CHAPTER 5

# Engineering Ethics

## INTRODUCTION

On January 28, 1986, seven astronauts were killed when the space shuttle Challenger exploded. Millions of people will never forget the awful sight of the NASA shuttle disappearing in a plume of white smoke, which was played over and over again on national television. The investigation following the disaster traced the cause of the explosion to the failure of the O-rings in the shuttle's solid rocket booster, which had been designed by the Morton-Thiokol Company. The O-rings were not seated properly, which allowed the combustion gases to leak out, burn through an external fuel tank and cause the explosion.

The night before the launch, Roger Boisjoly and another engineer working for Morton-Thiokol participated in a teleconference with managers from Morton-Thiokol and NASA. Temperatures at launch time were forecast to be close to $20^{o}$F, unusually cold for the Florida launch site. The teleconference was set up to discuss the engineers' long-standing concerns about the solid rocket booster design, specifically whether the O-rings would seat properly at such cold temperatures. The NASA managers challenged the engineers' arguments, ultimately leading the managers at Morton-Thiokol to override their engineers' recommendation. That night, temperatures at the launch site dropped to $8^{o}$F, raising additional safety concerns beyond those about the O-ring performance. Nevertheless, NASA waived low-temperature restrictions and proceeded with the launch. The shuttle exploded just over 70 seconds into the flight.

Roger Boisjoly first expressed his concern about the O-ring seal in the solid rocket boosters a year before the Challenger launch. He was vigilant in his efforts to avert the risk the problem potentially posed. His actions during the year leading up to the launch are widely recognized as exemplifying the highest standards of engineering ethics. Despite his best efforts, however, NASA managers were persuaded by political and economic pressures to go ahead and launch the Challenger on January 28, 1986 [1].

The space shuttle Challenger was a complex technological system. Technical considerations—as well as political and economic interests—shaped its design. In fact, engineers usually practice their technical skills on projects that are heavily influenced by complicated and competing interests of the public, government and private sector employers or clients. Decisions that appear correct from a technical perspective are often challenged or rejected for other reasons. And, competing interests often create ethical dilemmas for engineers.

## PROFESSIONAL ETHICS

Why raise the issue of ethics in an introductory engineering design course? The answer lies in the professional status of engineering. Engineering shares several defining characteristics with other professions such as nursing, law and accounting [2]. As with the other professions, engineering:

- requires extensive, specialized training
- provides knowledge and skills that are vital to society
- has a monopoly on practice of these skills (e.g., only licensed engineers are allowed to design highway bridges)
- has autonomy in practice (i.e., technical judgments in engineering are reviewed by other engineers, but not by medical doctors)
- is regulated by ethical standards above and beyond laws and personal morals

The last characteristic listed follows from the previous four. Special ethical standards are required of professions because society relies on the special skills and training of their members; because society grants them a monopoly on the practice of those skills; and because society grants them autonomy to police themselves with respect to the technical aspects of their practice.

Harris et al. [3] define professional ethics as:

"Special morally permissible standards of conduct that, ideally, every member of a profession wants every other member to follow, even if that means having to do the same" and which apply "to members of a group simply because they are members of that group."

Members of the engineering profession want all other engineers to behave ethically, because their behavior reflects on the profession as a whole. Conversely, by accepting professional status, individual engineers agree to behave ethically, recognizing that their behavior has implications for all other engineers.

The purpose of introducing professional ethical standards in this course is to help students recognize ethical conflicts when they arise, and provide the opportunity to practice making judgments about such conflicts. Moreover, as illustrated by some of the cases presented below, professional ethics relate to situations that routinely arise in college, as well as in engineering practice.

So, what are these professional ethical standards? Professional engineering societies, including the American Institute of Chemical Engineers (AIChE), the American Society of Mechanical Engineers (ASME), the American Society of Civil Engineers (ASCE), and the Institute of Electrical and Electronics Engineers (IEEE), have codes of ethics that articulate their members' consensus on what the ethical standards should be. Although these codes change from time to time and differ somewhat from one society to another, the basic principles do not change. The Code of Ethics of the Accreditation Board for Engineering and Technology (ABET) includes these basic tenants that are common to all of the codes [2]:

### Principles

Engineers uphold and advance the integrity, honor and dignity of the engineering profession by:

1. Using their knowledge and skill for the enhancement of human welfare;
2. Being honest and impartial, and serving with fidelity the public, their employers and clients;
3. Striving to increase the competence and prestige of the engineering profession.

### Canons

1. Engineers shall hold paramount the safety, health and welfare of the public in the performance of their professional duties.
2. Engineers shall perform services only in the areas of their competence.
3. Engineers shall issue public statements only in an objective and truthful manner.
4. Engineers shall act in professional matters for each employer or client as faithful agents or trustees, and shall avoid conflicts of interest.
5. Engineers shall build their professional reputation on the merit of their services and shall not compete unfairly with others.
6. Engineers shall act in such a manner as to uphold and enhance the honor, integrity and dignity of the profession.
7. Engineers shall continue their professional development throughout their careers and shall provide opportunities for the professional development of those engineers under their supervision.

The ABET Code of Ethics [2] highlights *integrity* and *competence* as essential characteristics of ethical behavior. It emphasizes that *service* (to the public, employers and clients) *is the primary role of the engineering profession*, identifying the safety, health and welfare of the public as a paramount concern. These critical aspects of engineering ethics are explored further in the following sections.

## RESPONSIBILITY FOR SAFETY, HEALTH AND WELFARE OF THE PUBLIC

In the Challenger disaster, the safety of the astronauts came into conflict with other pressures faced by NASA and the aerospace companies involved in the design, production and operation of the space shuttle fleet. Such is often the case with safety concerns in engineering design. It is often prohibitively expensive—if not impossible—to eliminate the possibility of injury from even simple devices, let alone from complex systems such as the space shuttle. Hazards are often difficult to anticipate, in part because it is hard to predict how and under what conditions a device will be used. Nevertheless, engineers have an ethical responsibility to protect the public from injury or harm that could be caused by the artifacts they design and produce. Engineers and the firms that employ them also bear legal liability, subject to both civil and criminal penalties, for injury due to negligent or incompetent designs, construction or production.

### Case A: The Hyatt Regency Walkway

On July 17, 1981, two suspended walkways at the Hyatt Regency Hotel in Kansas City, Missouri, collapsed, killing 114 people and injuring more than 200 others. The victims were in the hotel atrium and on the walkways suspended above it. The connections tying in the hanger rods that held up the walkways were unable to support the load; consequently they failed, sending the walkways crashing onto the crowded atrium floor.

To simplify the process of constructing the walkways, the fabricator of the atrium structure installed hanger rods and connections that were different than those specified by the structural engineering designers. The design engineer approved the change during his review of the shop drawings, despite the fact that the new connections could have been predicted to fail under the load applied at the time of failure. After an investigation, the principal engineers involved in the case were found guilty of gross negligence and misconduct, and lost their licenses to practice engineering in Missouri.

The Hyatt Regency walkway case [4] illustrates the legal and professional responsibility that engineers bear for ensuring the safety of their designs. This responsibility includes ensuring that design specifications are followed during construction. From a legal perspective, the status of engineers as skilled professionals subjects them to a high standard of responsibility for their actions.

### Case B: Good Intentions (A Hypothetical Case)

A group of four senior engineering students designed and built a water slide, with an innovative water circulation system, for a local elementary school. The students designed the slide to support three 70-lb children, which they thought was a reasonable load. However, the slide collapsed when ten unsupervised children crowded on at once; several children suffered broken bones. What ethical responsibility do the engineering students bear for the accident? Could they be held legally liable for it? Does it matter that the children who were injured were misusing the slide?

Regardless of their best intentions, legal liability is something that engineers must consider. Like physicians, private engineering firms often must carry liability insurance. The insurance premiums typically cost a few percent of a firm’s annual income. Liability for injuries or damage is usually tried in civil cases under Tort law, which deals with injuries that one person or entity causes another. The standard applied under Tort law is that the injury was caused by the defendant, either through error or neglect. That is, the defendant’s act or omission was the "proximate cause" of the injury.

With respect to legal liability, Case B actually represents a special situation. In fact, the students would probably have some protection from legal liability through a contractual agreement between the university and the school, or possibly through “sovereign immunity” if the university were a public institution [5]. Sovereign immunity is a legal principle that applies in some states to limit the liability of the government and its agents (i.e., the students in this case) for acts of negligence. Neither sovereign immunity nor contractual agreements can shield engineers from ethical responsibility, however. And, if the situation involved engineers in private practice, rather than engineering students, they might well face legal liability.

### Case C: TWA Flight 800

At 8:30 p.m. eastern time on July 17, 1996, TWA Flight 800 crashed into the Atlantic Ocean soon after taking off from John F. Kennedy International Airport. Early investigations considered the possibility that the plane, a Boeing 747-100, was accidentally shot down by the US Navy or blown up by an onboard explosive. However, recent National Transportation Safety Board investigations indicate that faulty fuel sensor wiring is likely to blame. On this particular flight, the center fuel tank was nearly empty. Prior to takeoff, heat from nearby air conditioning units vaporized the remaining fuel, which then mixed with the air in the center tank, resulting in a flammable mixture. Examination of wires leading to the fuel probe show that the insulation had degraded, and thus the wires may have provided an ignition source. This plane was one of the first few hundred that Boeing built, and was approximately 25 years old. Examination of the probe wiring was not part of normal maintenance, because no one ever thought that it would be necessary over the projected lifetime of the plane.

Since the TWA Flight 800 crash, greater attention is being paid to wiring inspections as part of routine aircraft maintenance. To date, no legal liability has been found in this case, nor have investigators accused Boeing's engineers of behaving unethically. Nevertheless, the case points out that an ethical regard for safety must go beyond the design stage of a product's life cycle, carrying through to its operation and maintenance.

A number of things can go wrong with a design, and possibly lead to injury. An operator can overload a device, as in the water slide case. The performance of parts can degrade over time, as in the case of Flight 800. Parts may not be made to specification in the first place, as in the Hyatt case. How can an engineer protect public safety in light of all these uncertainties? As discussed in this textbook's chapter on the Design Process, engineering designs typically incorporate a *safety factor*. The design is created not only to meet requirements, but also to exceed them by factors of safety. For example, if a beam, perhaps the joist beneath your kitchen floor, is reasonably expected to be subjected to a distributed load of 600 lbs, a safety factor of 5 means that the beam can actually withstand 3000 lbs before failure.

The appropriate size of a safety factor depends on the application. An elevator cable might be designed with a safety factor of 11 [6]. In contrast, a part for an unmanned rocket casing might have a safety factor of 2 if it is not to be tested before use, and a safety factor of only 1.25 if the part will be tested first [7]. Economics and the level of acceptable risk play a role in determining the size of the safety factor. In the case of the elevator cable, the size and weight of the cable will add to the cost of the elevator, but it will not be a major factor. The cable must be expected to last a long time, and its wear characteristics must be taken into account. Moreover, the loss of lives of elevator passengers represents a huge potential cost of a failure. Combined, these aspects make a large safety factor worthwhile. On the other hand, in rocket design, a part with a larger factor of safety will be bigger and heavier, requiring that the entire rocket be scaled up. Costs rise rapidly with spacecraft size, and if the rocket becomes too heavy, its entire mission will fail. Thus small safety factors are required. Think carefully about a design. What factor of safety is appropriate?

## RESPONSIBILITY TO EMPLOYERS AND CLIENTS

The ABET Code of Ethics recognizes responsibilities that engineers bear to their employers and clients, as well as to the public. Professional engineers have an ethical responsibility to provide competent services (including seeking assistance or declining projects that are beyond their capabilities), act in the interests of the employer or client, and maintain confidentiality concerning business matters or proprietary technical information. The Code also cites a responsibility for engineers to avoid situations in which they represent the competing interests of multiple parties. For example, an engineer representing a city in overseeing a construction project faces a clear conflict of interest if s/he is simultaneously receiving compensation from a contractor that is bidding on the project.

The ethical responsibility to serve an employer or client as a “faithful agent or trustee” does not imply that engineers should be blindly loyal. One of the toughest dilemmas that engineers may face is a conflict between their personal or professional principles and practices or activities that are undertaken by an employer or client. Such dilemmas arise in many gray areas of public safety and environmental protection; for example, in cases in which practices that comply with existing laws still pose risk.

### Case D: A Revealing Audit (A Hypothetical Case)

A manufacturing company hires a consulting engineer to perform an environmental audit on one of its plants, in order to identify waste minimization opportunities for reducing the use of toxic chemicals and thus lowering waste disposal costs. In the process, the engineer discovers a low-volume toxic waste stream of which the company leadership was unaware, and thus had not reported to the state environmental protection agency. The engineer notes in her report to the company that this waste stream should be reported to the state agency. However, a company manager tells her that because their waste minimization plans will soon eliminate that particular stream, they do not plan to report it. What should the engineer do?

### Case E: Side Saddle Fuel Tanks

In the early 1980s, engineers working for General Motors were concerned about the location of the fuel tanks in its 1973-1987 Chevrolet and GMC pickup trucks. The fuel tanks were positioned outboard of the truck frame, and thus potentially exposed in the case of collisions from the side. The GM trucks met the existing government standards for side-impact collisions, which were tested at impact speeds of 20 mph. There was no legal requirement that the truck be designed to protect its occupants from side-impact collisions at higher speeds, in which company tests reportedly showed that the fuel tanks could indeed rupture [8]. Nor was the company legally required to share its in-house test results with the government.

What is the engineer's ethical responsibility in these two cases? Professional codes of ethics cite a responsibility for engineers to act as "faithful agents" towards employers or clients, meaning in part that they will not reveal privileged information without the employer's or client's consent. However, the duty to maintain confidentiality is overruled if reporting the information is required by law, or necessary to protect the health, safety or welfare of the public. Moreover, in situations like the GM truck case, significant debate comes in determining how much risk is acceptable. The trucks at issue actually had comparable or better overall safety records than their competitors, but higher risk of fatalities due to fire.

The tension between ethical responsibilities to employers and to the public also suggests that engineers should exhaust internal avenues for addressing their concerns before reporting them to external authorities or to the public. In fact, GM's safety engineers worked internally to change the fuel tank placement. The truck design was changed with the 1988 model year, relocating the fuel tanks inside the truck frame.

## INTEGRITY AND INTELLECTUAL PROPERTY

Several of the canons of the ABET Code of Ethics cite honesty and integrity as ethical responsibilities of engineers. These issues in the professional codes align closely with the issue of academic integrity. The University of Colorado's policy on academic integrity [9] states that:

> "A university's intellectual reputation depends on maintaining the highest standards of intellectual honesty. Commitment to those standards is a responsibility of every student and every faculty member at the University of Colorado. Breaches of academic honesty include cheating, plagiarism, and the unauthorized possession of exams, papers, or other class materials that have not been formally released by the instructor."

Likewise, professional ethics requires that engineers respect the intellectual property of others, and represent only their own work or accomplishments as their own.

### Case F: Intellectual Property (Adapted from National Society of Professional Engineers Case No. 83-3 [10])

Andrew, an engineer who owns his own computer support company, submits a proprietary proposal for a local area network (LAN) installation to a small business owner. An innovative preliminary design and cost information for the LAN are included in the proposal. In an effort to solicit competition, the business owner provides copies of Andrew's proposal to another prospective bidder. Katie, an engineer working for the second company, identifies some potential cost savings and revamps Andrew's design. She incorporates her version of the design in the bid that her company submits for the job. Are the small business owner's actions acceptable? Is Katie's use of Andrew's ideas ethical?

### Case G: Intellectual Contributions

Logan is extremely annoyed because Taylor has not shown up for their group's last three design project meetings, and wants to tell the instructor about Taylor's absences. However, the two other group members, Blair and Lisa, know that Taylor is struggling with other courses and think that they should give him a break. Taylor feels that he can rely on the other group members to collectively achieve a good grade on the design project, and wants to devote more time to passing calculus and physics.

What should the group members do? Does CU's policy on academic integrity have any bearing on their dilemma? Are there parallels between this situation and Katie and Andrew's case?

## RESPECT: DIVERSITY AND SEXUAL HARASSMENT POLICIES

As mentioned above, the University of Colorado community views academic integrity as a responsibility of all of its students and faculty. Another ethical responsibility highlighted by the CU community is respect for diversity. The campus diversity committee adopted the following definition in 1994 [11]:

> "The University of Colorado is a community in which diversity is a fundamental value. People are different and the differences among them are what we call diversity. Diversity is a natural and enriching hallmark of life. It includes, but is not limited to, ethnicity, race, gender, age, class, sexual orientation, religion and physical abilities. A climate of healthy diversity is one in which people value individual and group differences, respect the perspectives of others, and communicate openly."

Lack of respect for others can be demonstrated in many ways. Sexual harassment is one manifestation of this problem that has been particularly widespread in business and academic situations. State and federal laws prohibit sexual harassment. To ensure that violations do not occur on campus, CU uses the following definition [12]:

> "Unwelcome sexual advances, requests for sexual favors, and other verbal, non-verbal or physical conduct of a sexual nature constitute sexual harassment when:
>
> 1. submission to such conduct is made either explicitly or implicitly a term or condition of an individual's employment, living conditions and/or academic evaluation;
> 2. submission to or rejection of such conduct by an individual is used as the basis for employment or academic decisions affecting such individual; and/or
> 3. such conduct has the purpose or effect of unreasonably interfering with an individual's work or academic performance or of creating an intimidating, hostile or offensive working or educational environment."

CU policy also states that:

> "Romantic/sexual relationships between faculty members (including instructors and teaching assistants) and students or between supervisors and supervisees are inappropriate when the faculty member or supervisor has direct professional responsibility for the student or the supervisee. Such situations greatly increase the chances that the faculty member or supervisor will abuse her or his power and sexually exploit the student or employee.
>
> Moreover, others may be adversely affected by such unprofessional behavior because it places the faculty member or supervisor in a position to favor or advance one student's or employee's interest at the expense of others..."

CU's policy prohibits romantic or sexual relationships between instructors and students who they are in a position to evaluate, unless the relationship is disclosed to the instructor's supervisor and arrangements are made to eliminate potential conflicts of interest or impropriety.

**Case H: The Relationship (A Hypothetical Case)**

An upper-class student in electrical engineering, Chris is a second-time TA for an introductory engineering projects course. The TAs' responsibilities in the course include assisting the students with their design projects and providing input to the instructor on how the groups and individual group members are performing. During the projects course labs, Chris has especially enjoyed interacting with J.P., one of the first-year students, also an electrical engineering major. J.P. frequently goes to Chris' office hours for help with physics homework and to shoot the breeze. The relationship develops, and toward the end of the semester, J.P. and Chris start seeing each other socially. Word gets back through the grapevine to the instructor of the course. What should the instructor do?

## ENVIRONMENTAL ETHICS

The first canon of the ABET Code of Ethics [2] states that "Engineers shall hold paramount the safety, health and welfare of the public in the performance of their professional duties." What does this imply about protection of the environment, beyond human health concerns? The “safety, health and welfare of the public” is intimately linked to the well being of the environment. However, the responsibility of engineers for broader environmental concerns such as animal rights, bio-diversity, sustainability and wilderness preservation remains controversial.

In this case, many engineers’ personal ethics may differ from those that are generally accepted by their profession. Engineers with a strong commitment to environmental protection express that commitment through lifestyle choices, volunteer activities and through their decisions about what career opportunities to pursue. Moreover, engineers from many different disciplines and in many different positions encounter and pursue on-the-job chances to conserve resources or reduce environmental impacts. The concept of “green design” encompasses many such opportunities.

### Case I: The Environmentally Conscientious Group Member

Kelly’s group is designing an interactive model of the hydrologic cycle for a middle school classroom. He insists that the group construct the exhibit out of recycled materials and has spent several hours on the phone trying to identify a supplier of recycled plastic. The other members of Kelly’s group know he is sincere in his belief that they can encourage middle school kids to recycle by modeling the use of recycled materials in their project. However, the recycled plastic that Kelly found is twice as expensive as the alternative and is less attractive. Moreover, if they purchase the recycled plastic, the group will have to purchase a smaller pump than they deem optimal, in order to stay within budget.

What should the other members of Kelly’s group do? Does the ABET Code of Ethics provide any guidance in this situation? Is this an ethical dilemma or just a disagreement? Thinking beyond this case, in what other situations might personal, cultural or religious principles come into conflict with an engineer’s responsibilities?

## CONCLUSION

The professional status of engineering depends on the ethical behavior of its members. Codes of ethics for engineers require integrity, competence, and fair service in the interests of clients and employers, and commitment to protecting public health, safety and welfare. A practicing engineer inevitably encounters situations in which professional ethics are at issue. In some cases, simply knowing the ethical standards of the profession makes it obvious what action to take. In other cases, though, conflicts arise between personal and professional principles or between competing professional standards, and coming to the “right” ethical decision requires careful deliberation. Examining historical or hypothetical engineering ethics cases, and discussing the academic ethics cases encountered as a student, will help in preparation for the ethical dilemmas that will be faced in engineering careers.

## REFERENCES

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