Improving Ethical Engineering Practice

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"Engineering takes the knowledge created by the sciences and applies it for the benefit of the people in order to create a higher standard of health, comfort, and living" [19, p. 35].

The production of knowledge in engineering is located both in science as well as in social life [9]. Further, engineers use not only scientific knowledge in their practice, but they also combine labor and capital in their application of this knowledge. Being employed in the private sector and working toward commercial ends, engineers are both the "objects and representatives of corporate power" [5]. As such, engineers are faced with ambiguities and issues concerning the use and abuse of power, which other professions are not.

Soon after its founding in 1884, the Institute of Electrical and Electronic Engineers, or IEEE, sought to prepare a code of ethics for the members of that organization, which was adopted in 1912 after a great many revisions. These codes emphasized the broad, general principles by which all members of the profession should be guided. Initially, the IEEE stressed gentlemanly conduct

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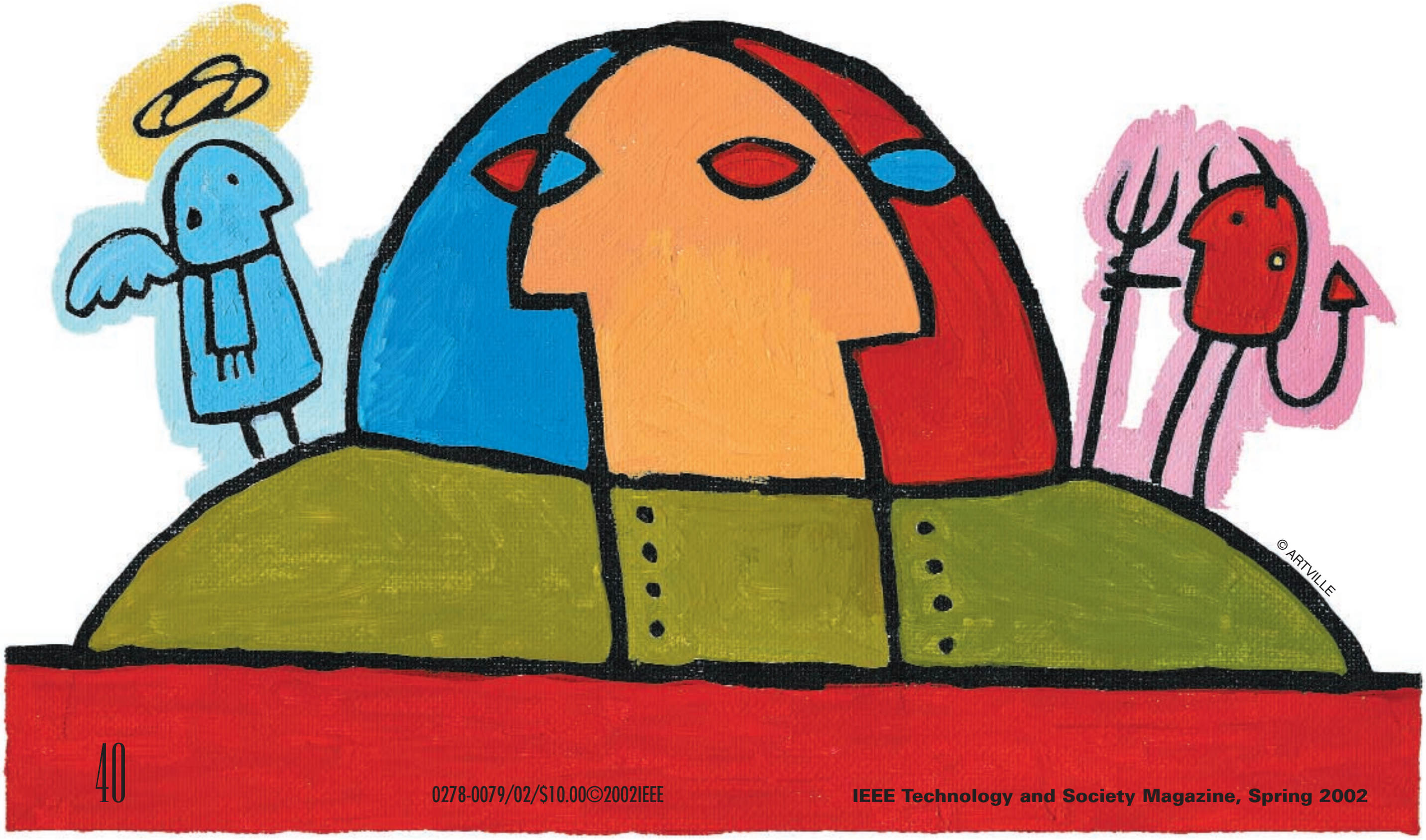

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rather than concern for public welfare. Traditionally, an engineer was to be honest, impartial, avoid conflicts of interest, not criticize a fellow professional, and not compete for commissions on the basis of price. For a long time, the IEEE had avoided open discussions of the social and political issues involved in the practice of engineering.

However, as the modern world brought new ethical challenges and posed new ethical dilemmas [17], the IEEE began both to assume special responsibility for the uses and effects of technology, and to consider the inherent conflicts and tensions in modern engineering. Accordingly, there have been attempts to update engineering codes of ethics to correspond with modern engineering practice. In 1990, the IEEE adopted a new code of ethics for its members as a guide to the ethical practice of engineering. The ten rules of conduct that comprise the IEEE code cover ethical topics that range from attending to the "welfare of the public" to concern for the "professional development" of colleagues. Engineering ethics has become an area of concern for the field of engineering in general [13]. For example, Engineering Criteria developed by the Accreditation Board for Engineering and Technology (ABET 2000) states that engineering education programs should incorporate ethics and ethical considerations into their program objectives.

This article discusses the relevance of engineering ethics codes in the practice of most professional engineers. An examination of the role of ethics in the engineering professions and paradigm cases of engineering failures—the Space Shuttle Challenger explosion, the Ford Pinto gas tank, the chemical leak in Bhopal, and the nuclear accident in Chernobyl — illuminates the difficulties in actualizing codes of ethics in practice, as well as choosing relevant examples in teaching engineering ethics. These paradigm cases reveal that they are not an adequate way of presenting ethical issues to young engineers.

Social Circumstances and Engineering Practice

In social life, individuals engage in a variety of practices. Some of these practices cut across various areas of social life and have been styled "dispersed" (e.g., the use of logic, mathematics, or rhetoric). Other practices, referred to as "integrative," are more confined and are both found in, and constitute, particular domains of social life. Integrative practices use shared understanding, meanings, and actions to organize a realm of social life. Engineering, considered as a social activity and an heterogeneous profession, is an integrative practice, though dispersed practices are used and take place in the engineering domain [15].

In the United States, the social circumstance in which engineering is practiced is somewhat distinct from that of other professions. The private for-profit sector is by far the largest employer of engineers. In 1997, 80% of engineers with bachelor's degrees, 75% of those with master's degrees, and 54% of those with doctoral degrees were employed in a private, for-profit company [12, pp. A142-A146]. Engineers spend at least a third of their waking lives at work and derive a good part of their self-esteem and sense of self from their jobs. The engineer in industry is neither an independent professional person, nor an employee of a firm who is bound primarily by principles of engineering ethics: the industrial situation calls for loyalty to the employer. Industry even stresses the engineer's responsibility in protecting trade secrets after leaving a particular employer.

In the social world of work, engineers meet with conflicts that are not handled by their professional paradigm. Unfortunately, some companies have tried to cover up or ignore serious problems, such as unsafe products, violations of environmental laws, falsified test results, or discriminatory hiring and promotion. If a problem seems serious enough, engineers may feel a need to blow the whistle on their company by taking the problem directly to the client, the regulatory agency, the media, or the public.

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However, the decision to blow the whistle is never an easy one because it involves a conflict between two fundamental loyalties — the firm and society.

Another characteristic of engineers' interactions with society is that the heavy focus on engineering science in educational training pushes engineers in the direction of positivist thinking. The essential axioms of modern positivism are that the physical sciences provide the paradigm of objective knowledge, science itself is value-neutral, and ethical and other normative judgments are expressions of emotions [1].

Engineers are taught to be pragmatic, logical, rational, sensible, and systematic in their approach to problems. These useful and absolutely necessary attributes also tend to alienate the engineer from the rest of society. Moreover, they may even confuse engineers themselves — many engineering decisions are value-laden, and positivist thinking helps very little in resolving social, personal, or ethical dilemmas.

Practically, in the social world, engineers differ greatly from scientists. Engineers not only advance knowledge and explore the unknown, but they create what has not been. The major function of the engineer is not merely studying the natural world, but getting things that need doing done, for social purposes. Yet, the successful accomplishment of these social ends is complex. While engineers see themselves as successful problem-solvers acting in the public interest, they are not always perceived that same way by others [16]. The fundamental difference between how engineers see themselves and how the public sees them depends on how well engineers meet public concerns. Engineers need to have a broad understanding of the context and a broad view of their responsibilities if they are to deal with ethical problems to the satisfaction of the community.

Many have recognized the social complexity and difficulty of the circumstances surrounding engineering practice. Rather than discount the insights or experience of non-engineers as irrelevant to engineering practice, they see this understanding as crucial to the development of ethical engineers [2]. There is a need to cross the cultural chasm between social scientists and engineers and bring social theory into engineering ethics [14]. Social scientists venture into engineering fields, but engineers show little interest in joining social scientists. Non-engineers, especially social scientists or philosophers, may lend to ethical engineering non-positivist knowledge about social life that helps engineers to paint a complete picture of the social circumstances of engineering practice. If, indeed, these students of social life and philosophy have something to offer, it may well be in understanding the limits of and defects in current devices for ensuring ethical practice: codes of ethics and paradigm cases.

Codes: Guidance for Ethical Decisions

The approach to ethics through the promulgation and adoption of codes of ethics by professional bodies is found in most professions. In general, professional codes of ethics must satisfy two important considerations. First, they must be of sufficient breadth that they cover the likely ethical conflicts and concerns of the professional field but do not reach to extraneous incidents. In achieving this end, a code needs to encompass the principles that guide professions in general and ethics in particular. Second, they must be of sufficient specificity that they can serve as guides to making sound decisions for practical action in actual circumstances. In accomplishing this aim, the success of a code of ethics is measured by the degree to which the rules it states serve as effective guides to action for practitioners.

Codes cannot provide meta-rules for interpretation

However, following rules is not as easy as stating them. The concepts embodied in rules for human action are always open to misunderstanding. This is because in practice — unlike numbers or mathematical algorithms, which can be specified ahead of time — concepts can admit of either identity through precision or general accuracy through open meaning, but not both at the same time. This is apparent if we focus for a moment on the complexity or combinatory vagueness that characterizes many social concepts. Many of the central concepts of ethical rules are of this nature, for example, "harm," "safety," "disclosure," "honesty," or "fairness." Certainly, we can attempt to achieve positive precision for ethical concepts by stipulating certain criteria over others and limiting vagueness. However, if the former is achieved, then generality is sacrificed, and the rules become meaningless for additional cases and lack relevance to social practice [3]. Likewise, if the concepts in the rules remain applicable to many instances, then they lack specific identity and thus lack clear certainty for their prior applicability to a specific instance.

One way to handle this problem is to specify meta-rules that help define the guidelines for applying rules. The idea here is similar to the use of handbooks for sports officials in how to apply the rules of a game. Unfortunately, this does not diminish the problem of rule interpretation or misinterpretation — it merely shifts it to the meta-rules themselves. In any event, even if logically possible, it would be as difficult and time consuming to reach agreement on such rules for professional codes of ethics as to promulgate the codes themselves, and clearly would not leave the codes easy to use and widely applicable.

Another way to handle this problem has more promise and may be more acceptable to engineers. Zadeh [21] and the theorists of fuzzy logic accept the pervasive vagueness of concepts, but have devised a formal apparatus to handle it. For them, concepts do not operate according to the precise rules of classical set theory, but instead operate as "fuzzy sets" — that is, classes in which the transition from membership to non-membership is gradual rather than abrupt. Engineers see the use of fuzzy logic in engineering as providing more efficient control mechanisms; they also recognize its applicability to social practice,

TABLE I
RELEVANCE OF PROCESS VS. OUTCOME ORIENTATION TO RULES IN IEEE CODE OF ETHICS

IEEE Rule	Process Oriented?	Outcome Oriented?
1. Concern for public safety, health, and welfare; disclosure of dangers to public or environment.	Partly (Disclosure)	Yes
2. Avoid and disclose conflicts of interest.	Yes	No
3. Be honest and realistic in claims and estimate.	Yes	No
4. Reject bribery.	Yes	No
5. Improve understanding of technology, application and potential consequences.	Partly (Understanding and Application)	Partly (Consequences)
6. Maintain and improve technical competence; undertake tasks for which qualified or disclose limits.	Partly (Maintenance and Improvement; Disclosure)	No
7. Criticize technical work; correct errors; credit work.	Yes	Partly (Correct Error)
8. Provide fair treatment, avoiding discrimination.	Yes	No
9. Avoid injury by false or malicious action.	Partly (Falsity; Maliciousness)	Yes
10. Assist and support others in professional development and ethics.	Yes	No

where concepts defy formalization and may have a zero sum relationship between precision and accuracy.

Codes cannot provide patterns from experience

As the famous philosopher Wittgenstein [20] has pointed out "…definition explains the use - the meaning - of [a] word…". Correspondingly, perhaps engineering practitioners simply should use professional codes of ethics to make ethical decisions. Maybe, just by applying codes of ethics they can learn to recognize correct applications of the rules. However, some current literature on professional decision-making has suggested that professional decision-making, especially under crisis conditions or time constraints is not a rational process and relies on considerable professional experience [8]. Basically, this research shows that, under these conditions of professionals recognize patterns of events from previous experience and act in a fashion similar to successful previous actions. Unfortunately, this approach leaves two problems for ethical practice. First, there is no assurance that a successful action has not come after considerable unsuccessful action — not necessarily a promising model for important ethical concerns. Second, recognition of successful actions is dependent on either great prescience or broad experience. So, just like the problem codes of ethics have with handling meta-rules, they cannot embody the patterns from experience necessary to apply them.

PARADIGM CASES: SOCIAL DISTANCE AND PROFESSIONAL JUDGMENT

The most prevalent mechanism for conveying an understanding of how to use and apply codes of ethics to practicing engineers is the use of cases. We call them "paradigm cases." These are model cases that embody what are perceived to be common, pertinent, appropriate, helpful examples of the sort of ethical conflicts, problems, tensions, and dilemmas faced by practicing engineers. In short, they illustrate what engineers take to be ethical problems and the situations in which they arise. These paradigm cases have become popular in the profession [10]. They are presented to students in the leading engineering ethics textbooks and to practicing engineers on web sites. (One

TABLE II
RELEVANCE OF KNOWLEDGE USED IN PARADIGM CASES FOR ENGINEERING ETHICS

Type of Knowledge Highlighted in Case Event		
Case	**Calculation?**	**Interpretation?**
1. Challenger	Yes	No
2. Ford	Yes	No
3. Bhopal	Yes	No
4. Chernobyl	Yes	No

notable example of the latter is the Ethics Center for Engineering and Science site http://onlineethics.org).

The most frequently mentioned of these cases are familiar to most engineers. They are the Challenger Space Shuttle Explosion, the Ford Pinto Gas Tank, the Bhopal Plant Failure, and the Chernobyl Melt Down. These cases are distinct, but they are seen as sharing features, most notably, the failure of some engineer in possession of positive knowledge to act sufficiently to avoid an outcome that caused harm to others. In short, they focus on cases where calculations appeared correct, though not always conclusive, but the outcome was adverse. Often, the problem was incompletely understood, schedule over safety was prevalent, and the judgment to proceed in the absence of complete information was made [7]. Also, problems were often compounded by the nature of technology, the process of design, and the operation of the technology.

However, with respect to the relevance of these cases to the practicing engineer, it might be illuminating to focus on other features of these cases. One feature of paradigm cases that bears on their relevance to engineering practice we call "distance." This term denotes nearness to the experience in the practice of the average engineer. This idea of distance is bound up with the social setting of the case events and engineering practice. We suggest that this notion of distance from common engineering practice has three aspects, as follows:

First, the aspect of the "impact" of an error or unethical practice—that is, are the consequences of the action far reaching socially, politically, and economically, or localized to the engineering practitioner?

Second, the aspect of the "locus" of the event - that is, does it occur proximately, in an organizational sense, to the work of most engineers and to their decision making purview, as well as close in time to the engineering decisions taken; or is it further removed from this reality?

Third, is the aspect of "locale" of the case event; that is, does the event occur in organizational circumstances that are near or far from those in which the average engineer practices, such as small private firms and endeavors, short term projects and time frames, and moderate budgets?

Applying these concepts one sees that most paradigm cases are rather distant from common engineering practice. One reason for this is that the paradigm cases tend to concern large-scale, costly disasters in large, bureaucratic, public, or quasi-public organizations. Even the Ford Pinto case, while occurring in a private firm, still occurs in an organization far larger and more complex than the workplace of the typical engineer, and so the event described is both distant in locus as well as locale from common engineering practice. Moreover, because of the productive size in the economy of the firm in the case event, the impact is as great on the community, if not greater, than if it were a public organization.

These are circumstances that are not common for most engineering practices that typically are small private sector firms working on short-term, medium-scale, and local projects. The focus on disasters may illustrate clearly what is meant by concern for the safety of others, just not in a way that relates to what many engineers do.

One difficulty with a concentration on disasters as case events for understanding the application of the rules in codes of ethics is that disasters give the mistaken idea that the codes primarily are aimed at achieving safety or avoiding harmful outcomes rather than the inculcation of ethical processes. The distinction between outcomes and processes in professional ethics is an important one. To act ethically in a profession, one must consider the outcomes of one's actions and pay attention to consequences. Acting ethically as a professional implies an outcome-centered obligation. However, even when pursuing favorable outcomes, some processes — the use of certain means or the taking of certain actions — are either encouraged or off limits to professionals. One may not pursue desirable consequences nor avoid them through certain means. For example, one is not behaving ethically as a professional by promoting safety through racism, neither by engaging in a "best practice" that results in harm in a certain situation, nor by falsifying records to avoid harm. Thus, acting ethically imposes both a process-centered obligation as well as a consequential obligation for professionals [11].

This distinction is embodied in engineering codes of ethics. Therefore, extreme attention to outcomes at the expense of processes is less than helpful to practicing engineers in applying ethics codes to their practice. For example, as Table I makes clear, the IEEE code of ethics has in its ten points a mixture of outcome- and process-oriented rules. Clearly, a focus on harmful outcomes not only hinders practicing engineers in applying the ethical rules in this code, but downplays the role of processes in achieving safety, and thereby avoiding harmful outcomes.

Paradigm cases fail to capture the social complexity of the engineering practice in another way, as well. They rely on one view of knowledge and discount a view that might be more ethically relevant. The essence of engineering professionalism is the autonomous or independent use of judgment. However, professional judgment has two aspects that are relevant to professional practice. The first of these aspects might be called "calculation," that is, the correct application of technical knowledge and procedures to facts for arriving at accurate results. This aspect is tied to the idea of positive knowledge found in science and mathematics. The second aspect of professional judgment might be called "interpretation," that is, the assignment of shared meaning to present social circumstances for arriving at an effective course of action. This aspect is tied to the idea of social and personal knowledge found in the social sciences and philosophy.

Table II presents an assessment of calculation and interpretation as related to the key paradigm cases used for educational purposes regarding complex situations like those faced by practicing engineers. Calculation includes not only the arrival at numeric answers using established formulae and algorithms, but also the judgment used in obtaining and delimiting information used to arrive at the numeric results and the judgment used in application of the results to design and other relevant circumstances. In engineering practice, calculation may not be conclusive and engineers often proceed in the absence of all the information they need, necessitating the use of some sort of judgment. Accordingly in an off hand way, when the cases focus on calculation they do focus on engineering judgment as well. However, even if individual judgment is included as part of the act of calculation, this aspect of decision making does not take into account the other form of understanding that is used in the sort of discretionary decisions that engineers encounter in practice, that is, interpretation.

Interpretation is the acknowledgment of circumstances surrounding a decision, including the social and historical setting, individual role sets, and professional and nonprofessional ethical obligations. Interpretation additionally recognizes the decision chains and premises that influence and give context to the ethical decision, and produce knowledge about its rightness rather than just its correctness. Table II assesses the paradigm cases on how well they explain ethical decisions by providing knowledge not only about (and thus insight into) the arrival at a right answer, but about the discernment of a correct course of action as well.

As Table II indicates, the paradigm cases rely on one sort of knowledge, that of calculation, over the idea of interpretation. Take for example, what might be called, the "paradigm case of paradigm cases," the Challenger Shuttle Explosion. This case is famous for indicating how the professional judgments of engineers — based as they are on positive calculation from scientific fact, may in some manner be supplanted by the professional judgments of managers — based as they are on positive calculation from shifting facts such as costs and schedules. Ultimately, the only engineering ethical failure in this case is failure to insist on what was positively known: the O-rings would fail in sufficiently cold weather. Conventional engineering ethics maintains that the responsibility for the failure to take this positive knowledge into account was a management failing NOT an engineering one.

In the social world of work, engineers meet with conflicts that are not handled by their professional paradigm.

This point of view lets engineers (most of the managers were indeed engineers) off the hook for failure to insist on what was right, by introducing a false dichotomy between managers and engineers or business and engineering. This dichotomy obscures what is brutally evident in practice and social life but easily ignored in concept: engineering is a profession and a business, and engineers are engineers and business managers contemporaneously [4]. This point of view makes the socially complex conceptually simple, and this may not lead to ethical understanding or good practice. Also, it reinforces the conventional model that holds that only technical experts have relevant risk information and are responsible for it [6]. Further, conventional analysis of the case presents a dilemma: if risk acceptance is a failure of managerial ethics rather than a failure of engineering ethics, why is it a case of engineering ethics at all? If an analysis of the case from an engineering perspective cannot admit an error as anything other than miscalculation (poor technical application) or inappropriate application of value premises (abandonment of value-free technique), then what relevance does ethics (a guide to conduct, not application of technique) have for engineering at all?

Conventional analysis also fails to examine what occurred in the case by interpreting the events and the complexity of circumstances. It does not examine the chain of decisions and organizational procedures that one-by-one adduced "acceptable" risk after acceptable risk until final arrival at an "unacceptable" risk [18]. It does not examine the perceptions of the individuals involved about what were the uniquely appropriate "engineering" and "management" purviews and how they arrived at these perceptions. It does not examine the social circumstances, the distribution of authority, and how various actors viewed themselves, their roles, the expectations, and the pressures brought to bear on them. In short, although the Challenger incident is an atypical case of a disaster in a large, public, organization, it belies much about average engineering practice by failing to focus on the social nature and complexity involved, and the sort of knowledge necessary to understanding it.

Paradigm cases then fail to help achieve an understanding for engineers of how to apply rules for ethical practice in four ways:

Focusing on cases that do not relate to the practice of most engineers may overstate the importance of applying ethical rules to large-scale undertakings and failures as well as diminish the influence of social complexity in most ordinary engineering practices.

By focusing on professional judgments in ethical situations that are calculative (positivistic) rather than interpretive, paradigm cases fail to develop engineers' sensitivity to the social nature of engineering practice or encourage their ethical responsibility or ability to apply ethical rules.

Focusing on paradigm case disasters gives the mistaken impression that ethical engineering primarily is about the avoidance of harmful outcomes rather than participation in ethical processes.

Review of paradigm cases reveals a failure to address non-disaster producing ethical failures, like racism, failure to mentor, and others that are indicated by ethical codes.

Learning that Engineering is a Social Activity

One critical question is: how can engineers learn that engineering is a social activity? This does indeed call for major changes in education, in particular the development of more hard and soft systems that can replace fragmented presentations of engineering science. There is a need for engineers to come to recognize that what they do is different in kind from either science or business [7]. Both students and practicing engineers must understand it.

In closing, we want to suggest that the application of ethics codes can be improved, and the codes themselves made more relevant to engineering practice by using simple techniques, rather than cases, to help engineers learn about ethics in practice. The aim of both of these ideas is to help engineers gain an understanding of their profession as a social practice by decreasing social isolation and multiplying experience. To do so, engineers need to depend on each other, as well as make their social knowledge accessible.

Improving Ethical Practice: Understanding through Mentorship

One way to improve ethical practice, especially among students and younger engineers is to use the practice of mentorship. Student or newly hired engineers would be paired with a mentor or practicing engineer — preferably not a member of the firm's management — who would have the express role of answering questions about ethical practices in a one-on-one, "hold harmless" situation. The mentoring sessions could be regular and programmed as part of an initial training period or, like employee assistance programs, could be on an as needed basis. Also, like employee assistance programs the discussions would be confidential (and, it is hoped, without record).

The use of mentors would complement the use of cases by making current, relevant experience accessible to practicing engineers. Mentors could easily answer process questions and would do so in the appropriate context of a practice. Moreover, being involved in day-to-day practice, mentors would not necessarily concentrate on outcomes over process.

Periodic certification of mentors is desirable, in fact may be essential if the mentoring process is to work in practice. One problem with mentoring is how to avoid systemizing old attitudes. The certification of mentors by professional societies like IEEE in conjunction with university engineering programs would help to ensure that mentors are innovative as well as conservative where appropriate. Mentoring certification courses could become an option for engineering continuing education. Moreover, by introducing mentoring as an activity early in the engineering curriculum, say as a module in engineering ethics courses, engineers in-training could be introduced to the practice and could be guided by the practical experience of the mentors in-training they encounter.

Improving Ethical Practice: Understanding through Communication Nets

An extension of the mentor idea is to develop communication nets among practicing engineers for the constant, contemporaneous, grounded, discussion of ethics and ethical dilemmas. The use of electronic communications such as bulletin boards, chat rooms, or list servers could ensure the assembly of widespread experience in a timely fashion. It is interesting to note that these mechanisms have been well and widely employed in engineering for the treatment of technical problems. So, there is no reason to believe that they could not be useful for ethical ones, as well. Also, electronic means, if implemented with proper safeguards, could guarantee anonymity and thus help increase the participation of engineers in ethics learning and sharing. Moreover, using technical means to improve ethical practice might be attractive to engineers. The propensity for technical disciplines to use technical means to solve problems is well known.

One idea that we have offered elsewhere is to use electronic bulletin boards and chat rooms to both allow and indeed encourage engineering students to openly discuss engineering ethics [13]. Ideally, these sites would be active even when a course was not being offered and would be open to students once they had left an engineering program with their degree and had entered into practice. This would give engineers somewhere to go to seek advice on ethics once they have left academe, as well as to share experience about practice with both students and other practicing engineers. The development of such a professional communication network would be invaluable to students, firms, and instructors. The latter could tap this network for experts, current cases, and materials.

Of course, one barrier to implementing this electronic connections idea is the real concern of firms with guarding intellectual property and the secrecy of business operations. These are legitimate concerns because these factors are genuine constituents of business profit. Nevertheless, the difficulties in working out such solutions in the academic environment can only help illustrate the crucial enigma for engineering ethics: the practice of engineering often dictates secrecy, whereas the ethics of engineering requires transparency. It is the working out of the boundaries of these two domains that provides a challenge for engineering ethics in practice.

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