>
<td>Ch 11: Robbing the Pillar</td>
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</tbody>
</table>

The initial lecture of each session focused on what engineering/human factors led to these cataclysmic events and how engineering development, public policy, and society responded.
While there are many examples in the literature of using case studies of catastrophic events precipitated by engineering failures to communicate concepts of engineering ethics\textsuperscript{13,14}, the main goal of the seminar was to engage first year STEM students to discuss ethics from an engineering perspective, give them tools beyond their intuition, and assist them in their transition into collegiate level academic work. The introduction to ethical thinking would then translate into better preparedness and engagement with later discussions held during in-major courses.

**Course Specifics**

The course objectives (Table 2) were introduced to the students on the first day. The course objectives are focused on comprehending the multiplicity of factors that lead to an engineering catastrophe, how these decisions/factors are both technical and managerial in nature, and how history tends to repeat itself despite the engineering community’s best efforts. These issues are then viewed through the lens of ethical analysis and behavior to highlight for the students how ethics is a foundational component of engineering professionalism. The expected outcomes center around synthesizing the material presented in the text and during the lecture portion of the class into short in-class writing assignments and a larger paper on risk assessment. These objectives and outcomes were explicitly stated and often repeated to focus the students’ expectations that the lectures and discussions would be directly applicable to the short writing assignments that would be asked of them outside of class (and not just to base their arguments on their own opinions).

<table>
<thead>
<tr>
<th>Objectives</th>
<th>Expected Outcomes</th>
</tr>
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<tbody>
<tr>
<td>Understand the factors that lead to an engineering catastrophe – human, economic, social, safety, environmental</td>
<td>Students will be able to understand both the technical and human factors associated with catastrophic events. Students will participate in in-class writing assignments and discussion delving into these factors.</td>
</tr>
<tr>
<td>Develop an understanding of ethics and ethical behavior in engineering practice</td>
<td>Students will be familiar with ethical analysis approaches esp. risk assessment. A short writing assignment will focus on risk assessment of an engineering problem.</td>
</tr>
<tr>
<td>Comprehend how decisions made throughout the engineering design and implementation processes affect the failure modes of a system</td>
<td>Students will understand how both technical and managerial decisions affect the outcome of historical engineering failures. A short writing assignment will focus on “breaking” the chain of events (“crackstopping”) of a case study.</td>
</tr>
<tr>
<td>Consider current engineering achievements in light of historical failures</td>
<td>Students will examine engineering issues relevant to current events and evaluate their potential risks, taking into account historical case studies. Students will complete one paper on this topic.</td>
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</tbody>
</table>
For the class sessions, the engineering students were hungry for the technical details associated with the catastrophe under discussion. As first-year engineering students, most were eager to have a chance to look at engineering problems (rather than physics, chemistry, and math). However, the lecture portion of the discussion provided them with just enough engineering details to be conversant in the reasons behind why the failure escalated into a catastrophe and how the human factors interacted with the technical aspects of the situation. For the ninety-minute meeting, the lecture portion usually lasted approximately 25 minutes. The lecture would typically focus on a case study (or history of several related case studies) to motivate the follow-on writing and discussion period.

**Example Case Study Implementations**

A reading assignment, typically a chapter from the required text would be completed before the class discussion. Chiles’ text is eminently readable for first year students with accessible language and tone. He approaches individual catastrophes with a storyteller’s style without imbuing his text with overt ethical explanations, largely focusing on the narrative and historical context. The fact that the case studies were presented in this style, rather than a textbook, engaged the students to view the catastrophes in their appropriate historical timelines (i.e. considering both earlier situations as well as near misses). This allowed the lecture portion of the class period to skip some of the historical context of the particular catastrophe and focus on the larger context of issues affecting a particular human endeavor or industry while concentrating on current events or future concerns within the discussion topic.

The fifth topic of discussion was human factors, or how safety is managed in large organizations and the use of “crack-stopping” methods. Chiles views catastrophes as “system fractures”, where initially harmless technical or managerial decisions can grow and propagate through a project. The safety of complex systems requires the intense scrutiny of all aspects of the design and implementation processes, where workers are encouraged to admit errors, report mistakes, and feel supported in that environment. The students read two chapters of the text that discussed how small technical issues escalated into catastrophic mission ending failures (including Apollo 13 and Thresher submarine incidents). Since the Apollo 13 story is well known due to the movie, the lecture for this topic sought to weave several elements together which created a coherent story about a single issue: the transport of pure oxygen. Short technical histories were given behind the Apollo 1 fire, the Apollo 13 cryogenic tank failure, and the Valuejet 592 crash due to O2 canisters. The issue was then brought to further relevance by quickly examining modern oxygen transport events (2-3 significant issues reported every year to the National Transportation Safety Board) and extending the discussion to the use and transportation of Lithium batteries. Parallels were drawn between these historical oxygen related tragedies and current issues with the Boeing 787 battery systems and recent FAA testing into the destructive power of thermal battery runaway fires in cargo holds (several reported each year).

The lecture portion of the session was largely focused on why these types of similar events keep occurring throughout history even though the engineering community is aware of the attendant problems and is continually working to correct them.

The discussion portion session of the lecture always begins with an individual response to the writing prompts for ten minutes. The particular writing prompts for this lecture were:

- Whose responsibility is safety?
How can “crackstopping” methods be employed in global supply chains?

The students are encouraged to frame their answers to these questions in light of the historical evidence provided but also using the risk assessment tools described in the first lecture and revisited in previous discussions. The initial writing prompt in particular leads the students to consider both the personal interactions (i.e. the individual engineer with his/her supervisor discussing a particular facet of an engineering problem) as well as the larger organizational issues. Many ethical texts focus on these individual interactions in their case studies as a method to make personally relevant the ethical issues at hand. In addition, it has been shown that student exposure to these case studies involving smaller scale interactions leads to better retention of the ethical decision making process as it is more relevant to situations individual engineers will face in their proximal future. The second writing prompt guides the students to consider the rather colossal problem of engineering safety and corporate culture in a global context, where societal norms associated with ethical behavior and safety may differ.

After the students have individually framed their responses to the writing prompts, small group discussions (typically 2-3 students) are formed where each student presents ideas to their peers and begins the process of debating the considerations. These group discussions typically lasted ten to fifteen minutes, allowing students to further crystalize their arguments and check-in with others to widen the scope of their thoughts. After these breakout sessions, a full discussion and debate, moderated by the instructor, comprised the remainder of the class meeting (typically thirty minutes). Students were encouraged to speak both individually and from their groups, which seemed to allow the more shy students a sturdier platform from which to share their thoughts. Efforts were made to highlight where risk assessment tools could be used to help unravel some of the institutional complexities associated with engineering decision making, assist the development of student empathy for varying points of view, and to continually make the concepts more personal.

The point of the individual discussion was not to delve too deeply into a particular disaster or individual ethical decision, necessitating a decision tree or other analytical formalisms. Rather, the purpose of each debate was to extend the thinking of the students and infuse an ethical framework from which to view historical and current events with the expectation that this approach would follow the students to more focused case studies that they would see in the latter part of the engineering curriculum. The students appreciated both the high- and personal-level ethical discussions and communicated their enjoyment of being able to simultaneously appreciate the technical and human factors elements of the catastrophes. Since this was only a one-unit course for first-year students (where typical first-year courses are three or four units), in-class participation, outside reading, and short writing assignments were the only requirements.

Typically, two or three writing prompts were given for each topic. Writing prompts typically focused the students on the both the societal implications of catastrophes [A-type questions] as well as the personal ethical issues [B-type questions] that a practicing engineer might face. Examples include:

• [B] How can safety/ethics be communicated across cultural and socio-economic divides?
• [A] How can ethical and safety standards keep up with a rapidly advancing scientific forefront?
• [B] How do engineers best approach the unknown unknowns of new technologies when employed in consumer products?

Use of Risk Assessment

During the early discussions, students reported high levels of satisfaction with the technical descriptions of the catastrophes and the discussions of the underlying ethical choices. Engineering students early in their student careers generally possess good black/white critical thinking skills on technical issues. However, since almost all of the case studies occurred in the past, they found it difficult to objectively assess the events leading up to these incidents with their hindsight and full knowledge of the consequences. Students also found it difficult to correlate related catastrophic events if their pathways to failure differed. Since the class was focused on engineering catastrophes, the concepts of safety and acceptable risk were omnipresent and used as the framework to assess larger ethical concepts. From the initial lecture where we discussed the students’ prior exposure to ethical decision making, it was clear that they possessed a reasonable familiarity with risk assessment as it related to the workplace (management of personal or local health and safety). They had the ability to implement a basic risk-benefit analysis on a discussion of cheating at the collegiate level. However, due to their difficulty with the more complex situations under discussion, the lecture material needed to focus on hazards and risks that were outside of the students’ proximal viewpoint.

In order to create a personal relationship to topics and utilize a more structured (tiered) framework with which to evaluate potential ethical decisions, risk assessment was introduced in the first lecture and reinforced in subsequent lectures and discussions. A risk assessment model of the ethical decision making process was adapted from the project ethical audit as described in Armstrong Dickson and Robinson and the risk-benefit analysis as detailed in Martin and Schinzinger. This model attempted to incorporate the basic questions of risk-benefit analysis (Is the system under discussion worth the risks connected with its use? What are the benefits? Do they outweigh the risks?) with information on the decision makers, constraints and context, and implementation of the system. In a much simplified form tailored for first year students, we approached each catastrophe by examining the fundamental technology and the needs it met, attempting to include the motives and conflicts of the decision makers and stakeholders, the constraints in which that technology was implemented including both political and societal contexts, and the long term effects and impacts of the catastrophe. At each of these stages, the basic risk-benefit questions were discussed from varying points of view. All students appreciated a framework from which to base the progression of the discussion.

Students were instructed to evaluate hazards both inside and outside of the technical realm. Discussion of uncertainty in engineering design and operation was balanced with estimation of non-routine operation, historical failures, managerial complications, and consequence potential. Hazards were then folded into a risk profile with sufficient resolution for the students to capture the most important and provocative hazards. Special detail was given to
the quantification of personal/public risk and risk perception (as often the mere hint of a catastrophic risk in an engineering project can seal its fate). Finally, the original risk-benefit analyses of each catastrophe were outlined such that the students could appreciate that well-developed foresight in a large, complex system is very difficult to achieve.

With additional evaluative tools students found a greater ability to personally relate to complex ethical decisions inherent in the more complicated case studies. They found comfort in defending their risk profiles and analyses rather than relying on and upholding their own personal opinions. This was especially important when examining emergent technological issues with significant scientific uncertainty (such as the environmental impact of nanotechnology) as the hazard matrix presented a high degree of uncertainty. Using these tools, their discussions and papers presented a more nuanced and enlightened approach to the discussion of the acceptability of risk. With this better understanding of risk, students had a larger appreciation for the difficulties of the ethical decision making process.

Course Feedback

Student comments

“Amazing seminar. The presentations that the professor gave were very interesting and gave me many new insights into complex engineering projects. It taught me how to be more than just someone trying to solve problems but to also gave a sense of ethics.”

“It sparked my interest and allowed students to participate in ways that are not available in regular classes. Moreover, I liked the structure of the class--specifically, how we worked in groups and then discussed the material of the class.”

Student surveys

Assessment of the course was done through pre and post surveys using a Likert scale. Students reported high levels of satisfaction with the class discussions (4.6/5), their ability to consider multiple sides of an issue (4.7), and their engagement (4.7). Since introduction to college level academics of first year students was also important goal, survey questions were targeted towards the students’ engagement with the discussion process and their level of comfort with the new intellectual material. Students reported that the course inspired them to think in new ways (4.6), ask questions and express ideas (4.3), engaged them with new ideas (4.8), and was a positive learning experience (4.6). Areas to improve from the course assessment included enhancement of students’ research interest (3.4), better use of university resources and libraries (3.4), building a community outside the classroom (3.1). These areas of improvement can mostly be addressed by assigning a single longer paper written by a small group, enlarging one of the in-class writing assignments. The students would be asked to work together with a research librarian to obtain original materials to support their writing.

Student work

Assessment of written student work was performed using a rubric that evaluated their initial in-class writing assignments and their final risk assessment papers. Since the seminar was a one-unit course, the number of out of class writing assignments was kept to a minimum. The initial writing assignment was geared towards a risk assessment analysis of cheating on exams at the college level. A short lecture was given in the introductory class to introduce the students to
the tenets of risk assessment. Students were tasked with explaining the ethical concerns by viewing the risks and benefits from many perspectives (their current, their future, parents, professors, school administrators, future employers, and alumni). Their papers were evaluated on the depth of their exploration of the ethics of professionalism and their ability to identify motivations of each of the stakeholders. On average, students’ understanding of ethical concepts was scored at 2.1 out of 5 and their ability to apply risk assessment tools to ethical problems was scored at 1.6 out of 5.

The final risk assessment paper was a detailed examination of a catastrophe that was related to one examined during the seminar but not specifically discussed. Examples subjects of student final papers include typhoons in the Philippines, structural failures post-earthquake in China and Haiti, vaccinations and the swine flu pandemic, and drone aircraft. Students were asked to analyze these other (potential) catastrophes in light of the historical case studies presented in class as well as to apply the risk assessment tools developed during the seminar. Final papers were judged using the same rubric as the initial writing assignment. On average students’ understanding of ethical concepts more than doubled to 4.3 out of 5 as did their ability to apply risk assessment tools to ethical problems (4.1 out of 5).

Acknowledgments

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References


