Importance of Ethical and Business Issues in Making Engineering Design Decisions: Teaching through Case Studies

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ABSTRACT

This paper discusses the development of a multi-media case study that documents the events and decisions leading to the January 27th, 1986 teleconference where the decision on launching the STS 51-L, Challenger Space Shuttle, was made. The difference between this case study and others is that it focuses on the processes used, the five design options that were presented to the NASA management during 1977, the choice made by NASA during 1980, and the final decision instead of focusing on the disaster alone. Videos, charts, and animations explain the technical material lucidly. This case study has been tried in engineering classrooms and has received very positive feedback. Engineering students found the use of the case study methodology that dealt with a real-world example to be highly motivating and useful in understanding the importance of ethical and business issues in making engineering design decisions. The paper summarizes the case study and discusses the students' and educators' reactions to this new approach of teaching engineering design by providing a longitudinal view of the design decisions. Information on this case study and book could be obtained from http://litee.auburn.edu.

Introduction

In the information age, where engineering and technology are part of every day lives, many engineering companies have been sued for product failures, improper design, and copyright violations due to unethical behavior. In order to determine solutions to the various ethical issues that arise in the workplace, it is crucial for every engineer to understand what is considered to be ethical behavior in the engineering profession. The need for this ethical knowledge in professional engineering decisions has led to the development of the field of engineering ethics (Logsdon, 1986; Martin and Schinzinger, 1996).

Fasching (1993) dramatically illustrates the importance of good ethical judgment in all engineering situations with his dark warning of a heartless bureaucratic civilization:

> Our modern technological civilization offers us seemingly infinite utopian opportunities to recreate ourselves (e.g., genetic engineering, behavioral engineering) and our societies (social engineering) and our world (chemical engineering, atomic engineering). But having transcended all limits and all norms, we seem bereft of a normative vision to govern the use of our utopian techniques. This normlessness threatens us with demonic self-destruction. It is this dark side of technical civilization that was revealed to us not only at Auschwitz but also at Hiroshima.

Engineering ethics can be defined as (1) the activity of solving moral problems by understanding, developing, and justifying moral judgements related to engineering issues and (2) the development of and compliance to currently accepted ethical codes of conduct. It is also the creation, development, and establishment of moral codes that prescribe what people ought to do. Engineering professional societies such as NSPE, IEEE, ASME, and others have codes of ethics made available to their members.

In the work force, engineers are faced with ethical decisions that may change many lives. Taking responsibility for one's own actions is the key to making true moral decisions. If all professionals take this responsibility to act ethically in the work place, engineering and technology will not only sustain but could enhance the dignity of human life (Petroski, 1985).

Engineering educators are aware of the importance of teaching ethics to their students, but most often, a course on ethics is taught by professors in the liberal arts. These ethics courses are not integrated into engineering profession and thus the students cannot realize the relevance of the course to their professional life. In order to rectify this problem, many researchers have developed case studies to illustrate the importance of ethics in engineering profession (Fleddermann and Fleddermann, 1999; Johnson, 1991; Pinkus et al., 1997, Petroski, 1985; Schlossberger, 1993, Roland, 1985).

A popular real-world problem that explains engineering ethical issues is the 1986 Final Voyage of the Challenger. Many authors (Haupman and George Iwaki, 1991; Pinkus et al., 1997) have written good case studies based on this real-world problem. When we reviewed these case studies, we found that they are good in relating the problem as it happened on Jan. 1986, but were limited in technical details. For example, in these case studies not much details are presented regarding the design of the field joint considered by NASA engineers during the 1970s, ethical issues relating to the decisions made by NASA during the period 1972 to 1986, and the technical discussions and modifications that were done to the field joint over that period. There are not many videos available that described real-world engineering design decisions as related to the Challenger field joint. These limitations in the current literature motivated us to develop a technical case study that illustrates the solid rocket booster design problem and describes technical issues along with ethical, financial, and management issues. In addition, the availability of multimedia technologies during the past few years made it possible for us to dramatically illustrate the technical issues, such as adding shims, O-ring, joint rotation, etc., using videos, photographs, and animation.

What is Different about this Case Study?

A case typically is a record of a business or technical issue that has been faced by engineers and managers, together with surrounding facts, opinions, and prejudices upon which engineers' and managers' decisions have to depend. These real and particularized cases are then presented to students for considered analyses, open discussion, and final discussion as to the type of action that should be taken (Edlund, 1997).

We have modified the ideas used in the traditional case study method to include engineering, technical, ethics, and business issues. In the past, books on case study described the case studies and asked the students to analyze them. Frequently, they did not provide the technical background that was needed to work on the case study. We have rectified this by (a) adding chapters that describe the competency material required to analyze the case studies and (b) including photographs and videos that describe the technical problem visually. We explain these next.

Competency Material for Analyzing the Case Study

For this case study, we have created competency materials that could help students learn the basics of engineering design, ethics, and business fundamentals that are essential in order to analyze the case study. In addition, we refer students to library resources so that they can perform library research.

Inclusion of Photos and Videos

In the case study, we have included plenty of photographs and schematic diagrams in order to make the processes understandable to the students. We have also created videos to illustrate the engineering details. These visual materials should help students witness the problem in a virtual manner.

We expect these additional materials to help students learn the real-world issues from an engineering point of view. These improvements make it possible for the case study to be self-contained. The case study developed in this project is expected to provide complete and detailed presentation of the subject under investigation.

Solid Rocket Boost Case Study and CD-ROM

The case study was developed so that it traced the technical, business, ethical, and managerial issues that were debated and resolved in the design of the solid rocket motor starting in 1971 and end in 1986. We describe below the major events that have been covered in this case study (Sankar, et al., 2000; Vaughn, 1997).

Testing of Solid Rocket Motor

Morton Thiokol, Inc. (MTI) used many tests including joint lab tests, structural test articles, seven static firings, and two case configuration burst tests to verify the performance of its product, the Solid Rocket Motor. The Solid Rocket Motor (SRM) is the principal component of the Solid Rocket Boosters (SRBs) the main propellants for the Shuttle during initial launch. A hydroburst test conducted by MTI in the late 1970s indicated that problems did exist in the SRM and its field joints. The field joints that connected the segments of the SRB were being distorted upon the high pressure of the launch. This **joint rotation** was enlarging the gap that the O-ring must seal and could cause hot gases to **blow by** the putty and **erode** portions of the O-ring. MTI and Marshall

Space Flight Center had to fix this joint rotation problem before they could certify the SRBs as a safe component of the Space Shuttle.

Leon Ray's Recommendation

In 1977, Leon Ray had recommended several solutions to fixing the joint rotation problem in a memo. He recommended that one of the following options be implemented:

1. No change
2. Shims between tan and clevis
3. Oversized O-rings
4. Redesign tang and reduce tolerance on clevis
5. Combination of redesign (option 4) and use of shims

Ray visited the manufacturers of the O-ring in 1979 and they recommended that "tests which more closely simulate actual conditions [of flight] should be done." Marshall and Thiokol engineers followed this advice and continued tests into 1980. After many tests, Marshall and Thiokol felt confident in the primary O-ring's sealing ability since it sealed in much more severe conditions than was expected in a launch. When they purposely failed the primary O-ring, the engineers found that pressure at ignition activated the secondary O-ring, which sealed the joint, and fulfilled the redundant function. Further tests proved that the joint would seal at compression values lower than the industry standard when three field joint aspects were changed.

Design Option Chosen during 1980

At the completion of these satisfactory tests, engineers at Marshall and Thiokol unanimously agreed that although the performance of the field joint deviated from expectations, it was an acceptable risk. In 1980, with the approaching launch of *Columbia*, Marshall and MTI decided that, instead of redesigning the entire joint to solve the joint rotation problem (Option #4 in the Leon Ray memo), they would use thicker shims (Option #2) and larger O-rings (Option #3) on current hardware, and all new hardware would be redesigned. However, a redesign was not sanctioned until six years later. Therefore, all SRBs used between 1980 and 1986 had the 1977 field joint design with thicker shims and larger O-rings.

In September 1980, the SRM, with the newly modified field joints, was certified by the NASA Space Shuttle Verification/Certification Committee. Shortly after this certification, the SRM field joints were classified on the Solid Rocket Booster Critical Items List as criticality category 1R. NASA defines "**Criticality 1R**" as any subsystem of the Shuttle that contains "redundant hardware, total element failure of which could cause loss of life or vehicle." The use of "R", representing redundancy, meant that NASA believed the secondary O-ring would pressurize and seal the gap if the primary O-ring did not work.

Reclassification of SRM Field Joint to Criticality 1

The SRM field joint was classified under Criticality 1R between November 1980 to the flight of STS-5 in November 1982. Between the first and fifth flight three significant events occurred that caused NASA and Thiokol engineers to rethink the field joint classification. After the second flight, STS-2, in November 1981, inspection revealed the first in flight erosion of the primary O-ring. The erosion of .053 inches occurred in the right SRB's aft field joint and was caused by hot motor gases. In mid-1982, Thiokol began tests of the method of putty placement and the effect of the assembly of the rocket stages on the integrity of the putty. Thiokol conducted these investigations because they believed blow holes in the insulating putty were a cause of erosion on the STS-2. In May 1982, high pressure O-ring tests and tests of the new lightweight motor case were conducted. These tests convinced Marshall management that the secondary O-ring would not perform its redundant function if the joints rotated when the SRM reached 40% of its maximum expected operating pressure. Since the dual O-rings were not a *completely* redundant system, the Criticality classification was changed from Criticality 1R to Criticality 1 in December, 1982. This idea that the secondary O-ring would seal except for in the worst conditions prevailed in both Marshall and Thiokol.

O-Ring Erosion and Putty

Between 1980 and 1984, the O-ring erosion/blowby problem was infrequent. However, the erosion on STS 41-B, launched on February 3, 1984, was more severe and caused concern among Marshall and Thiokol engineers. After this flight, Lawrence Mulloy, the director of the SRB project at Marshall, sent a letter to Thiokol which asked for a formal review of the booster field joint and nozzle joint sealing procedures. Thiokol was required to identify the cause of erosion, determine its acceptability, define any necessary changes, and reevaluate the putty that was in use.

Shortly after Mulloy's memo was sent to Thiokol, John Miller, Marshall Chief of the Solid Motor Branch, wrote a memo to George Hardy, Deputy Director of the Science and Engineering Directorate. This memo identified several problems with the putty of 41-B and was mainly concerned with the charred rings on 41-B and "missing putty" that was discovered when the Solid Rocket Boosters were recovered and disassembled. Although erosion was a problem, Marshall and Thiokol allowed further shuttle flights since there would always be this safety margin.

The Launch Decision Process for STS 51-L

On January 15, 1986, NASA held the Flight Readiness Review for STS 51-L. Jesse Moore, the Associate Administrator for Space Flight, issued a directive on January 23rd that the Flight Readiness Review had been conducted and that 51-L was ready to fly pending closeout of any open work. No problems with any Shuttle components were identified in the directive. The L-1 Mission Management Team meeting was conducted on January 25th. No technical issues were brought up in the meeting and all Flight Readiness Review items were closed out. The only remaining issue facing the Mission Management Team at the L-1 review was the approaching cold front, with forecasts of rain showers and temperatures in the mid-sixties. There had also been very heavy rain since the Shuttle was rolled out onto the launch pad.

At 8:00 p.m. on Friday, January 27th, 1986, engineers and managers from Kennedy Space Center, Marshall Space Center, and Morton Thiokol, Inc, participated in the teleconference. Roger Boisjoly and Arnold Thompson, both Thiokol engineers, presented the argument that lower temperatures resulted in longer primary O-ring sealing time. Robert (Bob) Lund, the Vice President of Engineering at MTI, presented the final conclusions of the engineers. Although they agreed that factors other than temperature controlled blow-by, they decided that the launch should not be held outside of the current database. Lawrence Mulloy, the Marshall Space Center Project Manager for the SRB, asked Joe Kilminster, the Vice-President of Space Booster Programs at MTI, for the formal MTI recommendation. Kilminster responded that based on the engineering conclusions, he could not recommend launch at any O-ring temperature below 53°F. At this point, Kilminster asked for a five minute off-net caucus within MTI. Approximately ten engineers and four managers participated in the caucus. Mason stated that a management decision must be made and asked Bob Lund to "take off his engineering hat and put on his management hat."

Lund, who had previously been against the launch, reversed his opinion in the subsequent discussion and agreed with the other managers to recommend a launch. The managers felt that this was the best decision since much of the engineering data had been unsubstantiated and contradictory. Kilminster went on-line again and gave Marshall and Kennedy the MTI recommendation that STS 51-L launch should occur as planned. Mueller, a NASA administrator asked if everyone supported this decision, but no engineer from MTI responded to this question. NASA proceeded with its plans to launch STS 51-L on January 28^{th}, 1986.

Ethical Issues Addressed in the Case Study

The case study was modified to add fictional characters in order to bring out the ethical issues that were present during the 1979 decision to choose the option to add shims. An excerpt from the information added and presented in the case study is as follows:

Billy: Both Option #2 and Option #5 may work without any problems. But, if there is a problem in the future, we will be at fault. We have an ethical obligation to protect the safety and welfare of everyone that is involved in any of our projects. This includes the astronauts that will go on these space shuttle missions, their families, and the American public. The space shuttle's field joints are designated criticality 1, which means there is no backup. Therefore a leaky field joint could result in failure of mission and loss of life. The very first ideal in the NSPE code of ethics is that engineers must hold paramount the safety, health, and welfare of the public. We must not forget that we are working for our country not just our bosses. We cannot let the design of the SRB just be acceptable. We need to make it foolproof; there can be absolutely no mistakes.

Tom: But, Billy you must also consider the ethical value of Option #2. You know of utilitarianism, right? If we apply the utilitarian principles to this discussion then every American citizen is receiving utility from the Space

Shuttle flights. If we postpone the launch by two years, a lot of American people will become unhappy since we will be perceived to not be utilizing the taxpayer's dollars appropriately. The risk incurred by a few astronauts on the flight is outweighed by the obligation to pursue new innovations and utilize the taxpayer's dollars effectively. The American taxpayer has bet about $14 billion on the shuttle. NASA is betting its reputation. The Air Force is betting its reconnaissance capability. The astronauts are betting their lives. Without a national consensus to back our operations, the shuttle program is a victim of year by year funding policies. We cannot just drag the design issue for another couple of years looking for the "perfect solution."

Candice: Exactly. Our management subscribes to the philosophy "fly unless it can be shown not to be safe." If we subscribe to the philosophy, "don't fly if it cannot be shown to be safe," Congress might cancel our space mission in the coming years. We know that the probability of failure is always there in a research and development environment. However, our probability of failure is very low. Engineers at Rocketdyne, the manufacturer, estimate the total probability of failure as 1/10,000. Engineers at Marshal estimate it as 1/300, while an independent engineer consulting for NASA thought 1 or 2 per 100 is a reasonable estimate.

Billy: Our management estimates that only one crash in every 100,000 launches is probable. To me that one crash seems to be one crash too many.

Candice: Billy, most probably that one crash will never occur. We have to balance safety issues with deadlines and a restricted budget. We have to constantly strive to minimize risk and maximize performance, while meeting the proposed schedule and cost. At the same time, we have to uphold the ethical issues of competence, responsibility, integrity, truthfulness, objectivity, honor, and safety. Let us work together to come up with a decision that is acceptable to all of us and to our management.

The above narrative shows that the problems with the Solid Rocket Motor were well known and documented since 1977. It took national prominence when the Challenger disaster happened. The students are provided this case study in a three-part series and asked to defend the options of "launching the shuttle," "not launching the shuttle," "becoming a consultant and making a recommendation," and "deciding as NASA managers."

Development of a CD-ROM

A feedback we obtained while administering the case study was that many of the technical elements (such as joint rotation, O-ring) were not clear by just looking at the photographs or drawings of O-rings etc., on paper. Therefore, a multimedia version of the Design of Field Joint for STS 51-L Case Study was developed in order to provide a much more interactive approach to analyzing the case study. The multimedia version details the problem statement in an audio or a textual manner. The actual case study itself is presented in a much more visual nature using a timeline that shows the different events that occurred from 1971 to 1986. By clicking on a specific year, the student could obtain further information on the events surrounding the field joint design. Clicking on the photographs on the top line could obtain further information about the events that happened in that year. Many videos that describe different concepts such as joint rotation and “blow by” have been included. Important terms and concepts are linked to their respective definitions or pictures that further explain them in greater detail. If a person clicks on the menu, it shows the various options available to the students such as checking the assignments, the tools section, etc. The decision facing the manager is also presented in both a text and audio format. A video explaining the problem statement may be viewed to further develop students’ understanding of the problem. The engineer and manager's recommendations may both be accessed from the CD-ROM.

The multimedia version of the case study also provides a "Tools for Analyzing the Case Study" section. This section includes textual and visual glossary of the terms used in the case study. In addition, background information on ethics and design issues are included. References to popular sites that provide more information on STS 51-L and ethics are also given. A site map provides students an ability to go to any video or textual information without having to navigate through the menu system.

Administration of the Case Study

This case study and the CD-ROM have been brought out together as a text book by the authors (Raju and Sankar, 2000). The text book has been used by students at Auburn University and University of Virginia. It has been used by 140 undergraduate engineering students at Auburn University and 70 students at University of Virginia. In addition, it has been used by 30 faculty members in a workshop conducted at Auburn University during May 2000. No measures other than self-evaluations were used.

Two questionnaires and an electronic journal were used to evaluate student feedback on the case study. Evaluation I consisted of 24 bipolar descriptors. In other words, an item on the evaluation form would represent the concept of clarity on a 5-point continuum from unclear to clear or the case study's relevance on a continuum from irrelevant to relevant. The respondents would circle a number on the scale from 1 to 5 which most closely corresponded to their attitude toward that element of the case study. The respondents continued to follow this process through all 24 bipolar descriptors. Because the 24 questions yielded substantial reliabilities for four clear concepts or constructs, the analysis for Evaluation I was organized by the following four case-study descriptors: (a) interesting and exciting, (b) important and valuable, (c) instructionally helpful, and (d) relevant and useful.

Evaluation II asked the respondents to indicate the extent of their agreement with 16 evaluatory statements on a 5-point Likert scale. Some sample items include statements such as "I improved my ability to evaluate critically technical and managerial alternatives" or "I learned to design." The response scale progressed from a rating of 1 which represented the least positive or least favorable response of strongly disagree to a rating of 5 which represented the most positive or favorable response of strongly agree. In addition, in Evaluation II a qualitative element was added to the evaluation process. The form ended with three open-ended questions which asked the students to provide written responses concerning the strengths and weaknesses of the SRB Case Study as well as suggestions for improvement.

Evaluation by Students

The evaluation results for one course, ME 260 (Concepts of Engineering Design), in which this case study was used at Auburn University are shown herein. The students completed two evaluation forms (Evaluation I and Evaluation II) in order to discern their reactions to the case study method of teaching. In this course, students were taught concepts of engineering design using three different case studies in Fall 1998. Presented herein are the students' (N = 19) reactions to the case study, the Field Joint Design on Solid Rocket Booster (SRB Case Study).

Alpha indices of reliability for constructs in evaluation were as follows: (a) interesting and exciting (alpha = .7522), (b) important and valuable (alpha = .8125), (c) instructionally helpful (alpha = .8524), (d) relevant and useful (alpha = .7457), (e) perceived skill development (alpha = .8691), (f) self-reported learning (alpha = .8408), (g) intrinsic learning and motivation (alpha = .6042), (h) communication skills (alpha = .5867), and (i) learn from fellow students (alpha = .6922). Using an established criteria of .60 for the reliabilities, all the constructs, except for communication, met the minimum alpha level.

The means for the constructs considered in Evaluation I are reported in Table 1, and the means for the constructs from Evaluation II are given in Table 2. These means represent the students' reactions to the Field Joint Design on Solid Rocket Booster Case Study.

Table 1: Means for Constructs in Evaluation I

Interesting and Exciting	Important and Valuable	Instructionally Helpgul	Relevant and Useful
3.8	4.2	4.0	4.3

Table 2: Means for Constructs in Evaluation II

Perceived Skill Development	Self-Reported Learning	Intrinsic Learning and Motivation	Communication Skills	Learn from fellow students
4.2	4.2	4.2	3.5	4.1

Given that the scores fall on a 5-point continuum with a score of 5 representing the highest possible response, the means are on the positive side of the continuum for all nine constructs. In fact, seven out of the nine constructs received mean ratings over a 4.0, indicating that the students had an extremely favorable reaction to the Field Joint on Solid Rocket Booster Case Study.

At the end of the quarter, a final evaluation was given to the students to rate their reactions to various components of the course, such as the use of technology, case studies, subject relevance, etc. The use of technology got varying responses from the students. Whereas some of the students listed the Web pages (N = 5) and CD Rom (N = 6) as the most helpful of the course materials, other students listed the Web pages (N = 2) and CD Rom (N = 3) as the least helpful of the materials. Almost one third (N = 6) of the students listed the course packets as the most helpful material. The least helpful course materials varied per individual, with some students listing the pictures and graphs in the reading material, the statistics in the reading material, the electronic journals, the videos, and portions of the text as being the least helpful.

The students' comments regarding the strengths of the course emerged to reveal three clear patterns: the course's ability to improve problem-solving and critical-thinking (N = 7), the course's interesting and varied format (N = 6), and the course's encouragement of teamwork (N = 4). Two students each opted to write about the course's real world application and the course's emphasis on communication skills as the strengths. The following comment made by one student incorporates and sums up all the course's strengths as noted by the other students:

> This class is extremely helpful in improving an engineering student's capability to define and evaluate all issues, both technical and non-technical, relevant to engineering design. It also gave the students the opportunity to improve team work and communication skills, both of which are essential in a professional career.

This student indicates that the course achieved two of its primary objectives: combining theory with practice and improvement of higher-order thinking skills.

Response of the Students as expressed in Electronic Journals

In the previous section, we presented the results of evaluation for Fall 1998, but this course (ME 260) was taught using the case study approach during Winter 2000 and Spring 2000. We are not presenting the evaluation results for the additional courses, but, we are summarizing the student comments sent to the instructors by means of an electronic journal for all the different offerings. This revealed in a qualitative manner the students comments on the usefulness of this case study. The case study seemed to have impacted the students under three major categories: improved learning about importance of ethics to engineers, better understanding of engineering design process, and learning outside the objectives set for the case study. The comments made by the students under these categories are listed below:

Improved Learning about Importance of Ethics to Engineers

- With this case study I enjoyed learning about the ethical issues. Applications of Kantianism(which basically says treat others as you would like to be treated) to the problem was enjoyable.
- I learned about myself that I am more of an ethical engineer than strictly an engineer alone.
- I learned that utilitarianism is not a very good ethical view. This situation called for a more analytical and accurate decision making method.
- I will definitely use some of the ethics taught in this case study. Engineering is not all about design and creating something. There are responsibilities in other aspects of business that an engineer has to pay attention too.
- While working on the case study I learned how to make ethical decisions by using the facts and knowing what would best benefit the group of people.
- I learned that ethical decisions are a big factor in the whole equation. One can never rule them out.
- The most difficult part of the study was deciding if Kantianism or Utilitarianism was the better ethical view to follow. Kantianism says that life should be regarded over everything else, and Utilitarianism says that the over-all good is more important. To make this difficult decision, I applied my personal opinions to the case.
- I have picked up ethical point of view towards many situations now. I think that this will help me to see all sides of a problem and help me see the most rational, and ethical, yet most productive decision.

Better Understanding of Engineering Design Process

- I think I learned from this and the previous two case studies that management is primarily focused on money. However, as an engineer I have to put ethical and safety issues before a dollar value of any product.
- I learned that in the engineering field there is an enormous number of aspects that must taken into consideration behind ever decision/recommendation that is made. Unfortunately, if these aspects are not weighed carefully the results could be devastating. For example, I believe that the managerial aspects, the financial issues, and the overall image of NASA (and the US as a whole) were weighed too heavily when the case actually happened.
- I learned that not all decisions in engineering and business rely on technical values. There are other responsibilities required to produce and operate something like a SRB. The case study was an excellent example of utilitarian principles. It

also had money and time management factors that contributed to the problem at hand. An engineer has to learn to balance the business ethics, money, time, and technical aspects.

- I learned that ethical questions that come up can be seemly solved even though they are really not. For example you may say the design is safe but no one knows for sure till it is actually used. this is a lot of responsibility for designers.
- The most important thing I learned from this case study is that the engineering aspect of real life situations is much more important than people realize. I have learned that no matter how good your managerial skills may be it is extremely important to be able to make a decision through the eyes of an engineer.
- I learned that even with thousands of people checking and double checking every component of a machine that disasters will sometimes happen and it is just an unavoidable part of engineering.
- The most difficult thing is just the fact that there were so many solutions, and each of these solutions seemed to make just as much sense as the next. This made it very difficult to persuade the audience that your choice is the right choice. The advice that I would give would be to make sure you understand your solution. This will allow for you to speak with ease on your decision, therefore effectively explaining why your solution is best.

Learning Outside the box (beyond Objectives Provided in the Case Study)

- I learned a fair amount of information on a topic that was foremost in all America during the mid-80's: the Challenger explosion. I learned that a very small error in today's engineering fields may cause a very public and destructive accident.
- Would the astronauts have still went up that cold morning, had they known the information they should have been told?
- I believe the results of the bad decisions made in this case study will help me to keep safety always on the forefront of my thoughts.
- I learned about the importance that the environment plays in engineering issues. Nature is something that cannot be controlled, but is something that is very important. Design must take nature into account for everything. If the design does not hold up well in nature, then lives will more than likely be lost.
- It stimulated my brain to the extent that I did some extracurricular research on things indirectly associated with the space shuttle program, NASA, and its affiliates, such as Lockheed Martin.
- This case study was initially difficult because my group had to defend a decision, that we knew was disasterous. Through discussion and research, we did, however begin to understand the decision of management. By using an Utilitarianistic point of view, it was the rational decision.
- I learned that I have more of an engineering mind than a political mind. Just because a decision will make a couple of Congressman happy, doesn't mean it is the right decision.
- I have learned that I will really enjoy the field of engineering because these are real life problems that engineers have to solve on the job.

- Working in groups and sharing ideas about the subject helped with our decision. Others put in their 2 cents and we were able to agree on the final decision.
- This presentation taught me to always think twice before making a final decision, because we can see how traumatic a permanent decision can be not only on the people involved in making the decision, but also on the people who were involved in many other parts.
- I used mostly the drawings in the text, I also did some CAD drawings of my own to prove the validity of the u -shim itself. I also used the conversations of the decision makers of the job to help support my ideas.
- Visualization, I think it is a good quality, if everyone can understand what you are trying to do it will help them to make a good choice on the design you are pitching.
- As I went through this case study, I tried to assess the engineering aspects as well as the ethical and economical aspects.

Summary and Conclusions

The data from the various aspects of the course evaluation seem to indicate that the case study method of instruction, which incorporated varying aspects of technology, is a worthwhile and beneficial method of instruction for teaching an engineering design course. Through positive ratings, the students indicated their favorable responses to each of the solid rocket booster case study. Comments gathered from the students through the e-journal also indicated that the students enjoyed and benefited from this mode of instruction. The case study method of instruction appeared to combine theory with practice as well as encourage the use of higher-order thinking skills within the students—the two primary objectives of this particular case study.

This leads the authors to believe that it was worthwhile creating this case study and CD-ROM since it fulfills objectives that could not be met using past educational material on the Challenger Disaster. The differences between past work and this case study are shown in Table 3. The feedback from the students by the use of the electronic journal indicates that this method could provide major benefits in integrating ethical, business, and engineering topics. Multimedia adds considerably to the written material by bringing real-world into the classroom and making the students excited about the learning process. The feedback shows that use of this approach could make the students think out of the box and start learning using non-traditional means.

The textbook and CD-ROM are available for other instructors who want to adapt the materials in their classrooms. In addition, workshops are being offered where educators could obtain hands-on training on use of this material in their classrooms.

Table 3: Difference between the Process used in the current project and past work.

Elements in Case Studies integrating Ethics in Engineering	**Past Work**	**Our Work**
Dramatization	Included	Included
Impact on society	Included	Included
Time element	At a point in time – Oct. 1986	Longitudinal – covers 1971-1986
Engineering design options	Not included – only one option discussed	Discusses five options faced by NASA in 1979
Details	Short on detail – 1 page or less	Long enough to bring out the technical issues alive – such as joint rotation, shims, O-rings, etc.
Photographs	Limited	Extensive since a CD-ROM has been developed
Explanation of technical details	Limited since it is based on paper description	Animation, Videos explain the technical details explicitly
Bringing reality into classroom	Limited to printed material	Live videos, timeline, and photographs using multimedia
Focus	Communication difficulties between engineers and managers	Ethics, Engineering Design

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